Travel Demand Model | 2050 LRTP

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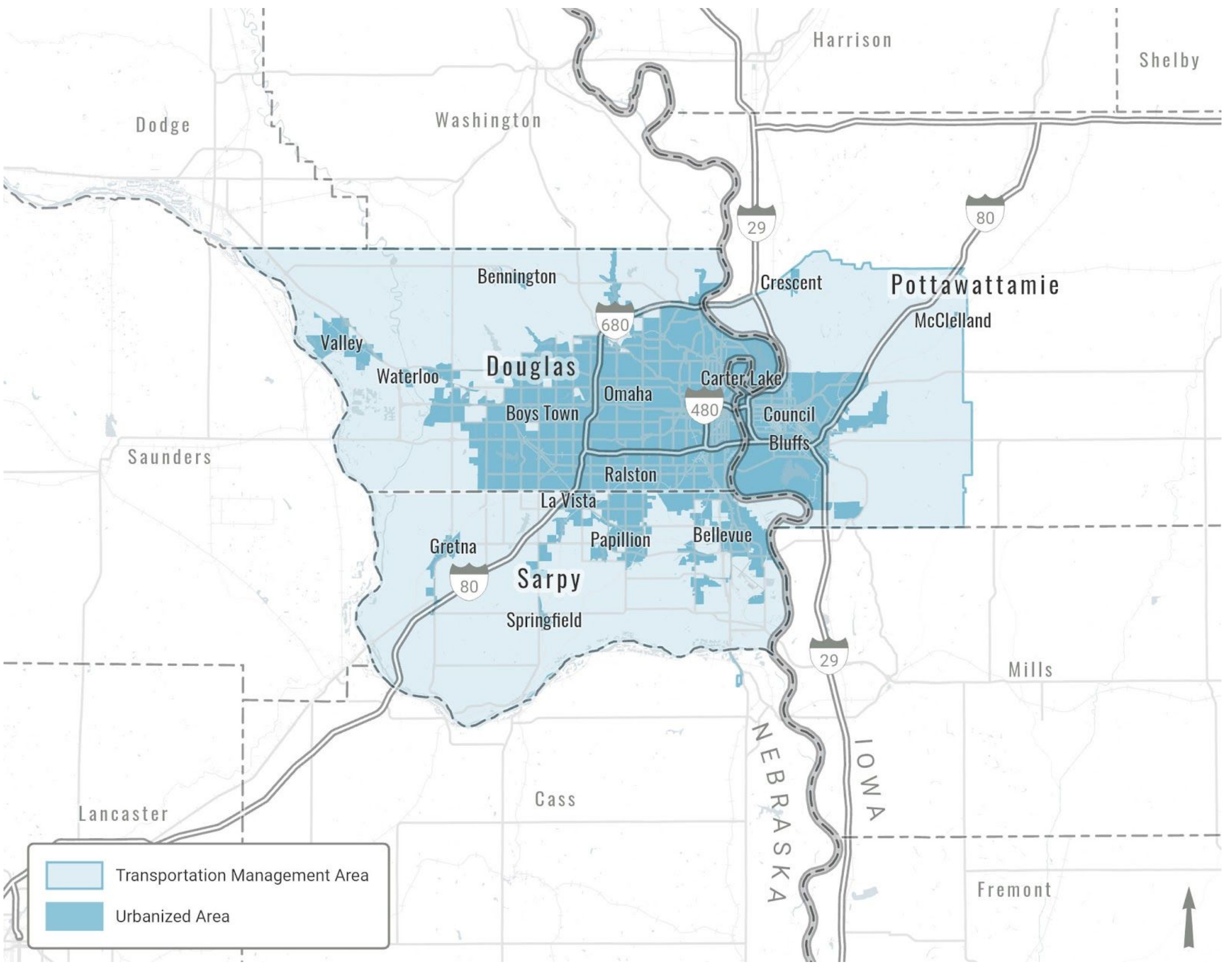
Introduction

The Metropolitan Area Planning Agency (MAPA) maintains a Travel Demand Model (TDM) for use by its member entities as a tool for traffic forecasting. This model primarily supports the Long Range Transportation Plan (LRTP) in the evaluation of roadway projects based on future land use, household, and employment growth. This model also supports various corridor studies, sub-area analyses, and other planning activities throughout the region. The model is calibrated to a base year of 2015 and has a horizon year of 2050.

The current version of the MAPA TDM was completed in 2020 and was built using TransCAD. The model has been reviewed by the Nebraska Department of Transportation (NDOT), the Iowa Department of Transportation (IowaDOT), and the Federal Highway Administration (FHWA).

Figure C1: MAPA Transportation Management Area



The MAPA TDM is used to study the Transportation Management Area (TMA) that encompasses Douglas and Sarpy Counties in Nebraska, a small portion of Cass County in Nebraska, and the western portion of Pottawattamie County in Iowa as seen in Figure C1.

TMIP Peer Review 2010

In 2010 MAPA participated in a Travel Model Improvement Program peer review. Key recommendations from this review included:

- Improved model documentation
- Changing from daily to time of day model output
- Using average weekday daily traffic (AWDT) instead of average annual daily traffic (AADT)
- Representing all person trips (auto/walk/bike/transit) in the model output
- Improved land use allocation methods including the use of a software platform
- Cross-classification of trip rates with a combination of household vehicle ownership and household size
- Addition of multiple household and employment types for productions and attractions
- Additional trip purposes
- Incorporate NHTS data into validation
- Updates to the gravity model
- Implementation of a mode-choice component
- Improve highway network consistency
- Explore additional validation techniques from the TMIP Travel Model Validation and Reasonableness Checking Manual

The 2006 base year model was updated to include these recommendations. MAPA developed an updated land use methodology that utilized CommunityViz software for allocation and with assistance from Norm Marshall of Smart Mobility a revised travel demand model was produced.

Federal Certification Review

FHWA's 2014 Federal Certification Review included additional recommendations for model improvement. These changes were recommended to be implemented at various future stages of the model development and include the following:

- Additional base and future year validation for speed, travel time, and mode share at the district level
- Comparing results to supplemental data sources such as INRIX/AirSage and the CTPP
- Adoption of a freight model
- Development of additional special markets (universities)
- Updated zone size consistency
- Development of a QA/QC plan

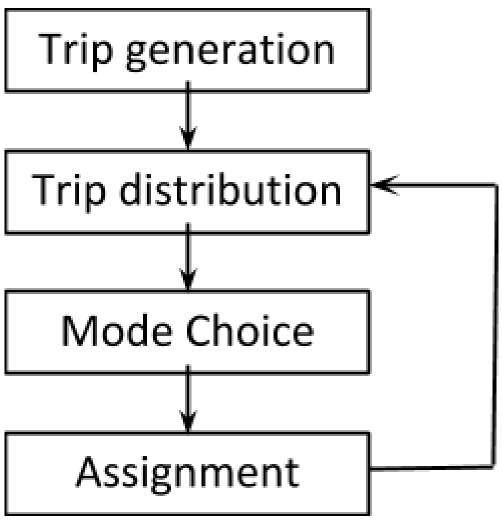
Model Structure

This model utilizes a four-step travel demand modeling process. The standard four-step travel demand modeling process includes:

- Trip generation (calculating trip ends from households and jobs)
- Trip distribution (linking trip ends to form trips)
- Mode choice (dividing trips by mode)
- Assignment (assigning trips to the network)

Congested travel times are typically fed back to the Trip Distribution and Mode Choice steps to assure consistency of travel times and travel choices. This process is illustrated in Figure C2.

Figure C2: Four-Step Travel Demand Model Structure



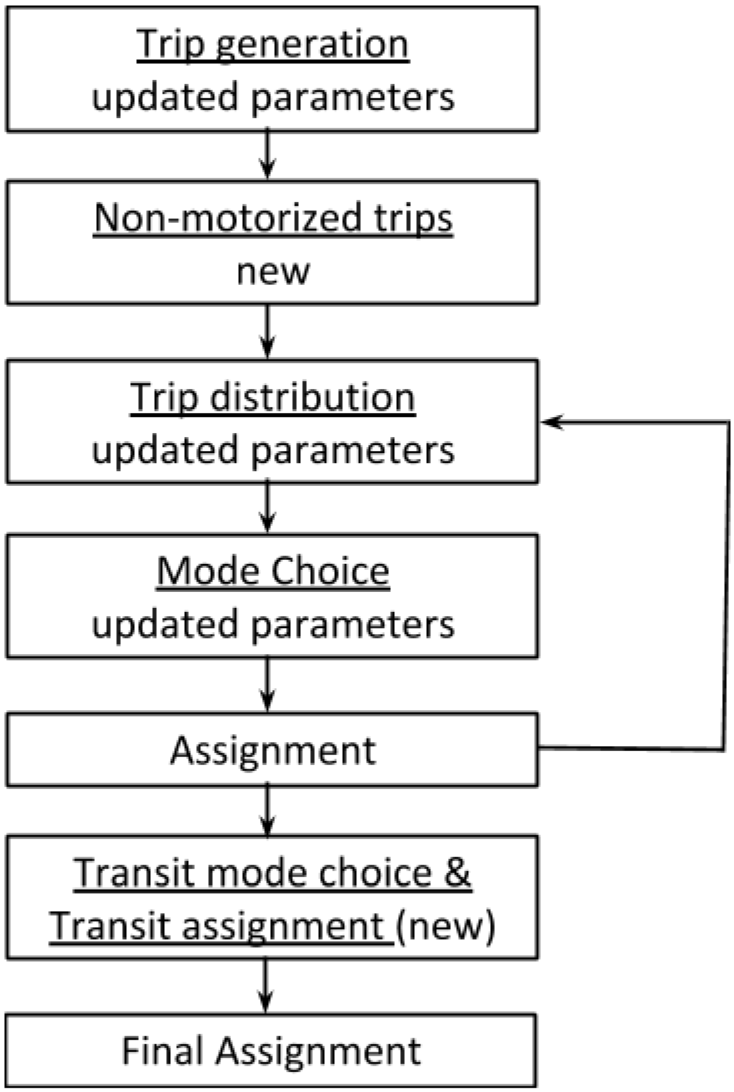
The standard four step process takes a series of choices that are made simultaneously and treats them as a sequential process to aid computation. In reality, we don't decide whether to make a trip, next decide where to go, then decide how to travel, and then choose a route. We make all those choices at once.

Enhanced Model Structure

In general, the sequential treatment in travel demand models does a reasonable job of approximating behavior. However, the standard four step process does a poor job modeling walk trips. Someone in a walkable mixed use area does not consider all possible destinations (Trip Distribution), select one, and then decide whether it is possible to walk there. The decision of destination and walk mode are made simultaneously. This model places the walk mode decision ahead of the Trip Destination step. Descriptions of this approach have been published by the developer in peer reviewed journal articles.[1]

The resulting enhanced model structure used in the MAPA time-of-day multimodal model is shown in Figure C3.

Figure C3: Multimodal Travel Demand Model Structure



[1] Marshall, N. and B. Grady. Sketch Transit Modeling Based on 2000 Census Data. Presented at the Annual Meeting of the Transportation Research Board, Washington DC, January 2006, and *Transportation Research Record*, No. 1986, "Transit Management, Maintenance, Technology and Planning", p. 182-189, 2006.

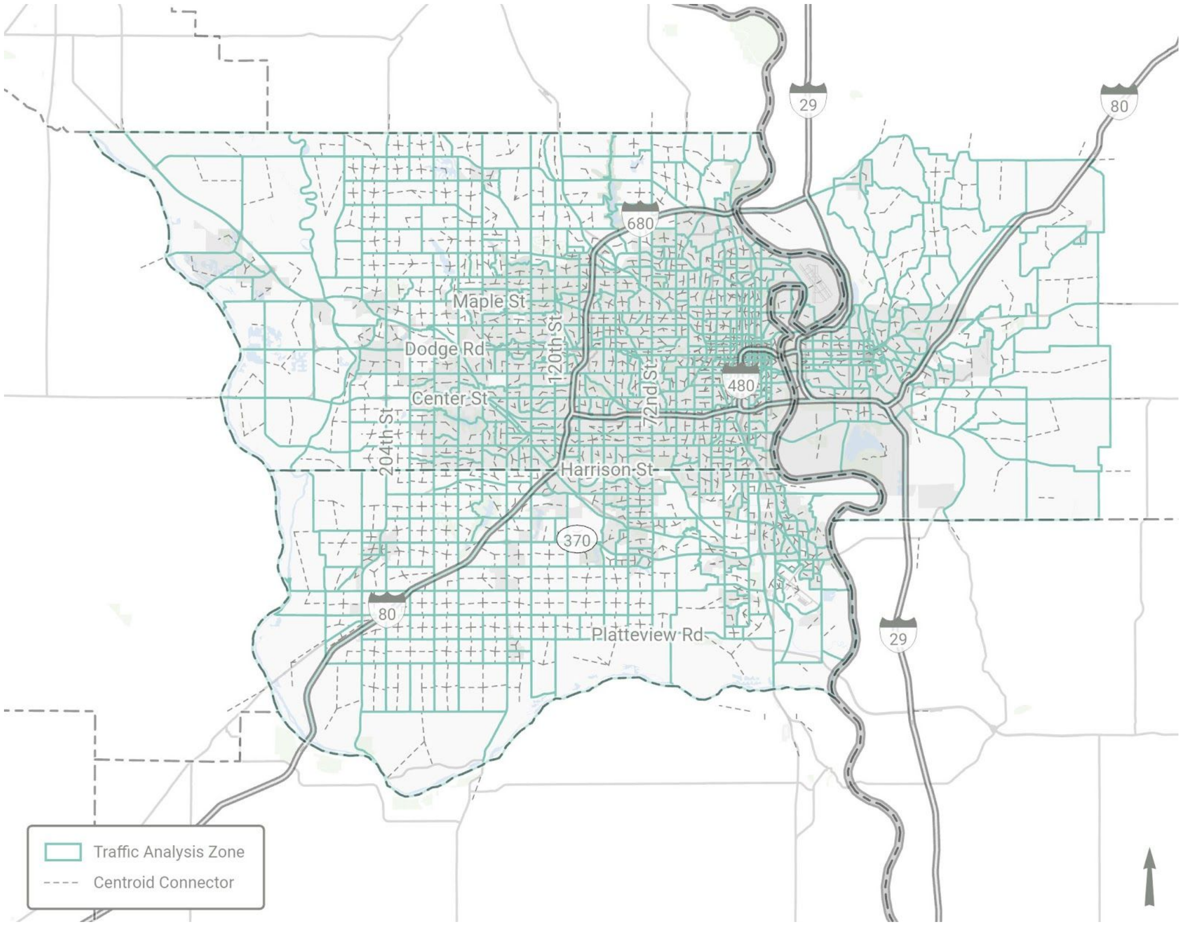
Existing Network and SE Data

Socio-economic data and the base network were updated for the 2050 LRTP and reflect a base year of 2015. The links represented in the model network reflect all functionally classified highways, arterials, collectors, and other significant local roads within the MAPA region. Each link contains information about speed, number of lanes, and capacity. Attributes representing walk and bus components are also included. Capacities are based on guidelines from the 2009 Florida Department of Transportation Quality/Level of Service Handbook.

Traffic Analysis Zones

The model area is divided up into a number of Traffic Analysis Zones (TAZs). TAZs are geographical areas that represent groups of homes and employment locations with somewhat similar trip making behavior. The TAZ is used as the unit in which the model generates and distributes trips.

Figure C4: Traffic Analysis Zones



The MAPA TDM has 806 TAZs (700 in Nebraska, 106 in Iowa), which are shown in Figure C4. Data that relates to the TAZs is stored in SEData BIN files by year, which are joined to the TAZs during a model run, and can also be joined to the TAZs for mapping or analysis.

Socio-Economic Data

MAPA maintains household and employment projections as an input to the TDM. The most recent projections were informed by a regional visioning process known as Heartland 2050. The goal of this process was to develop a growth scenario for the region that promoted the interests of each community. The preferred growth scenario included considerations for economic well-being, education, healthy living, diverse housing and transportation choices, and the preservation of natural features.

These preferences informed a parcel-based land use allocation process which matches standards defined in the Iowa Standardized Model Structure (ISMS). Through this process diverse land uses are identified at the parcel level and then allocated to available future development areas based upon local planning guidance and suitability modeling. The parcel data is then aggregated to TAZs to create existing and future land use inputs.

Table C1: Historic Population Trends in the MAPA TMA

County	1970	1980	1990	2000	2010	2019
Douglas	389,455	397,038	416,444	463,585	517,110	571,327
Sarpy	66,200	86,015	102,583	122,595	158,840	187,196
Pottawattamie	86,991	86,561	82,628	87,803	93,158	93,206
MAPA TMA Total	**542,646**	**569,614**	**601,655**	**673,983**	**769,108**	**851,729**

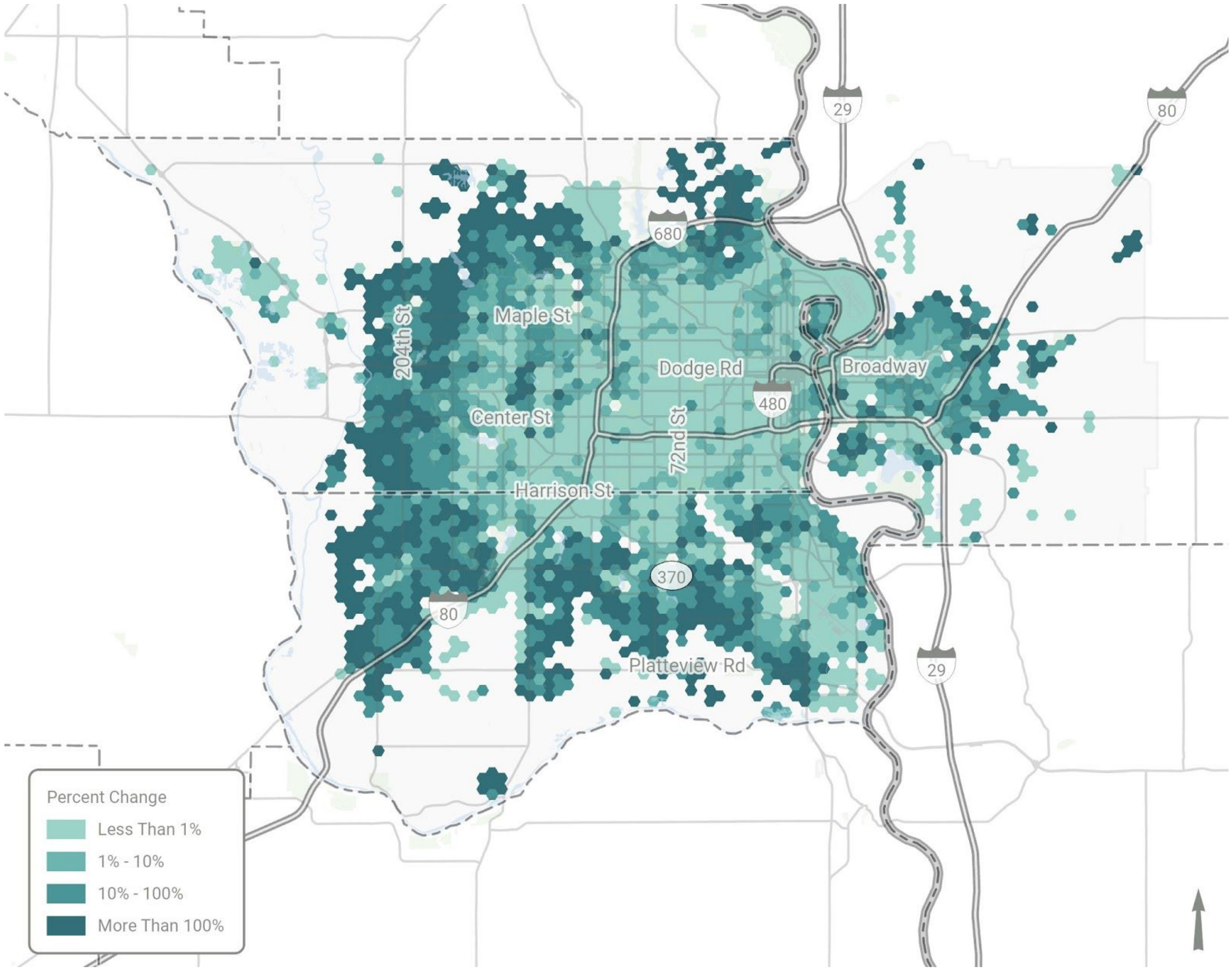
Table C2: Forecasted Population Growth in the MAPA Region, 2010 to 2050

County	2010	2020	2030	2040	2050
Douglas	517,110	571,311	625,173	680,008	736,658
Sarpy	158,840	196,701	233,688	274,837	317,618
Pottawattamie (TMA)	80,509	81,909	84,705	85,968	85,646
TMA Total	**756,459**	**849,921**	**943,566**	**1,040,813**	**1,139,922**

Population growth in the MAPA region is not consistent between all three counties. Growth in Sarpy County has outpaced growth in Douglas and Pottawattamie counties as seen in Table C1. Our forecasting process assumes that higher growth in Sarpy County will continue into the future. By 2040 the expected regional population is forecasted to exceed 1 million people (Table C2.)

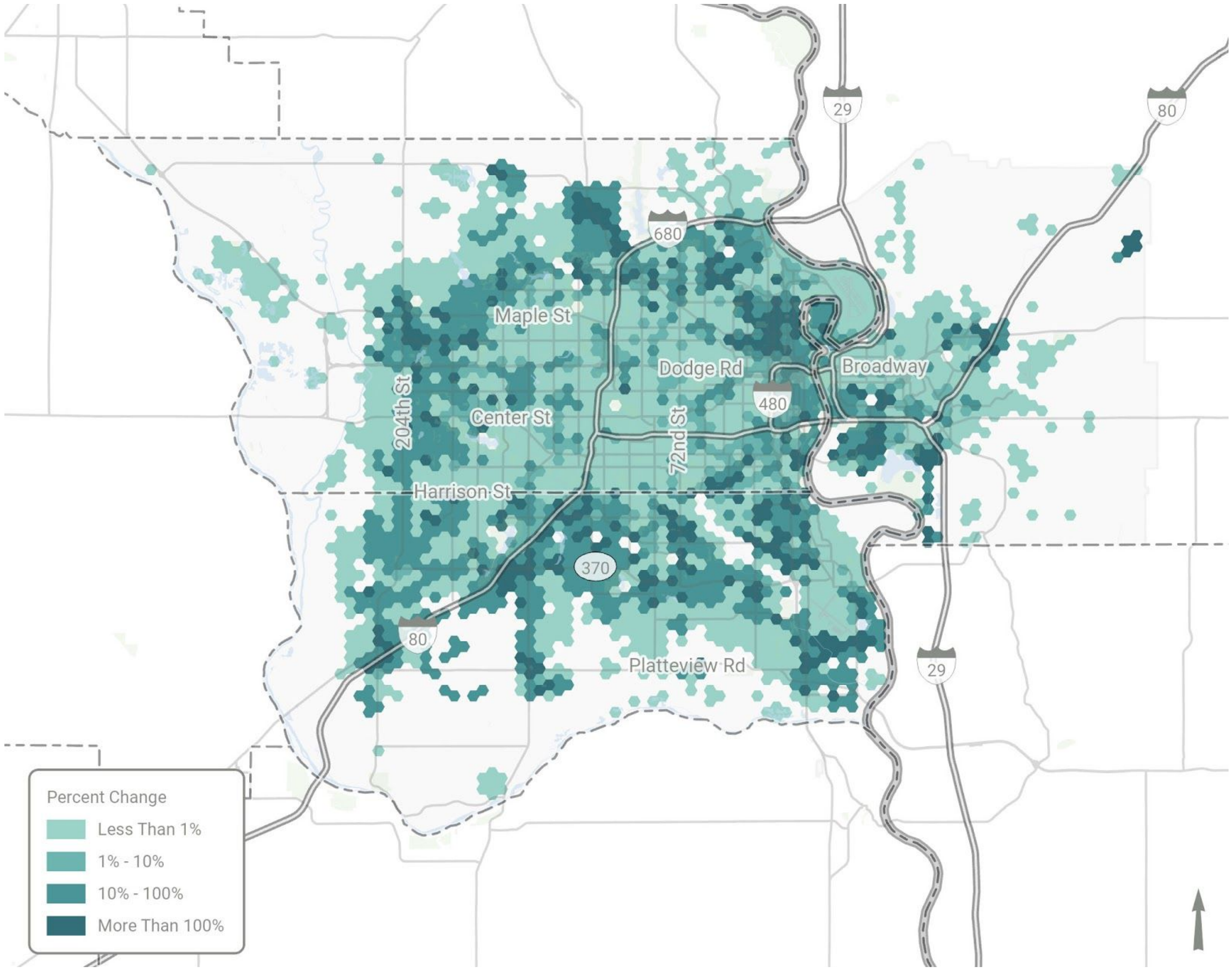
Future household projections show growth distributed around already developed areas in Figure C5. This land use scenario assumes that there will be additional infill development and that housing density will increase in the future.

Figure C5: Change in Single Family Households



Employment growth is expected to follow existing trends with some additional infill development and increases along the I-80 corridor in the southwest portion of the MAPA region (Figure C6.)

Figure C6: Change in Employment



Network Updates

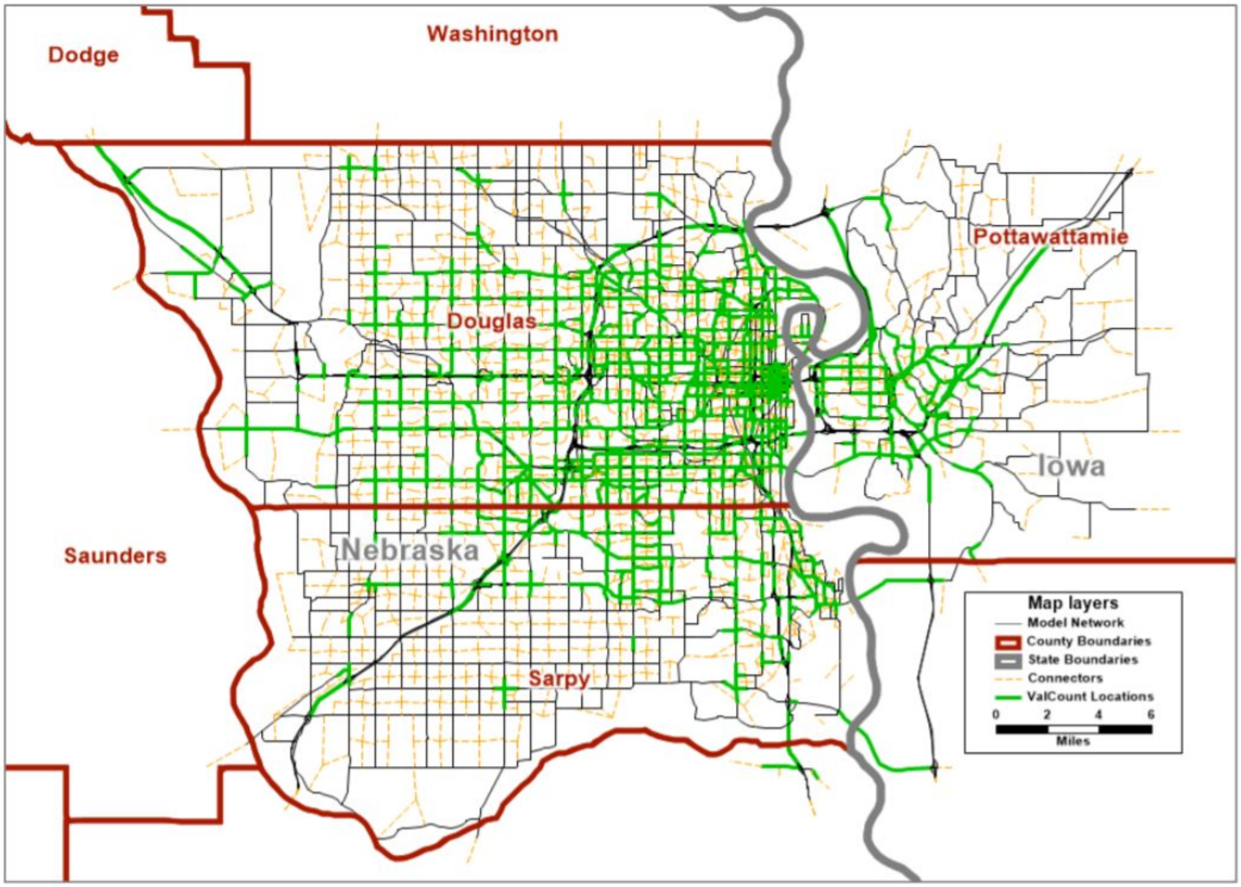
As part of the 2050 LRTP the base year road network was updated from its previous 2010 base year to match existing year roadway alignments and attributes. The primary inputs are listed in Table C3, and are consistent with the 2040 model with the exception of AADT_2016, AADT_2018 and ValCount, which represent counts.

Table C3 - Road Network Fields

Field	Description
STREET	Street name
ID	Unique ID of link
Dir	Link direction of flow
	0 = two-way
	1 = one-way in AB direction
	-1 = one-way in BA direction
Length	Link length in miles
Fac_type	Facility type
	FRW = Freeway
	CD = Collector/Distributor
	SSA = State Highway
	MAJ = Major Arterial
	MIN = Minor Arterial/Collector
	RP = Ramp
	TRANSIT = Bus only
FFSPD	Free-flow travel speed
Travel Time (minutes)	Model-calculated travel time
	Length / FFSPD * 60
Lanes	Number of through lanes
BASE_Code_AB / BASE_Code_BA	Capacity lookup code
CAPACITY_AB / CAPACITY_BA	Daily capacity
AM_CAP_AB / AM_CAP_BA	AM capacity
MID_CAP_AB / MID_CAP_BA	Mid-day capacity
PM_CAP_AB / PM_CAP_BA	PM capacity
NT_CAP_AB / NT_CAP_BA	Night-time capacity
ALPHA	BPR volume delay function alpha value
BETA	BPR volume delay function beta value
WalkLink	Walkable link
WalkTime	Walk travel time
Bus Time	Bus travel time
Express Time	Express bus travel time
AADT_2016	2016 count
AADT_2018	2018 count
ValCount	Validation count used for model validation

AADT_2016 and AADT_2018 come from MAPAs traffic data, and represent a processed count value on every road segment. ValCount is the count field used for validation of the model assignment results. ValCount was produced by attempting to narrow down AADT_2016 to only actual count locations. Another reason to show each count on only one segment is to avoid using the same count multiple times in model validation statistics, which can unreasonably skew results. Additionally, counts were reviewed during model calibration and occasionally revised to another source (NDOT or Iowa DOT counts). Figure C7 shows the locations of ValCounts on the road network.

Figure C7 - Count Locations



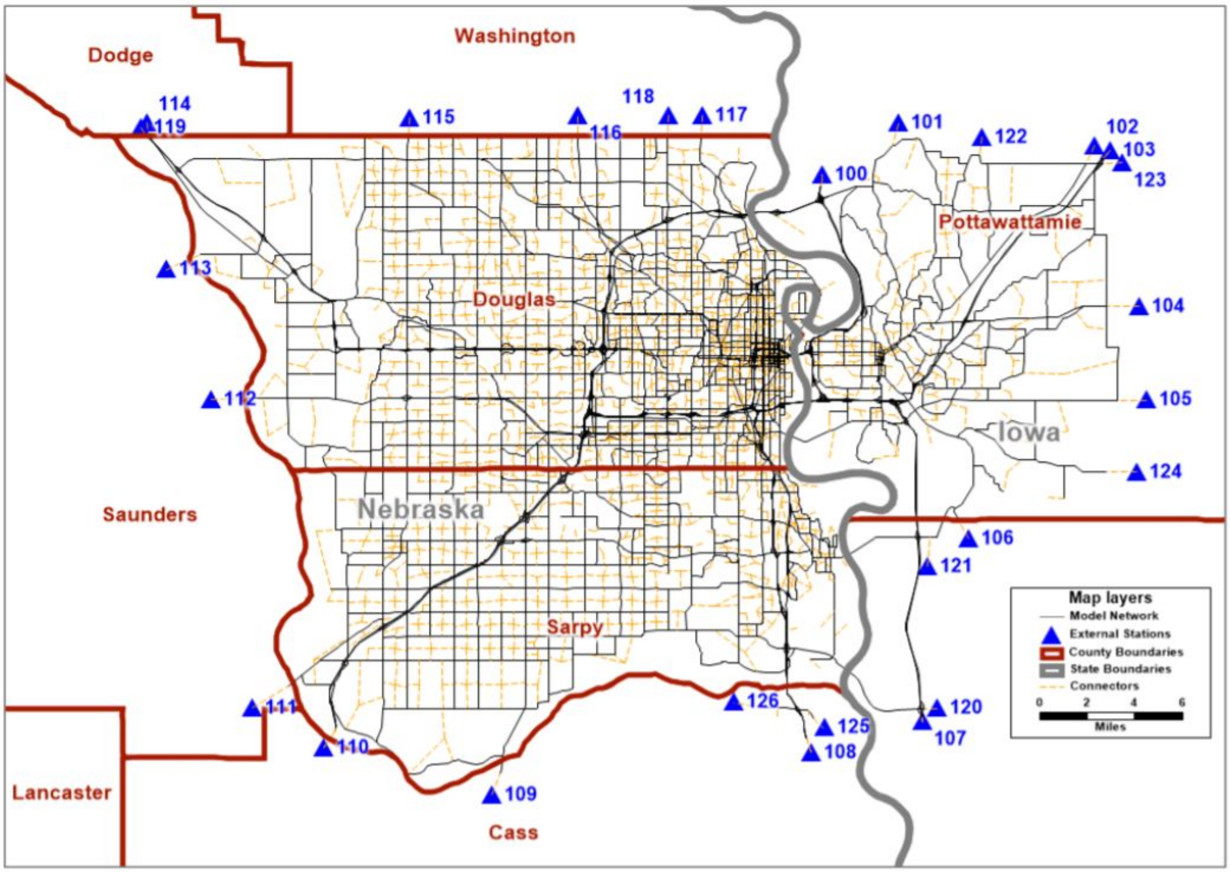
External Analysis Update

The MAPA TDM has 27 external stations shown in Figure C8. Trips both to and from external stations are External-External (E-E) trips. The trips that have one end at an external station and do not have the other trip end at another external station are External-Internal or Internal-External (E-I or I-E) trips.

Previous model updates included the results of the 2013 Metropolitan Area Planning Agency External Travel Survey to determine the origin-destination patterns for E-E trips, and determine the split in E-E compared to E-I trips. Therefore, the relative patterns in E-E and E-I trip distribution was kept the same as the 2010 base model. The trip purpose split for E-I/I-E trip was also kept the same. Counts were updated to the new model base year. E-E trips were then fratared (growth factored) for new input totals.

The forecast volume targets for the horizon year were provided by NDOT and Iowa DOT for the majority of the external stations. On the Nebraska side, the majority of roads use linear forecasts, but interstates and occasionally other high-growth roads may use an average of linear and exponential. For the remaining stations (all relatively low-volume corridors) a 10% growth assumption was made. On the Iowa side, historical trendline forecasts were also used and reviewed for reasonableness.

Figure C8 - External Station Locations



Model Features

MAPA has included a travel model as part of its long range planning efforts since the 2020 LRTP in 1995. Subsequent iterations of the model have included multiple feature updates to meet a growing number of model use cases.

Time of Day

The MAPA model includes a time of day component that distributes over four time periods:

- AM Peak – 6:30 a.m. – 8:30 a.m.
- Midday – 8:30 a.m. – 3:30 p.m.
- PM peak – 3:30 p.m. – 6:30 p.m.
- Night – 6:30 p.m. – 6:30 a.m.

Weighted values estimated from the 2009 National Household Travel Survey (NHTS) data were used to develop time-of-day factors including both the percentage of daily trips by type within each of the four time periods, and also the percentage of trips for each type within each period that are production-to-attraction vs. attraction-to-production.

Non-Motorized Trips

Non-motorized trip generation was improved with the 2010 model update and includes variables that take the built environment into consideration when generating trips.

The first step in the non-motorized trip generation is to develop trip tables of possible trips for each of the six trip types using a gravity model with very steep friction factors. This assures that the modeled non-motorized trips will be predominantly intrazonal and very short interzonal trips. These possible trips are multiplied times shares calculated with a binary logit model. The binomial logit model is calculated for each trip type and each TAZ-to-TAZ pair as:

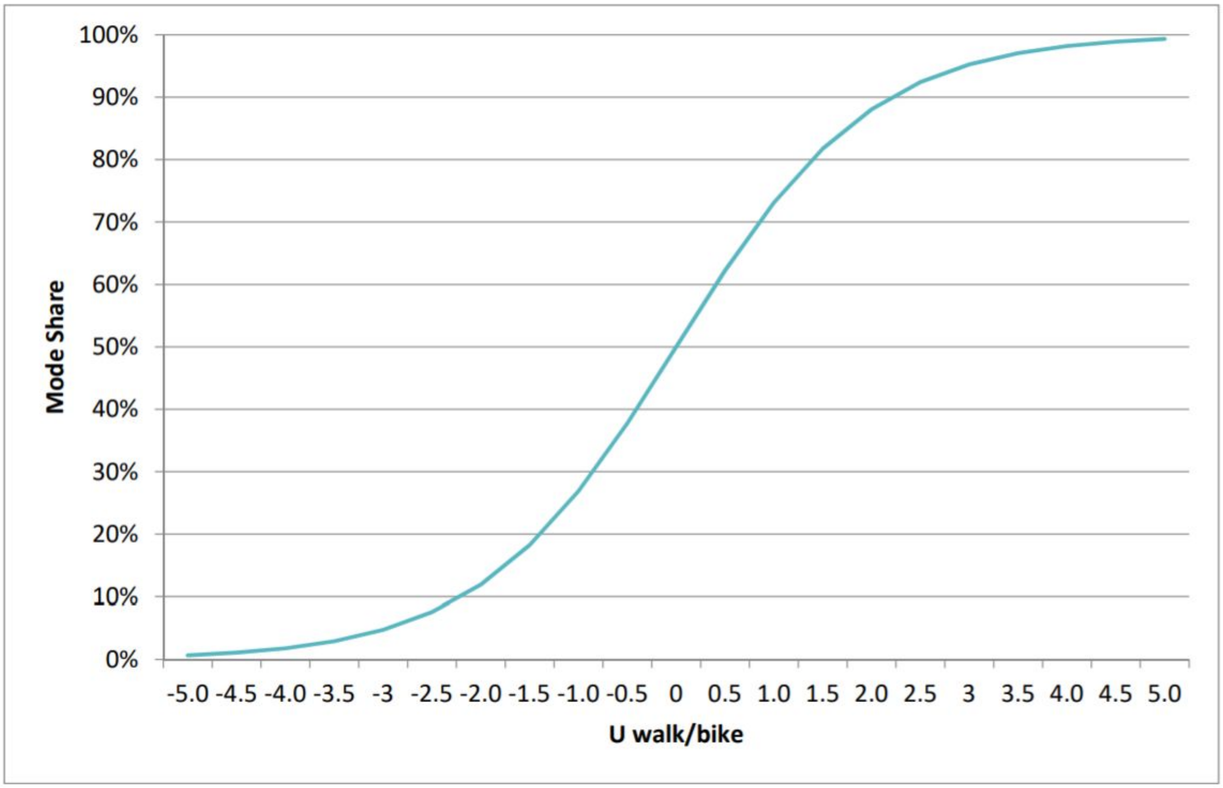
$$share = \frac{e^{u\ walk/bike}}{e^{u\ walk/bike} + e^{u\ motorized}}$$

Where u walk/bike and u motorized are utility functions for the two modes. The calculated share depends only on the difference between the two utility functions. Therefore, it is convenient to set u motorized equal to zero. As e raised to the 0 power equals 1, the equation can be simplified as:

$$share = \frac{e^{u\ walk/bike}}{e^{u\ walk/bike} + 1}$$

Figure C9 illustrates the calculated walk/bike mode share given different values of u walk/bike.

Figure C9 - Binomial Logit Model



The “3 Ds” – “Density”, “Diversity”, and “Design” – are used as independent variables. The 3 Ds have been used extensively in studies of land use/transportation interactions throughout the United States.[2] “Density” includes separate measures of housing density (units per square mile) and employment density (employees per square miles). “Diversity” concerns whether there are a mix of land uses, especially jobs and housing. “Design” approximates the walkability of a neighborhood by counting the number of intersections per square mile (GIS calculations from U.S. Census TIGER data).

The model incorporates these variables both directly and indirectly. Model variables include:

- HD2 – square root of the number of housing units per square mile
- ED2 – square root of the number of jobs per square mile
- IDEX – intersection density index relative to land use density calculated as:
    - Intersections per square mile / ((HD2 + ED2) ^ 0.5)

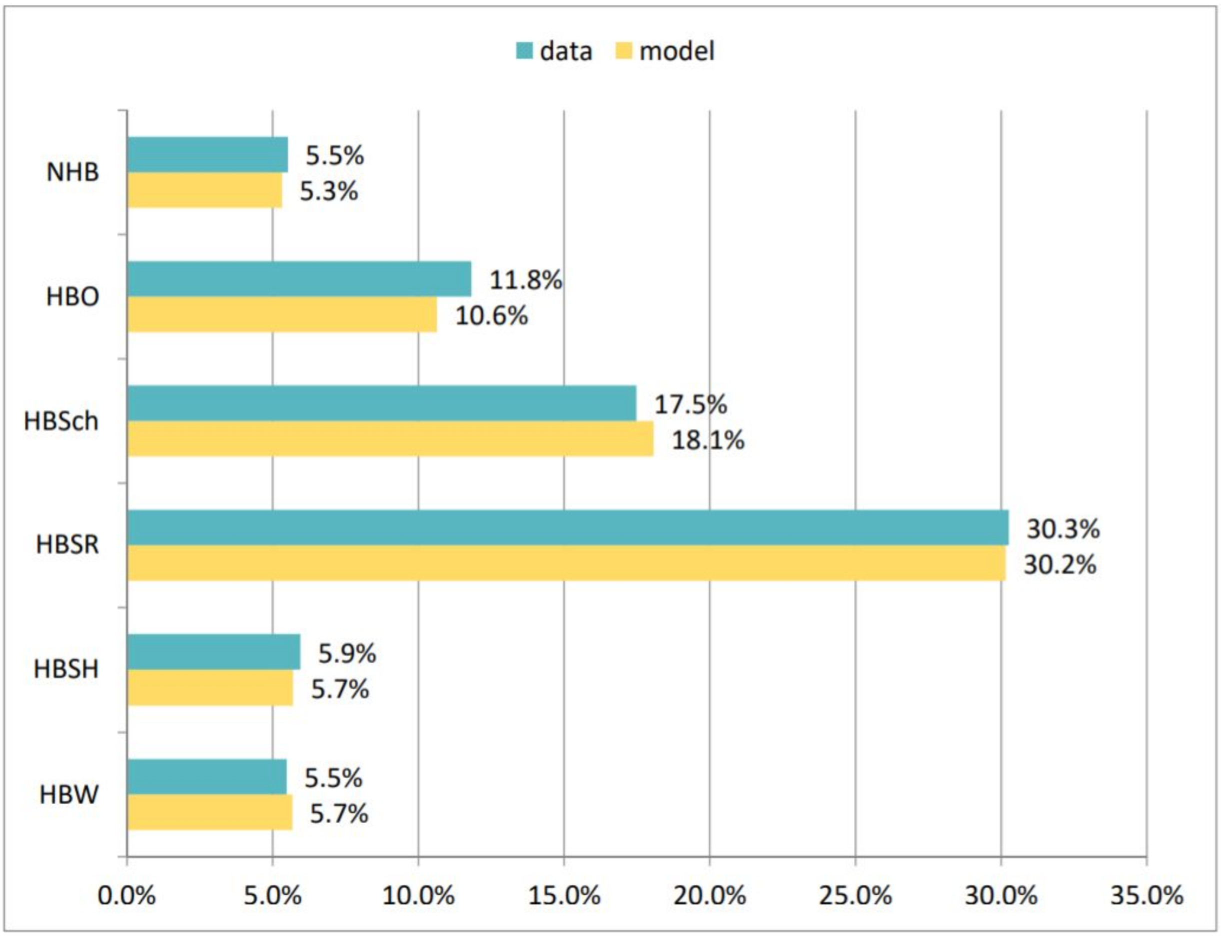
[2] Ewing, Reid and Robert Cervero. “Travel and the Built Environment – Synthesis”, presented at the Annual Meeting of the Transportation Research Board, January 2001.

The HD2, ED2, and IDEX variables were calculated at both the production and attraction TAZs (which can be the same TAZ in the case of intrazonal trips).

In the logit model, the large negative constant indicates that without the influences of density, diversity and design – walk/bike shares will be small. All of the "3 D" variables have positive effects – the higher the 3 Ds, the greater the calculated walk/bike share. The highest shares are calculated where there are high 3 D scores for both the origin and destination TAZ.

Non-motorized (walk + bike) modeled shares are compared with weighted NHTS shares in the Figure C10 below.

Figure C10 - Modeled Walk/Bike Mode Shares Compared to Weighted NHTS Data



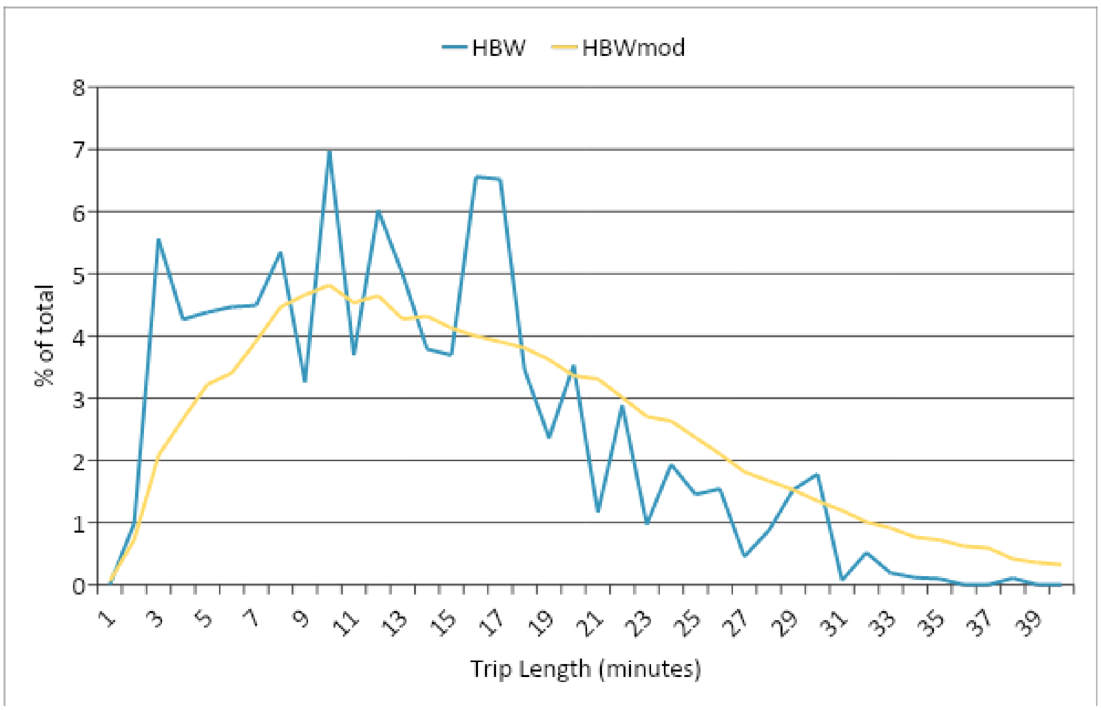
Income Based Trip Distribution

An income based trip distribution element has been added as part of ongoing model development. Data from the 2009 NHTS and AirSage was used to identify travel patterns. Income groups were developed to categorize trip length distribution. For more details, including information on income-based targets and validation please refer to the *"Implementation of Income-based Trip Distribution"* Technical Memorandum that accompanies this document. The distribution models have been implemented using gamma functions which were developed using weighted NHTS data, including trip origins and destinations.[3] The gamma functions coefficients are:

- HBW – alpha=1000, beta=0.5, gamma=.05
- HBNW – alpha=1000, beta=1.5, gamma=1.0
- NHB – alpha=1000, beta=.075, gamma=.075

The comparison of base year modeled internal trips to weight NHTS trips is shown in Figures C11-C13. (The NHTS data are a bit noisy so the graphics are more clear at showing cumulative distribution.)

Figure C11: HBW Trip Distribution – Model vs. Weighted NHTS



[3] These gamma coefficients were reviewed against the examples given in NCHRP Report 716. The NCHRP 716 coefficients vary widely so it is hard to conclude much about this comparison.

Figure C12: HBNW Trip Distribution – Model vs. Weighted NHTS

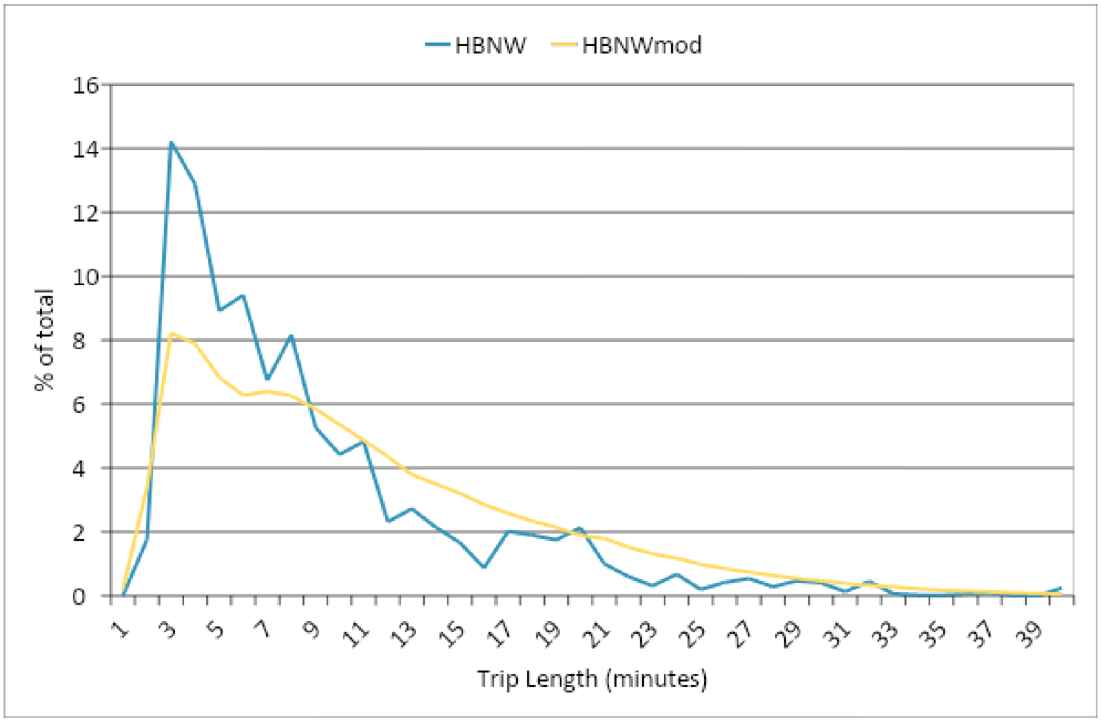
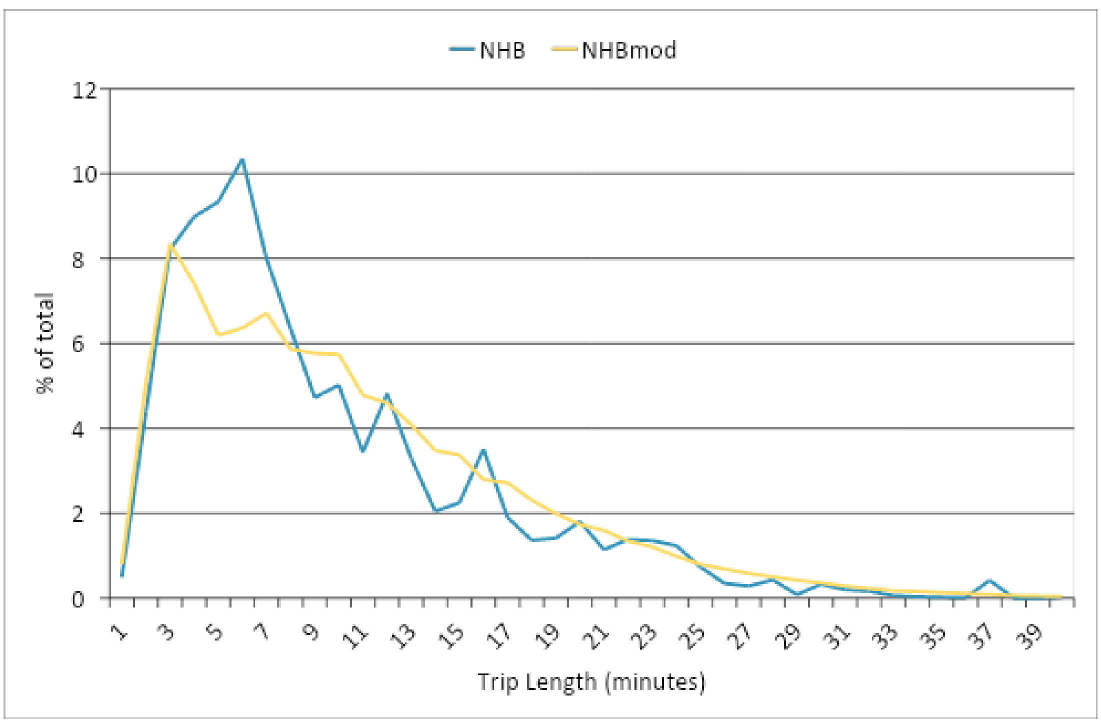


Figure C13: NHB Trip Distribution – Model vs. Weighted NHTS

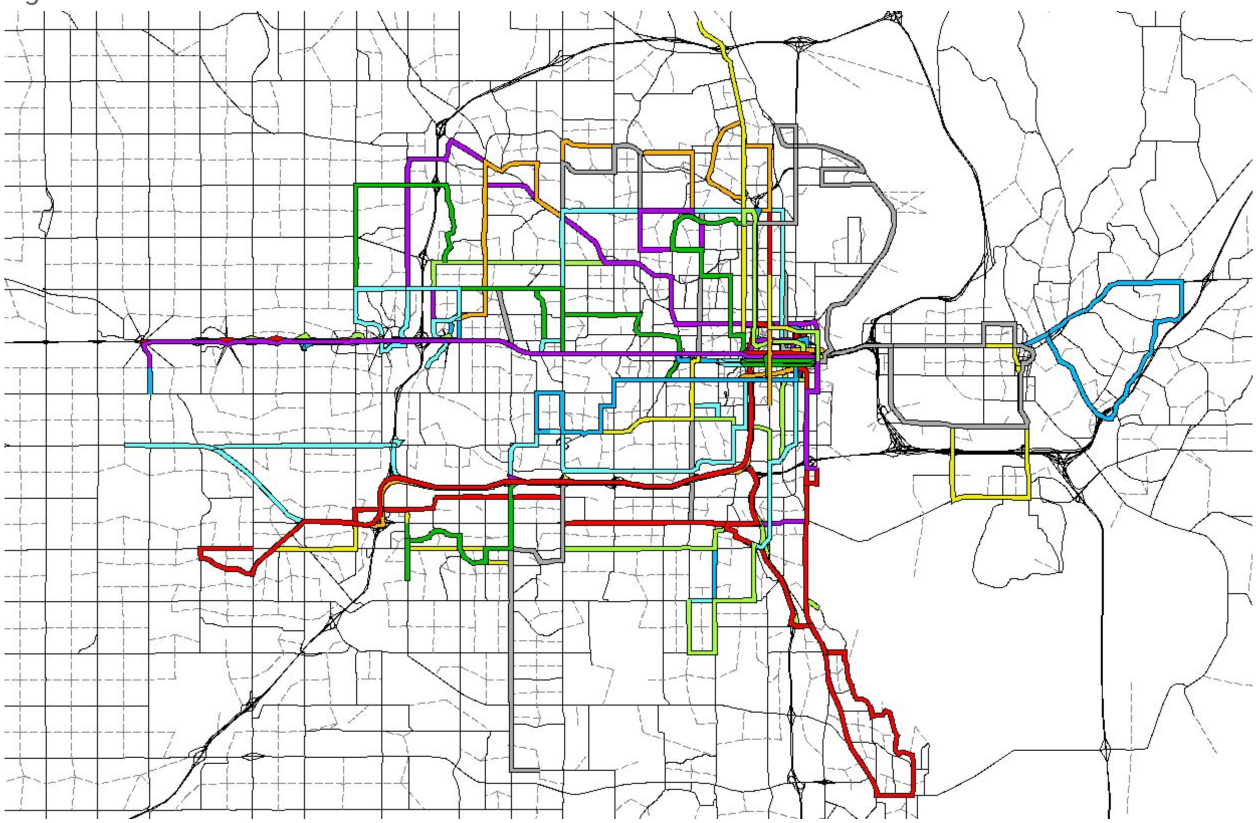


Mode Choice

Mode choice was improved to include a nested-logit mode choice model, provided additional validation to an onboard survey that occurred after the last model update, and added options that allow the testing of "transitway" alternatives which provide dedicated busways or bus lanes are also available. The transit network is shown in Figure C14.

For more details please refer to the *"MAPA Transit Mode Choice Model Updates"* Technical Memorandum that accompanies this document.

Figure C14: Base Year Transit Network



Truck Demand Module

A truck module has been implemented. The model estimates truck volume by origin-destination (O-D) for the entire MAPA Region, broken down into four time periods (AM peak period, midday, PM peak period, and night) and two truck types (light/medium and heavy).

More details can be found in the *"MAPA Truck Demand Module Development and Calibration"* Technical Memorandum that accompanies this document.

Access to Jobs

The MAPA travel demand model script was updated to produce estimates of access to jobs for the region. These estimates can be used in Geographic Information Systems (GIS) analysis to establish the access to jobs for a modeled scenario. Access to jobs is measured in peak travel time (minutes) by automobile and by transit travel time (minutes) where available. Performance thresholds such as percentage of regional jobs within 15 minutes can be evaluated.

More details can be found in the *"Accessibility Performance Measures"* Technical Memorandum that accompanies this document.

Calibration and Validation

The goal of a model is to create a realistic picture of travel patterns in the study area. As such, models should be calibrated to reflect current travel conditions. Travel is unique in each community, therefore results need to be reviewed in detail and adjustments need to be made to inputs or parameters to match local conditions. Each adjustment needs to be done without unreasonably modifying inputs to unrealistic values, which might constrain the model in future scenario years.

Validation refers to the statistical and non-statistical reasonableness checks used to assess the accuracy of the model. The best practice is to perform validation checks on each major step of the model process. This helps to ensure that data and model structure errors are limited or completely omitted throughout the process, and that the model will be flexible enough to respond to transportation and land use scenarios to be effectively used as a forecasting tool. The main validation checks and calibration adjustments are discussed below.

Trip Generation/Distribution

Trip generation rates were estimated from the 2009 National Household Travel Survey (NHTS) data including the local add-on samples. Rates were first estimated for the five standard NHTS trip types and then a school trip type was added. When school trips were added, the NHTS sample was constrained to trips made during the school year which was assumed to run from September – May. The six trip types are:

- Home-based work (HBW)
- Home-based shopping (HBSH)
- Home-based social/recreational (HBSR)
- Home-based K-12 school (HBSch)
- Home-based other (HBO)
- Non-home-based (NHB)

Two common trip generation validation checks are:

- The ratio of unbalanced productions and attractions by trip purpose.
- The total trips per household.

Each trip has a beginning and an end, and it is necessary for the trip producing trips ends to be equal to the number of trip attracting ends. While in practice, unbalanced productions and attractions are never completely balanced due to different data sources and trip rate sources, the ratios of productions and attractions by trip purpose should be reasonably close prior to balancing. If they are not, then it could be because of an input data error (whether socioeconomic data or trip rates) or a model processing error.

The Travel Model Improvement Program (TMIP) *Travel Model Validation and Reasonableness Checking Manual, 2nd Edition* recommends a preferred ratio of between 0.90 – 1.10 for unbalanced productions and attractions before trip balancing. The initial and updated ratios for the MAPA TDM are shown in Table C4 below. While overall productions and attractions were satisfactorily balanced, initially the HBSH and HBSch trip purposes had unbalanced ratios. This spurred a review of trip rates for these purposes. Trip rates were compared with *NCHRP 716: Travel Demand Forecasting: Parameters and Techniques*.

Table C4 - Unbalanced Production and Attraction Ratios

Trip Purpose	Original Trips	Original Ratio	Updated Trips	Updated Ratio
HBWP	539,144	1.03	539,409	1.03
HBWA	525,782		525,488	
HBSHP	573,211	0.74	655,934	0.88
HBSHA	774,606		744,975	
HBSRP	373,306	0.93	373,472	0.93
HBSRA	403,440		403,613	
HBSchP	444,515	1.20	346,465	0.93
HBSchA	370,720		370,720	
HBOP	587,511	0.92	587,773	0.91
HBOA	639,364		648,135	
NHBP	1,322,499	1.00	1,308,476	1.00
NHBA	1,322,499		1,308,476	
All Ps	3,840,185	0.95	3,811,528	0.95
All As	4,036,411		4,001,406	

A direct comparison of HBSH to NCHRP 716 was not possible because of the trip purpose categories available. However, MAPA HBSH, HBSR and HBO were summed into an aggregated HBO category and then compared with the NCHRP 716 HBO (not work or school) trip rates. The majority of the rates were higher in NCHRP 716. Therefore, the difference was taken and some manual review to smooth trip rates was completed. HBSH original and updated trip rates are shown in Table C5.

Original HBSch trip rates were much higher than NCHRP 716. However, during development of the 2010 model, these rates likely came from the past NHTS add-on household travel survey, so there is a desire to use some local input data. As a result an average of the two rates was used. Original, NCHRP 716, and updated trip rates are shown in Table C6.

Table C5 - HBSH Trip Rate Updates

HBSH Original

		Auto Ownership				
		0	1	2	3	4+
HH Size	1	0.8	0.82	0.93	0.8	0.8
	2	1.41	1.44	1.55	1.55	1.75
	3	1.41	1.44	1.85	2.31	2.31
	4+	1.41	2.36	3.14	3.3	3.3

HBSH Updated

		Auto Ownership				
		0	1	2	3	4+
HH Size	1	0.63	0.75	0.81	1	1.2
	2	1.04	1.49	1.55	1.7	1.75
	3	1.41	2.18	2.2	2.25	2.31
	4+	3.55	3.75	3.8	4.34	4.6

Table C6 - HBSch Trip Rate Updates

HBSch Original

		Auto Ownership				
		0	1	2	3	4+
HH Size	1	0	0	0.05	0.07	0.12
	2	0.31	0.31	0.31	0.31	0.31
	3	1.34	1.65	2.06	2.06	2.68
	4+	3.61	3.91	3.91	4.12	4.12

HBSch NCHRP 716

		Auto Ownership				
		0	1	2	3	4+
HH Size	1	0	0	0	0	
	2	0.1	0.1	0.1	0.1	
	3	0.8	0.8	0.8	0.8	
	4+	1.55	2	2.15	2.25	

HBSch Updated

		Auto Ownership				
		0	1	2	3	4+
HH Size	1	0	0	0.025	0.035	0.12
	2	0.205	0.205	0.205	0.205	0.31
	3	1.07	1.225	1.43	1.43	2.68
	4+	2.58	2.955	3.03	3.185	4.12

After these trip rate adjustments were made, HBSH and HBSch unbalanced productions and attractions were closer to being balanced. Additionally, the overall ratio of 0.96 indicates that trip generation results are satisfactory.

The final balanced trips per household after the HBSH and HBSch trip rate updates is shown in Table C7 and compared to Table 5.2 from The Travel Model Improvement Program (TMIP) *Travel Model Validation and Reasonableness Checking Manual (Second Edition)*. The modeled number of trips per household is slightly higher (+8%) than TMIP. However, the trip rates were informed by local survey data and unbalanced productions and attractions are reasonably balanced so there was not a desire to make further adjustments.

Table C7 - Trips Per Household Comparison

Source	Trips per Household
MAPA Model	11.46
TMIP*	10.59

*Travel Model Improvement Program

Trip Distribution Validation Checks and Calibration Adjustments

The trip distribution step takes the balanced trips and for each TAZ allocates them to other TAZs based on network travel times and friction factors. This is done using the gravity model within TransCAD.

Figures C15 through C20 below show the friction factor curves used for each trip purpose. The x-axis represents minutes and the y-axis represents the friction factor, which is the utility or likelihood of making a certain distance trip. For example, the longer a trip is, the less desirable it becomes. These vary by trip purpose as people will typically travel farther for a work trip than other trip purposes. This is represented by the flatter curve in Figure C15 relative to the other curves.

HBW trips are split into three income levels during model processing. Each has its own unique friction factor curve since high and medium income households tend to commute farther from work, as is discussed in Implementation of Income-based Trip Distribution, as part of a 2016 model improvement made by MAPA.

Changes to the friction factor curves were tested during calibration, but none were ultimately made, as the previous model curves fit the MAPA area well.

Figure C15 - HBW Friction Factor Curves

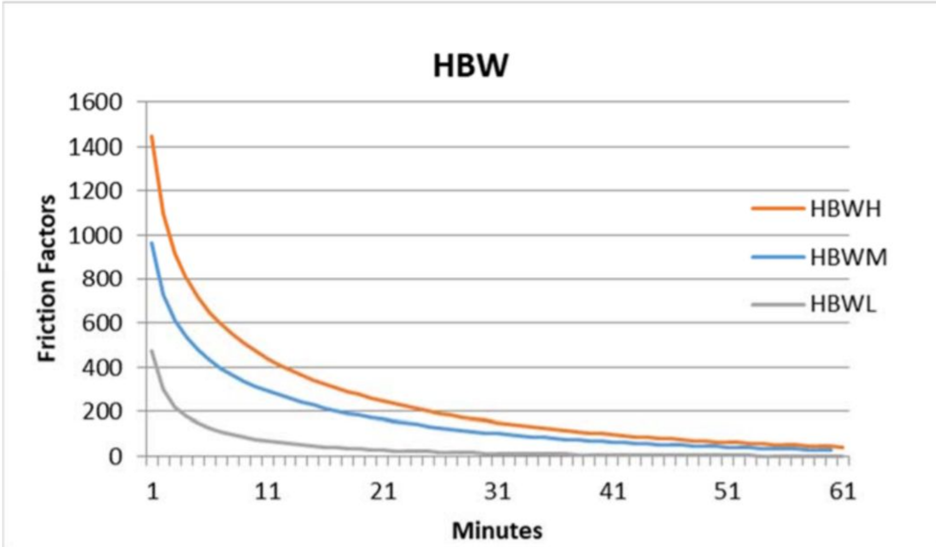


Figure C16 - HBSH Friction Factor Curve

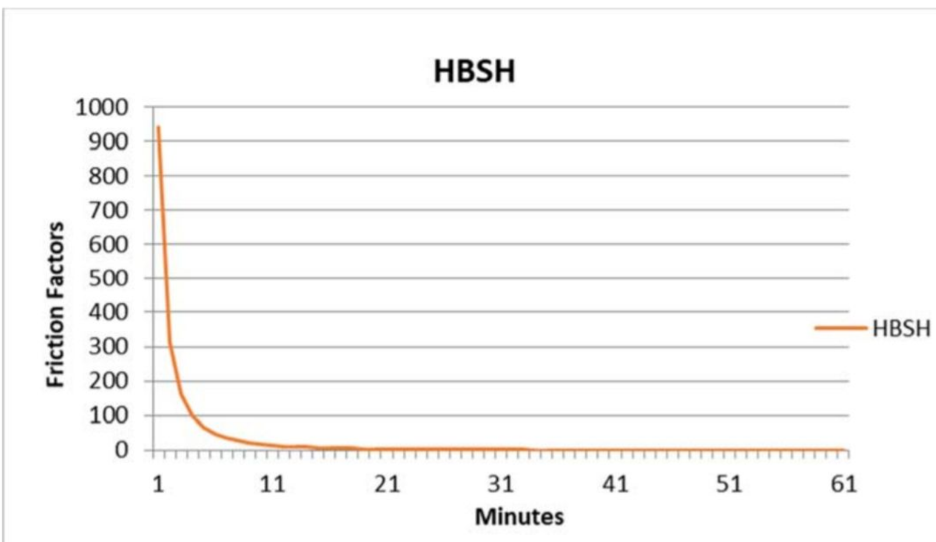


Figure C17 - HBSR Friction Factor Curve

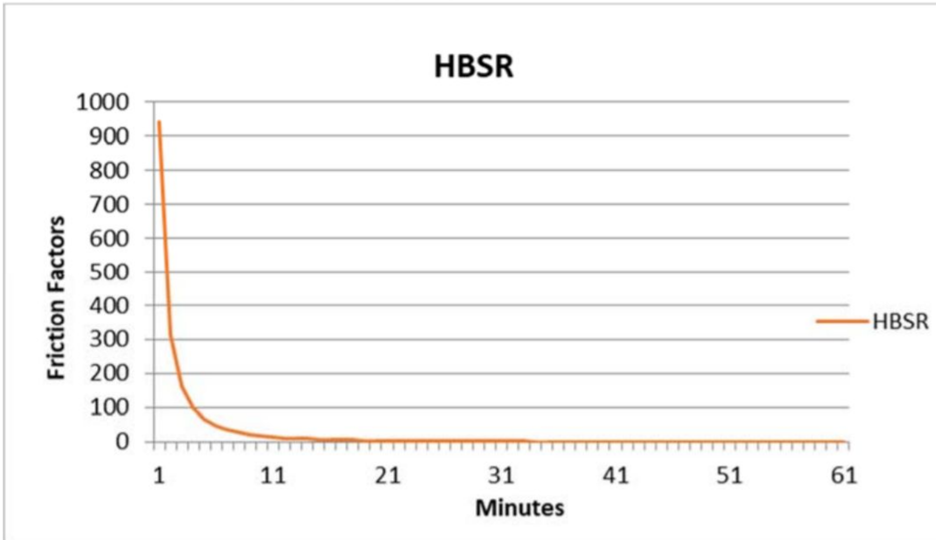


Figure C18 - HBSch Friction Factor Curve

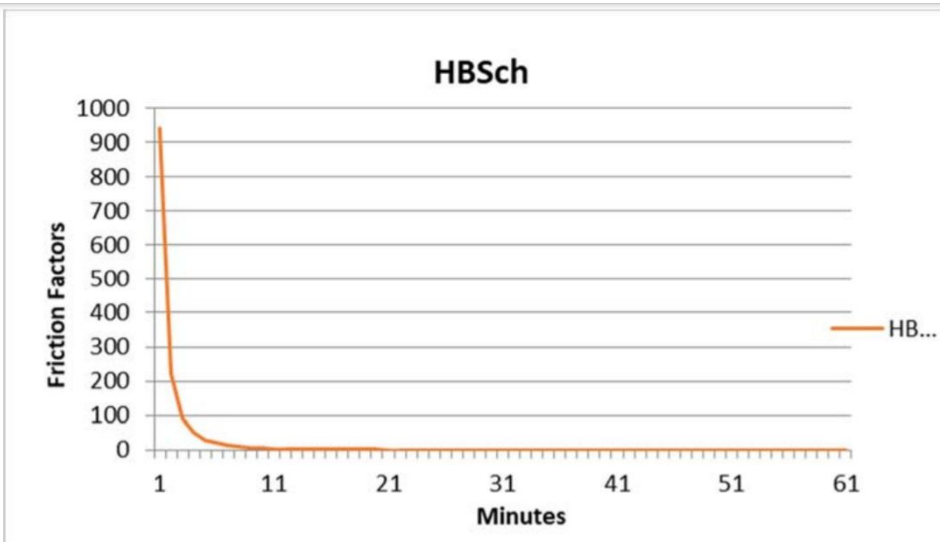


Figure C19 - HBO Friction Factor Curve

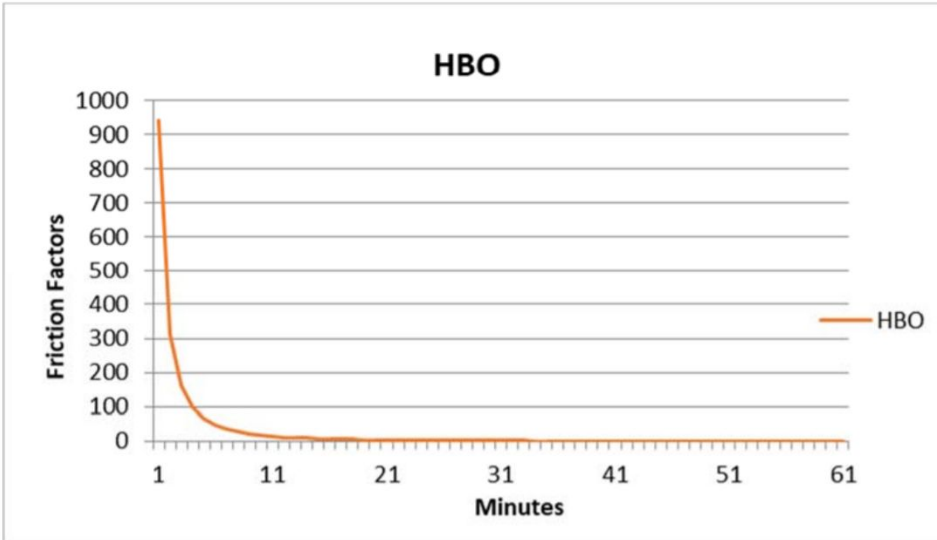
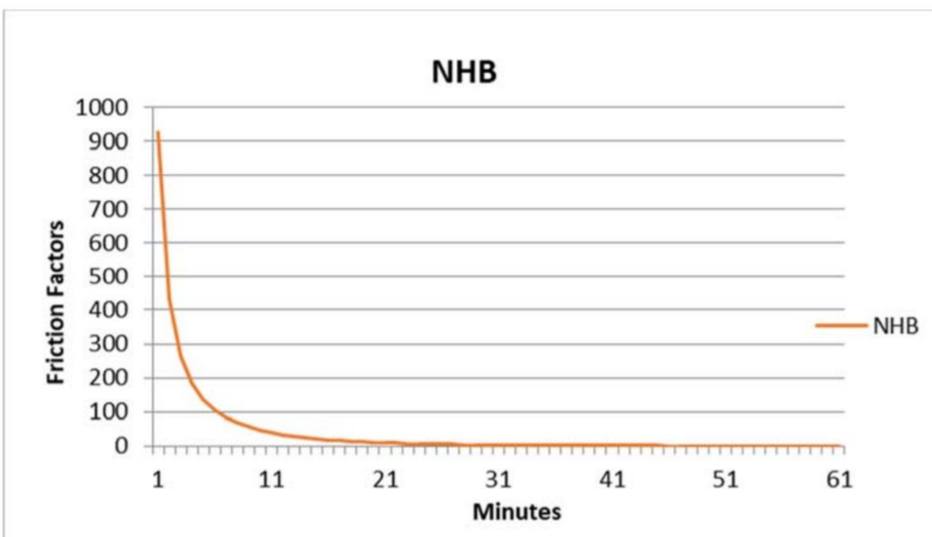


Figure C20 - NHB Friction Factor Curve



During the trip distribution gravity model, K-Factors can be added to reduce or enhance origin and destination pairs that the gravity model does not represent accurately. K-Factors are often referred to as a "socio-economic" factor to adjust travel propensity between origin-destination pairs that are not otherwise accounted for in the trip distribution model. In some situations, K factors may be warranted, but ideally are not required (or desired) in a trip distribution model. KFactors have been implemented in two scenarios for the MAPA model:

- IA to NE Trips: In the MAPA TDM, multiple K-Factors exist from previous work for the Missouri River Crossing as shown in Table C8. The HBW K-Factors were developed using AirSage data during a 2016 model update to calibrate income-based work trips.

Table C8 - K-Factors

Description	Factor	Trip Purpose(s)
Missouri River Crossing	0.20/0.40	HBWL & HBWM
Missouri River Crossing	1.50	HBWH
Missouri River Crossing	0.40	Not HBW

- Offutt Air Force Base Trips: One additional K-Factor was added to better represent travel to / from Offutt Air Force base, a major attractor in the Omaha-Council Bluffs area. The MAPA model previously used a special Offutt Trip Table, of unknown origin, that distributed nearly all Offutt trips to only 6 TAZs in immediately adjacent Sarpy County zones. Through model calibration, trips to and from Offutt were first distributed without K-factors via the gravity model. The initial results from the model runs with the gravity model showed too many trips between Offutt and Douglas County, based on Longitudinal Employer-Household Dynamics (LEHD) home and work pairs. The Offutt workforce is a relatively unique cross-section of the community, so it was regarded as an appropriate situation to introduce a K-Factor. A K-Factor of 0.60 was added between Offutt Air Force Base (Offutt AFB) and Douglas County. The comparison of trips between Offutt AFB and Douglas and Sarpy Counties compared to Longitudinal Employer-Household Dynamics (LEHD) home and work pairs is shown in Table C9. This one change improves distribution of trips to and from one of the largest employers in the model area.

Table C9 - Offutt AFB Trip Comparison

		Offutt AFB Destination		
		LEHD Observed Offutt Worker Location	Gravity Model Distributed (without K-Factor)	Distributed with Offutt Worker K-Factor
Home Origin	Sarpy County	57%	46%	58%
	Douglas County	25%	36%	26%
	Other	18%	18%	16%

After the gravity model was applied, a comparison of average travel times and travel time frequency distributions was made with observed data. Census Transportation Planning Products (CTPP) provides average travel time for Journey-to-Work survey data to and from Omaha and Council Bluffs. HBW trips from the AM time period in the model were used for the comparison since most HBW trips from home to work occur during that time period.

The initial average travel times are shown in Table C10. While it's not uncommon for a model to underestimate travel time compared to CTPP, the significant underestimates particularly when a trip did not leave a community, led to the decision to add terminal time to the model. The revised and final average travel times include the terminal times shown in Table C11.

Table C10 - Average Travel Time (Minutes)

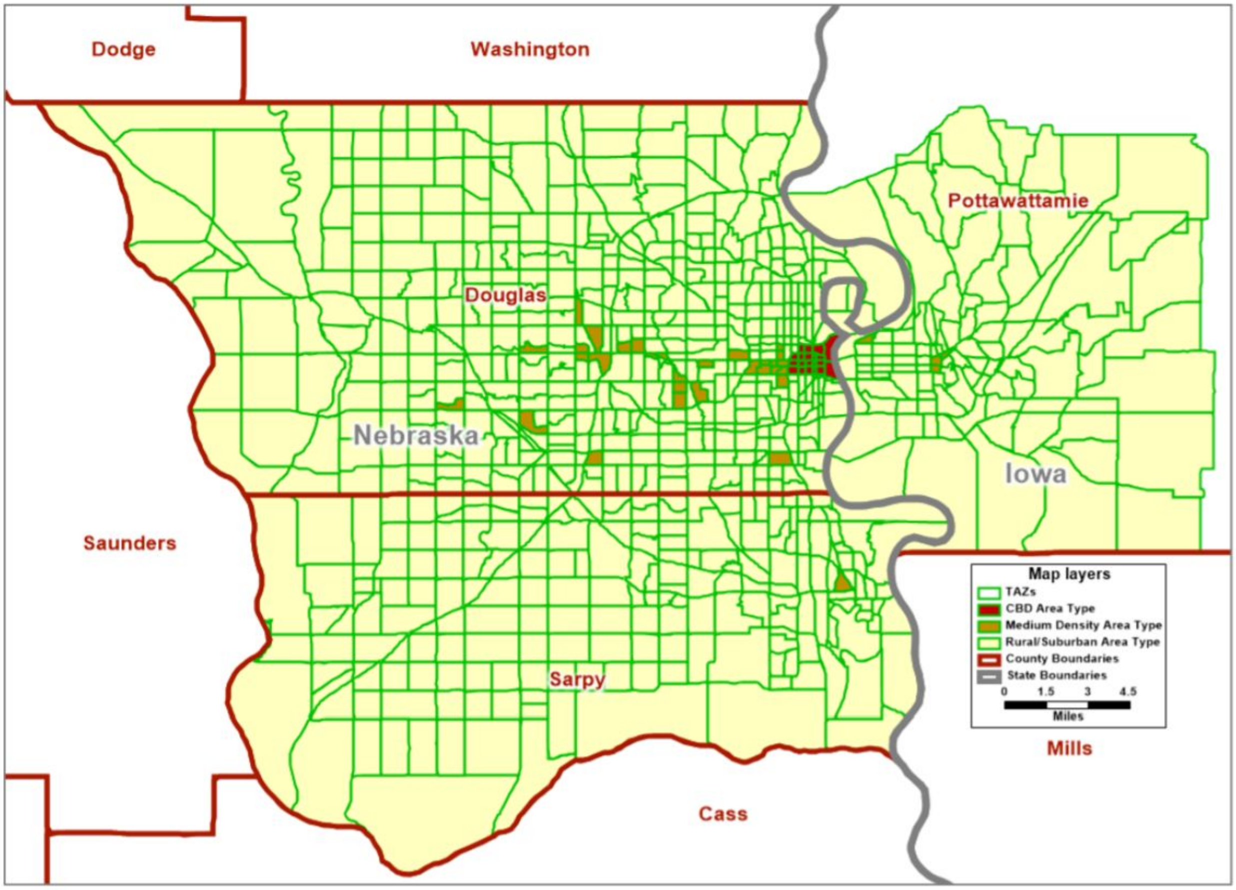
	Original Model Estimated AM HBW Travel Time	CTPP Journey-to-Work Travel Time	Revised Model Estimated AM HBW Travel Time
Council Bluffs to Council Bluffs	5.9	13.6	9.4
Council Bluffs to Omaha	14.2	21.2	18.8
Omaha to Council Bluffs	16.6	22.2	22.7
Omaha to Omaha	9.2	17.3	16.4

Table C11 - Terminal Times

Area Type	Terminal Time (Minutes per Trip End)
Central Business District (CBD)	3
High Density	2
Other	1
External	10

The locations of the area types used for the various terminal times are shown in Figure C21. These areas types were updated using aerial photos and the socioeconomic data to determine non-CBD zones that have a relatively higher density of socioeconomic information.

Figure C21 - TAZs and Area Types



A comparison of the resulting travel time frequency distribution curves are shown in Figures C22 through C25. The corresponding Coincidence Ratios are shown in Table C12. The Coincidence Ratio measures the areas under the curves that match compared to the areas that do not match. Although this comparison is not as ideal as it would be to compare to household travel survey data, it does show a decent match for most origins and destinations.

The least accurate curve is the Council Bluffs to Council Bluffs curve where the model is unable to distribute many trips beyond 15 minutes. Also, in each graph, the CTPP data shows more trips in the 30-44 minute range. Part of the reason may be that a vehicle trip table was compared to Census data that would contain all modes. Because of differences in time periods among walk and transit modes compared to vehicle modes, the tables could not be readily joined.

Figure C22 - Council Bluffs to Council Bluffs Frequency Distribution Curve

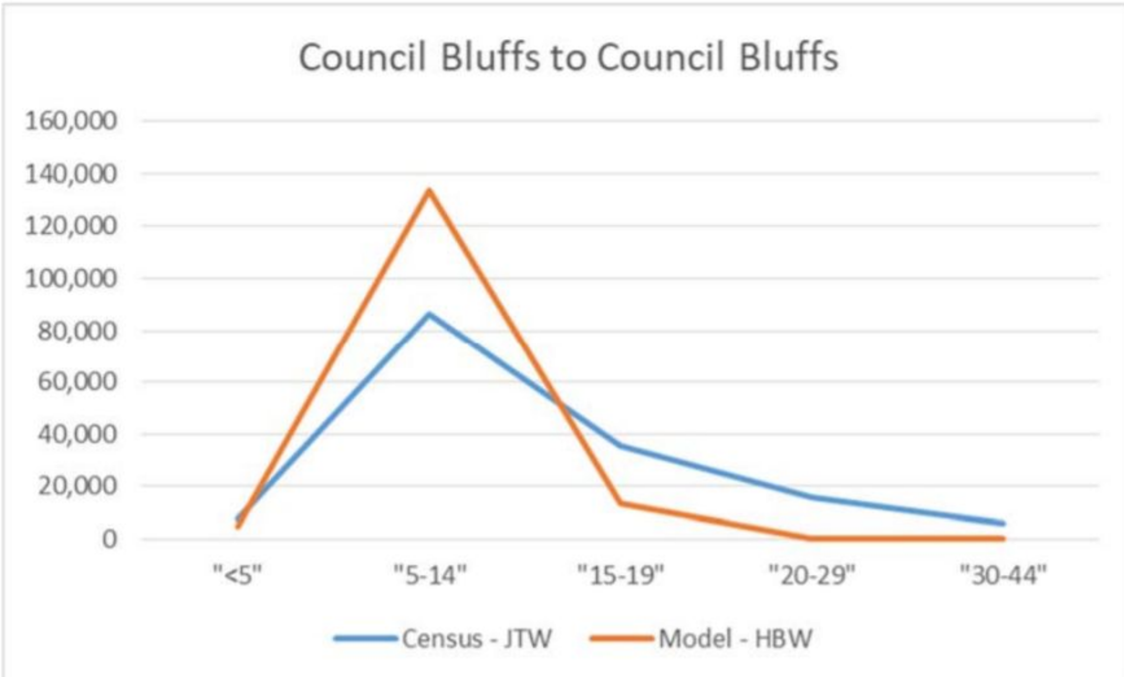


Figure C23 - Council Bluffs to Omaha Frequency Distribution Curve

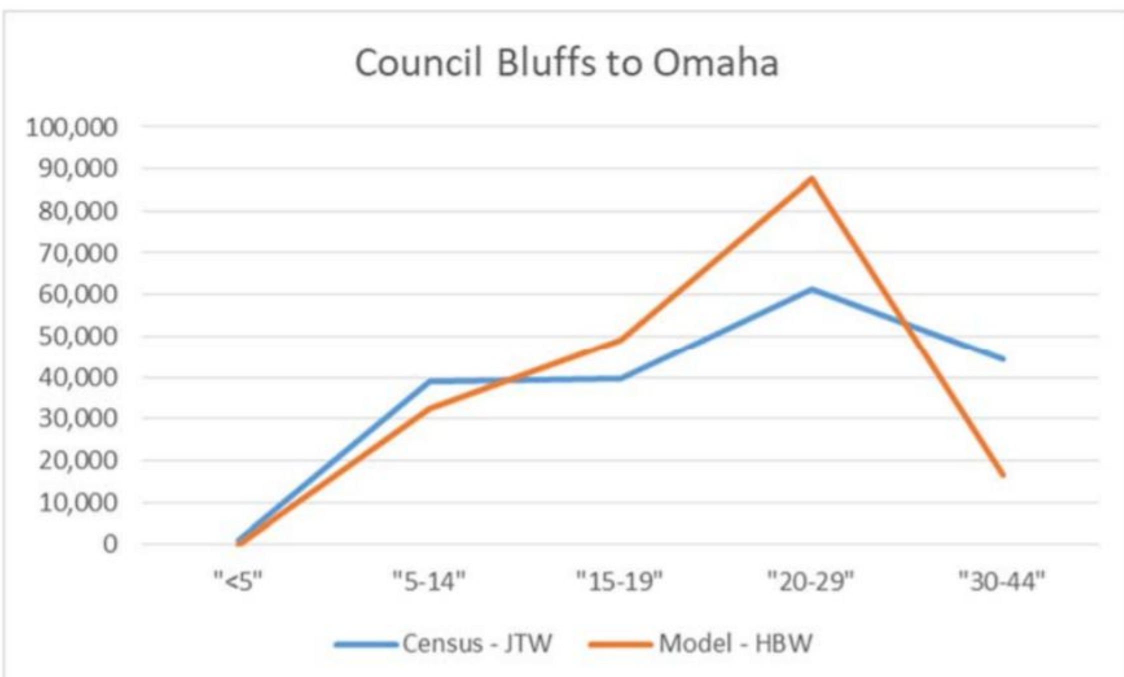


Figure C24 - Omaha to Council Bluffs Frequency Distribution Curve

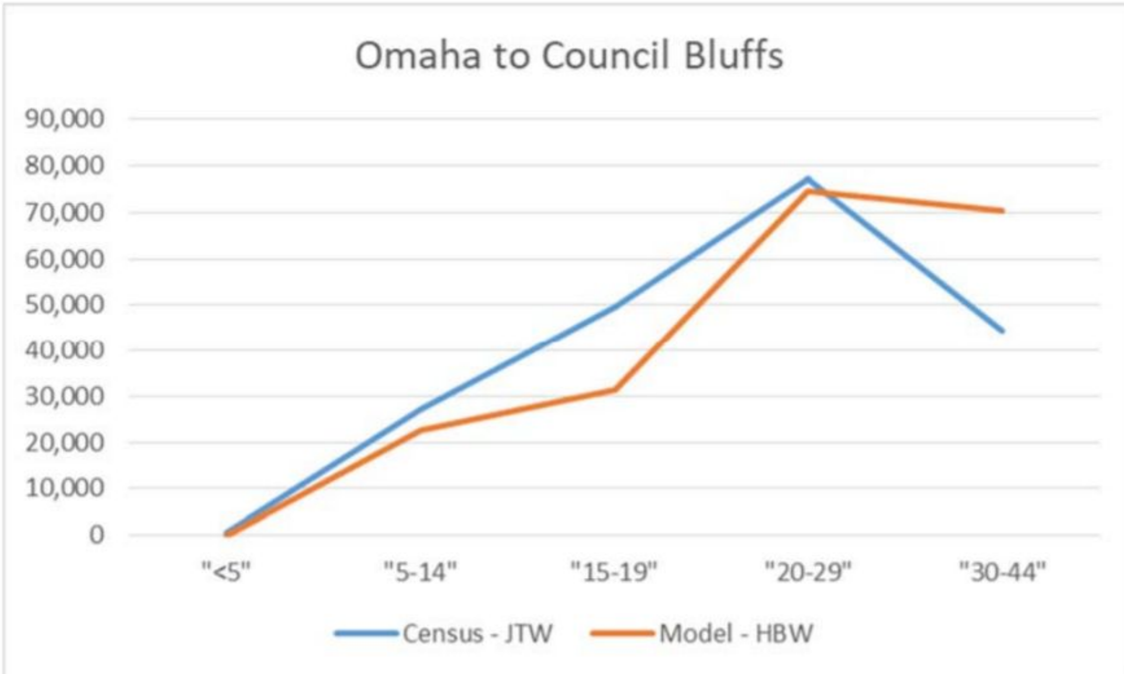


Figure C25 - Omaha to Omaha Frequency Distribution Curve

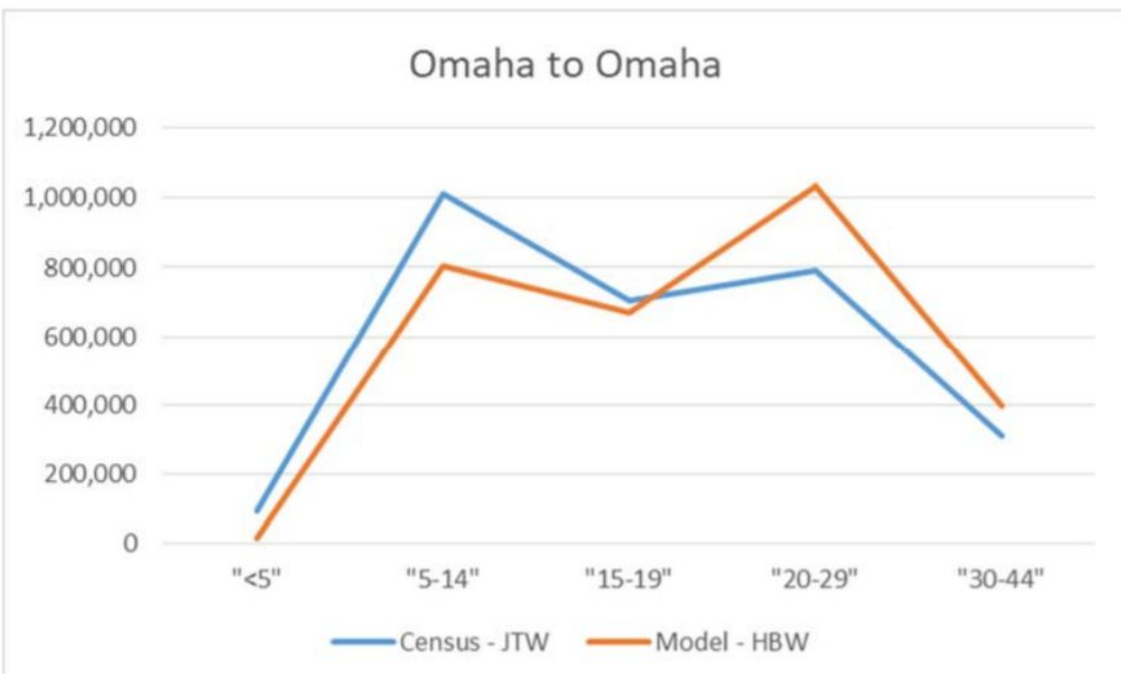


Table C12 - Confidence Ratios of Major Trip Interchanges

Origin and Destination	Coincidence Ratio
Council Bluffs to Council Bluffs	0.527
Council Bluffs to Omaha	0.678
Omaha to Council Bluffs	0.769
Omaha to Omaha	0.793

Mode Choice Validation Checks and Calibration Adjustments

Once all motorized trips are distributed, the model divides those trips into auto and transit trips through the mode choice step. The MAPA TDM uses a nested logit mode choice procedure that first splits mode choice decision between auto and transit modes. The transit trip decisions are further split among walk-to-transit or drive-to-transit trips. Then, those trip decisions are split among local, express, bus rapid transit, or premium transit. Each mode decision level is nested within the one above it.

For more details please refer to the "MAPA Transit Mode Choice Model Updates" Technical Memorandum that accompanies this document.

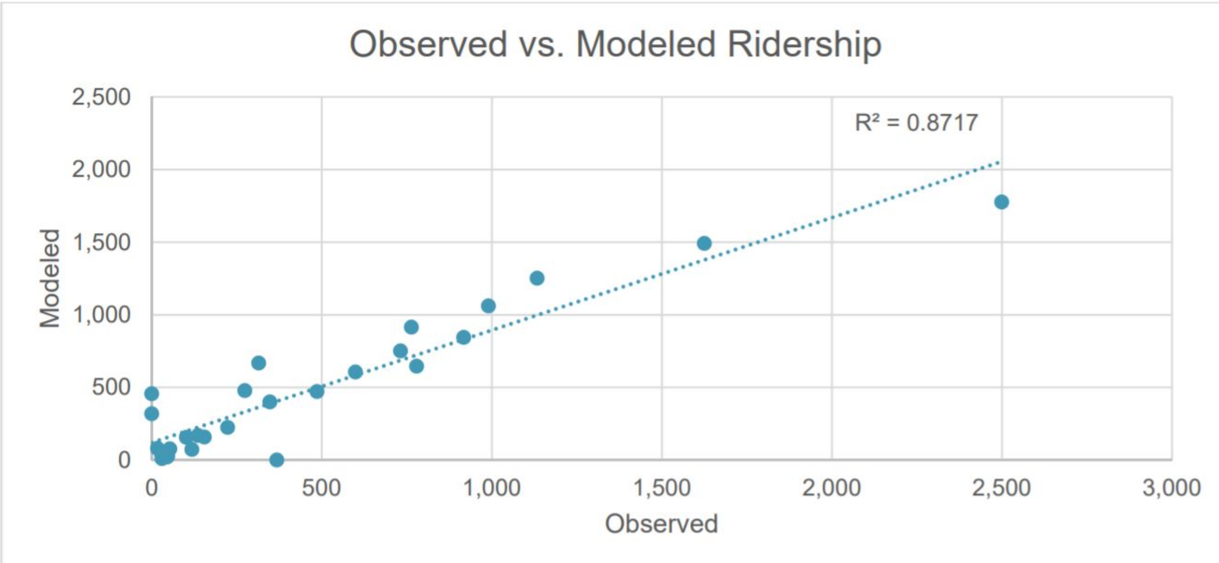
The mode choice procedure and transit assignment results were calibrated in 2019 to reflect updates to Metro Transit routes. Yet, as various inputs were altered during the update to 2015 and calibration, the transit ridership results were impacted. This required a minor re-calibration effort. Mode choice constants for peak and off-peak walk-to-transit and drive-to-transit were adjusted until total ridership numbers produced by the model were close to observed ridership.

The adjusted constants are shown in Table C13. The constants were all adjusted proportionally by 4%, so that the nested constants were not disproportionately impacted and results from the previous recalibration effort are similar among nested modes. The resulting ridership by route compared to observed ridership is shown in Figure C26.

Table C13 - Adjusted Mode Choice Constants

	HBWL	HBWM	HBWH	HBSH	HBSR	HBSch	HBO	NHB
Off-Peak Walk-to-Transit	-1.867	-2.683	-3.432	-4.586	-4.243	-4.753	-4.131	-4.41
Off-Peak Drive-to-Transit	-3.64	-6.24	-6.24	-5.72	-5.2	-5.616	-6.24	-5.2
Peak Walk-to-Transit	-1.587	-2.35	-2.48	-5.876	-4.69	-4.212	-4.94	-4.992
Peak Drive-to-Transit	-3.536	-4.264	-3.328	-7.28	-7.28	-6.24	-6.76	-6.344

Figure C26 - Observed vs Modeled Ridership by Route



Another step that occurs before final vehicle trip tables are assigned to the roadway network is the conversion of auto person trips to auto vehicle trips. This is done by applying auto occupancy factors. The original auto occupancy factors in the MAPA model were significantly lower than other sources, including NCHRP 716. Also, the original source of these values is unknown, but documentation from 2012 indicates that they were based on adjusted trip rates from the 2009 National Household Travel Survey (NHTS) add-on for the Omaha-Council Bluffs region.

Auto occupancies were switched to NCHRP 716 values for most trip purposes. HBSH and HBSR were assumed to be a type of HBO trip purpose, so the NCHRP 716 HBO auto occupancies were used. HBSch is the one exception. The NCHRP 716 value of 1.14 is very low, considering that a HBSch trip often involves an adult driving a child or multiple children to school. The value may be more reflective of an adult school trip. Therefore, an average of the original MAPA occupancy and the NCHRP 716 value was used.

Table C14 - Auto Occupancy Factors

Trip Purpose	Original Auto Occupancies	NCHRP 716* Auto Occupancies	Updated Auto Occupancies
HBW	1.04	1.10	1.10
HBSH	1.33	N/A	1.75
HBSR	1.45	N/A	1.75
HBSch	2.54	1.14	1.84**
HBO	1.33	1.75	1.75
NHB	1.26	1.66	1.66

***Table 4.16**

***Average of original value and NCHRP 716 value*

Traffic Assignment Validation Checks and Calibration Adjustments

The goal of a TDM is to replicate travel patterns as accurately as possible throughout each step of the model, without placing too many unreasonable constraints on its operation. Ultimately, the model predicted volumes should have a strong correlation with observed traffic count data.

Prior to traffic assignment, traffic counts were processed to isolate where actual counts occurred. The original count database included counts for the entire road network – most of which had been synthesized. A separate shapefile provided point locations of intersections that were counted. This was used to select only the counts at those intersections, which were placed into a new field called ValCount. In addition, counts were reviewed throughout assignment calibration and in some cases updated to NDOT or Iowa DOT counts where they diverged. Although the ValCount field may not represent actual count locations 100% of the time, this subset of counts is closer. Additionally, limiting validation to a subset of counts removes the possibility of validation statistics being reported multiple times for the same roadway.

In the traffic assignment step the model attempts to minimize a trip's cost (in the MAPA model, this is travel time) between its origin and destination. Travel time is a function of congested speed and distance traveled. The original input speeds were based on posted speeds.

Localized adjustments to centroid connectors were made during calibration to better represent how traffic flows in and out of neighborhoods. One additional calibration adjustment was the introduction of a global speed adjustment to arterials of positive three miles per hour. Assignment results initially underrepresented these functional class roadways when compared to traffic count data. The three mile per hour speed adjustment slightly reduced travel times and made travel on arterials slightly more attractive, balancing out traffic among all functional class roadways more evenly. This adjustment impacts the network shortest path travel times used to distribute trips, as well as the routes that traffic assignment assigns to the road network.

A comparison of model-estimated Vehicle Miles Traveled (VMT) to counted VMT for locations with traffic counts shows that all functionally classified road categories are within the validation goals provided by FHWA in 1990 (Table C15). Volumes are slightly underestimated on lower functional class roads compared to count data in terms of VMT, yet are still within validation guidelines.

Table C15 - Model-Estimated VMT by Functional Class Compared to Observed VMT

	Number of Counts	Vehicle Miles Traveled (VMT)		Error		Validation Goal*
Functional Class		**Estimated**	**Observed**	**Difference**	**Percentage**	
Freeways	127	2,321,645	2,315,698	5,948	0.3%	+/-7%
Principal Arterial	478	1,997,553	1,976,228	21,326	1.1%	+/-10%
Minor Arterial	1001	3,269,112	3,248,517	20,595	0.6%	+/-15%
Collectors	1119	903,442	996,312	-92,870	-9.3%	+/-20%
Total	2,725	8,491,753	8,536,755	-45,002	-0.5%	N/A

*FHWA-1990 goals

Percent Root Mean Squared Error (%RMSE) is a standard model validation check that measures the average error between the model-estimated and counted volumes. The lower the value, the less the error there is between the model-estimated volumes and the counts. Tables C16 and C17 show the %RMSE stratified in two different ways: by volume groups and by functional class.

The %RMSE in the MAPA model meets expectations for all volume groups except 10,000 – 15,000 vehicles per day, which is just slightly out of range. No validation guidelines are listed by functional class, but it is typical to expect a total model %RMSE to be around 30-35%. Given the uncertainty of the count data, these results should be considered within the "acceptable" range. Further calibration to better match counts may lead to unreasonable restrictions on the model which could potentially impact the sensitivity of the model to do traffic forecasts.

Table C16 - Percent Root Mean Squared Error by Volume Groups

Volume Range	Number of Counts	% RMSE	Validation Goal*	
			Acceptable	Preferable
0 - 5,000	899	79.58%	100%	45%
5,000 - 10,000	657	42.37%	45%	35%
10,000 - 15,000	369	37.38%	35%	27%
15,000 - 20,000	230	34.25%	35%	27%
20,000 - 30,000	402	27.15%	35%	27%
30,000 – 40,000	93	19.35%	35%	27%
40,000 – 50,000	42	14.11%	35%	27%
50,000 – 60,000	16	11.91%	35%	27%
Greater than 60,000	17	6.25%	35%	27%

*Florida Standard Urban Transportation Modeling Systems (FSUTMS)

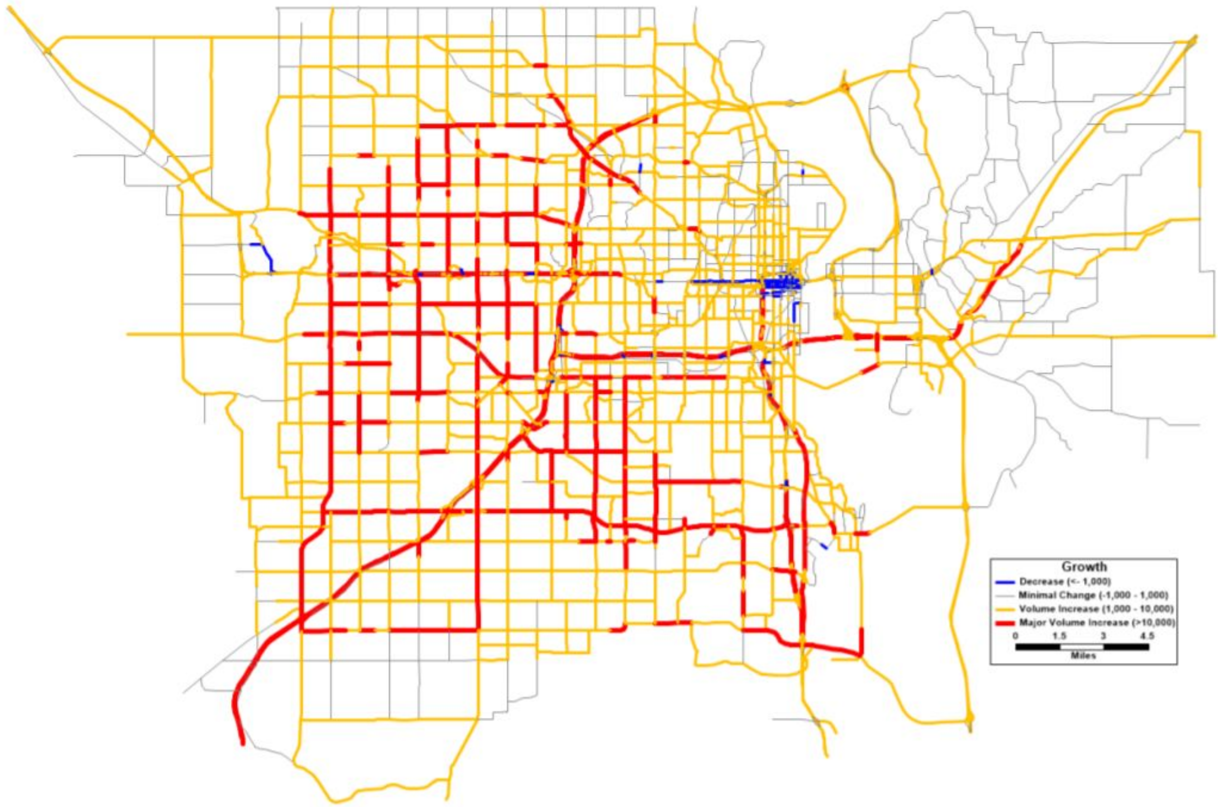
Table C17 - Percent Root Mean Squared Error by Functional Class

Link Type	Number of Counts	% RMSE
Freeway	156	15.32%
Principal Arterial	478	30.26%
Minor Arterial	1001	33.84%
Collector	1090	61.62%
Total	2,725	35.93%

Figure C27 shows the magnitude of growth on the road network when comparing a base year 2015 model run to a 2050 forecast run with existing and committed projects (E+C) included on the network. The committed projects include those listed in the Transportation Improvement Program (TIP) and recently built road projects. In addition, gravel roads adjacent to TAZs that are predicted to growth by 200 or more households or employees were converted to paved roads in the Existing + Committed road network set.

Volumes increase on the majority of roadways, particularly higher functional class roadways. Volume decreases are limited and scattered, but the CBD does show a decline in volumes on many of the roadways.

Figure C27 - 2050 E+C Compared to 2015 Base Magnitude of Growth



Figures C28 and C29 show the predicted level-of-service for 2050. A significant portion of the network in Nebraska is expected to be congested or congesting during the peak time periods. Roads in Iowa show significantly less congestion overall.

Table C18 shows a summary of growth. Balanced trips grow by 61%. While VMT grows by a similar amount, but slightly lower amount. The reason for this is the feedback loop which redistributes trips to closer destinations as roads become congested. VHT grows by a significantly higher amount than both VMT and balanced trips. This suggests that trips on the road network are expected to take longer as more and more roads become congested.

Figure C28 - 2050 AM Existing+Committed Network Predicted Level of Service

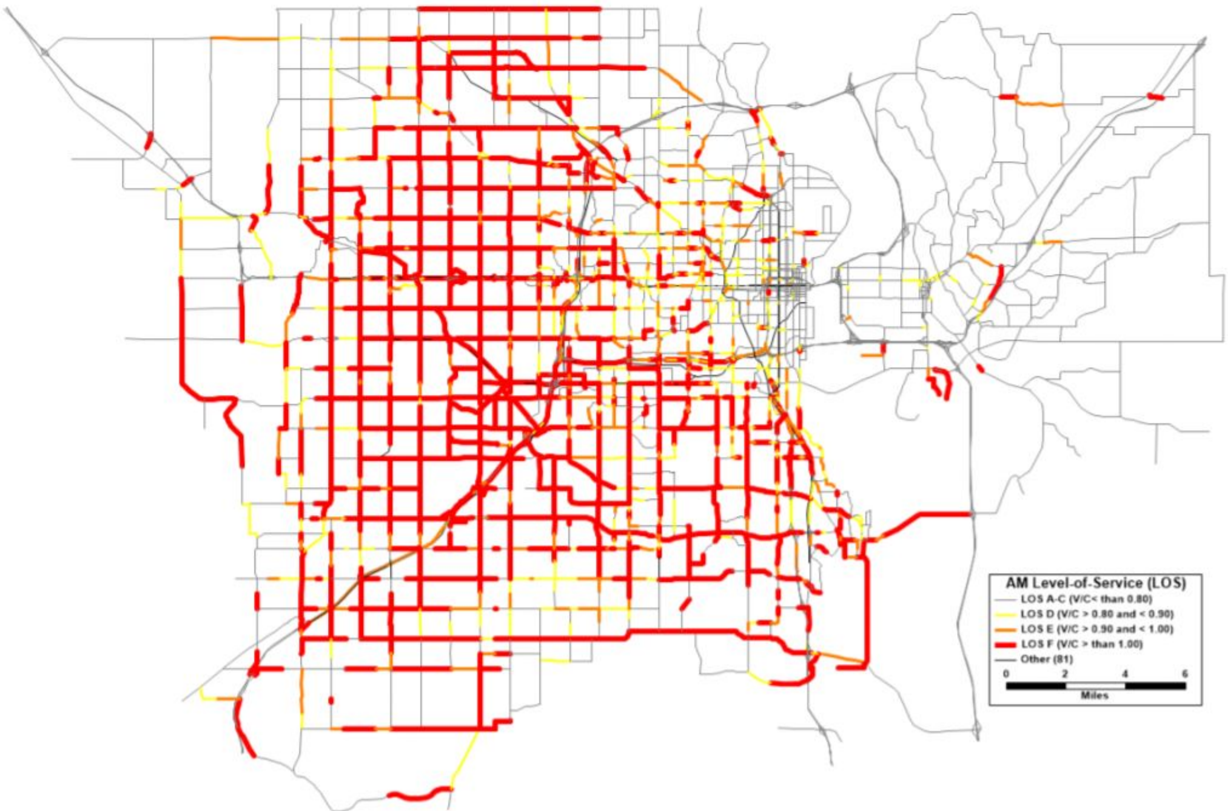


Figure C29 - 2050 PM Existing+Committed Network Predicted Level of Service

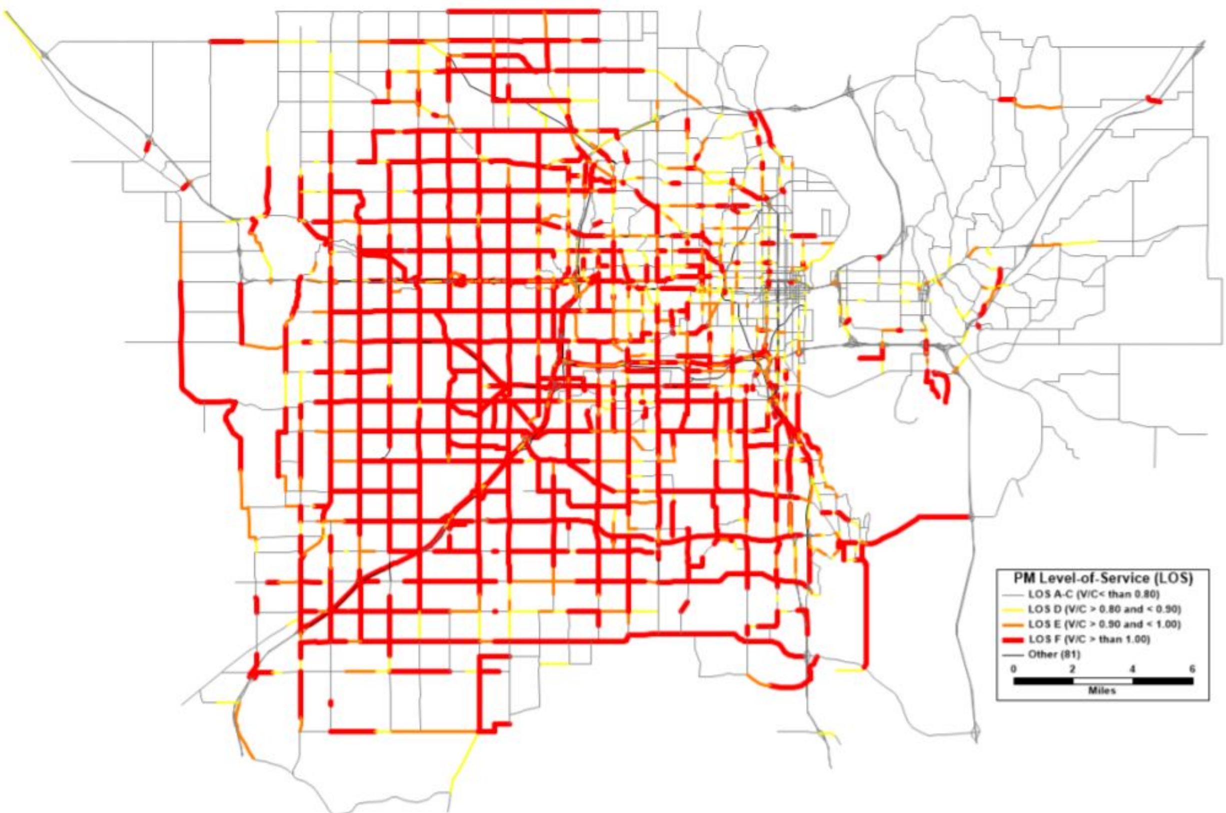


Table C18 - Summary of Growth

	2015	2050 E+C	Growth
Households	310,471	482,052	55%
Employment	435,781	649,216	49%
Balanced Trips*	3,557,905	5,719,108	61%
VMT**	16,611,822	26,291,791	58%
VHT**	385,601	916,006	138%

* balPersonTrips.bin

**Centroid Connectors not included

Conclusions and Next Steps

The major edits, updates, and adjustments that were made to the MAPA TDM were discussed in this documentation. The calibration process and validation results were also discussed in detail. The validation results indicate that the MAPA TDM is sufficiently accurate and usable for a forecasting tool.

While the accuracy is solid, improvements can always be made. One of the near-term improvements that is recommended is the conversion to the Iowa Statewide Model Structure (ISMS) standard. One of the primary benefits of ISMS is the file management and user friendliness of model applications, which will make running scenarios more straightforward.

Additionally, because ISMS is a standard model process across Iowa, it increases the understanding and usability of the model results. It has been noted that some of the MAPA model processes are more advanced than the current ISMS framework is capable of. Thus, the two model structures will need to be merged to take advantage of the benefits from both platforms.

Accessibility Performance Measures

MTIS

Modification of MAPA Model Script to automate quantification of access to jobs using travel model data

Omaha, NE
January 26, 2016

1 Accessibility Performance Measures

1.1 Access to Jobs

The MAPA travel demand model script was updated to produce estimates of access to jobs for the region. These estimates can be used in Geographic Information Systems (GIS) analysis to establish the access to jobs for a modeled scenario. Access to jobs will be measured in peak travel time (minutes) by automobile and by transit travel time (minutes) where available. Performance thresholds such as percentage of regional jobs within 15 minutes can be evaluated.

1.1.1 Accessibility Script

The MAPA travel demand model TransCAD script was modified to utilize the model input socio-economic data, along with auto and transit time skims (origin to destination times computed by the model) to compute the percent of model regional employment within a specified travel time threshold. This computation is carried out for every TAZ in the model and for each travel mode in the model (auto, drive-to-transit, and walk-to-transit). This provides a measure of accessibility to jobs for the households in each TAZ. Maps of accessibility can be made by joining the accessibility measures computed by the script (Accessibility{time limit}{scenario}.dbf in the model output directory) to the TAZ shapes using GIS.

A model input parameter is added to the USER CHANGE AREA of the script, titled AccTimeLimits. This is a list of time thresholds (in minutes) to be used during the model run for determining accessibility. By default it is set to {15,60}. 15 minutes is suggested for automobile access times, and 60 minutes is suggested for transit access times. This list can be extended or changed if more or different access limits are desired.

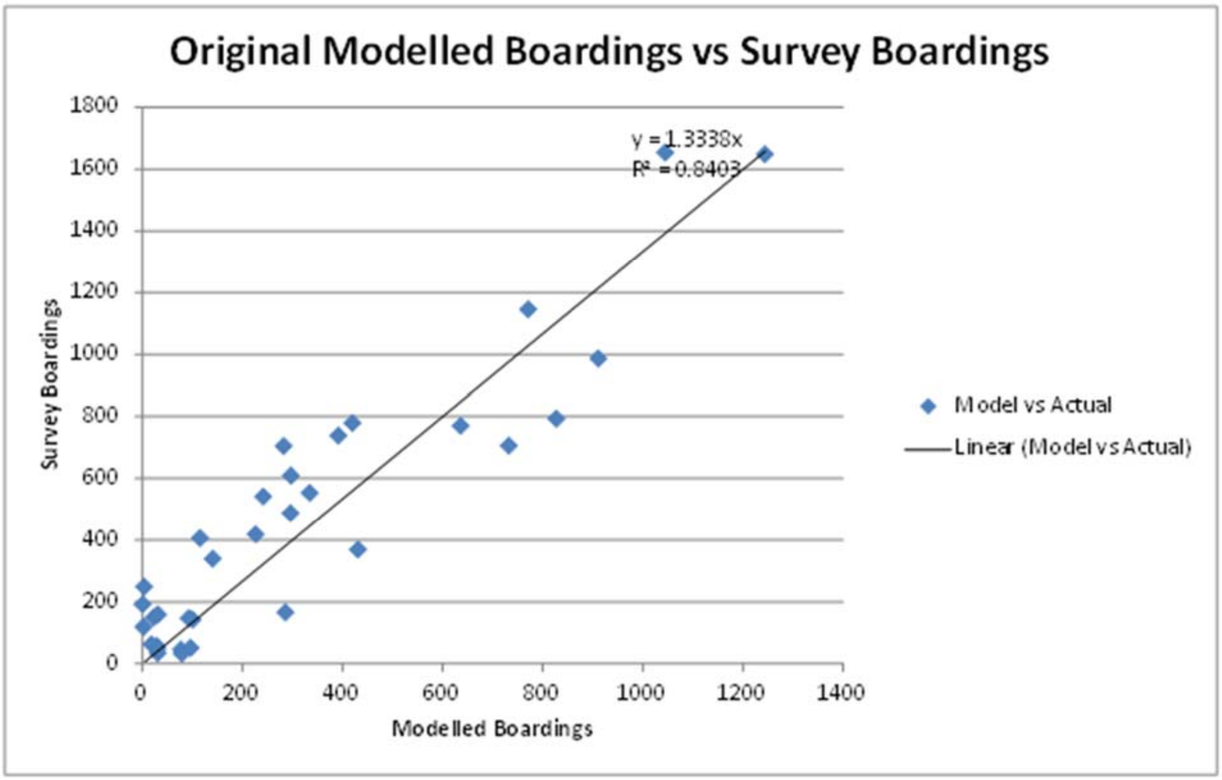
Additionally, the script computes the percentage of regional households that are within the travel time threshold from each TAZ. This provides a measure of accessibility to households for jobs in each TAZ.

Date:	**Tuesday, March 29, 2016**
Project:	**Metropolitan Area Travel Improvement Study**
To:	**MAPA Staff**
From:	**Jason Carbee, Mike Rose (HDR)**
Subject:	**MAPA Transit Mode Choice Model Updates**

Introduction

This memorandum outlines the key updates made by HDR in for the mode choice element of the MAPA travel demand model.

The figure below provides a summary of the goodness-of-fit of the transit assignments prior to the model updates.



Validation of Transit Assignment

The process of updating the transit assignment validation involved:

1. Extracted transit PA trips from survey by mode and purpose

2. Created survey based trip tables for testing assignment

3. Tested modifications to walk and drive to transit network settings and assignment parameters to improve validation of assigning the survey trip tables against actual ridership indicated in the survey

    a. Version 2 Adjustments - Changed headway calculated to use in skimming and assignment to reduce the impact of long headways. Reasoning is that people use scheduled time to determine when to go the bus stop when the headways are long >30 minutes. Particularly for express routes that only run 1 or 2 trips each way. This improved the model goodness-of-fit (r2) from 0.85 to 0.86 and reduced the under assignment of long headway routes. Formula used to compute effective headway: (if AM_headway < 20 then AM_headway else (if AM_headway < 30 then 20 + (AM_headway-20)*0.5 else (if AM_headway < 60 then 25 + (AM_headway-30)*0.25 else (32.5 + (AM_headway-60)*0.1))))

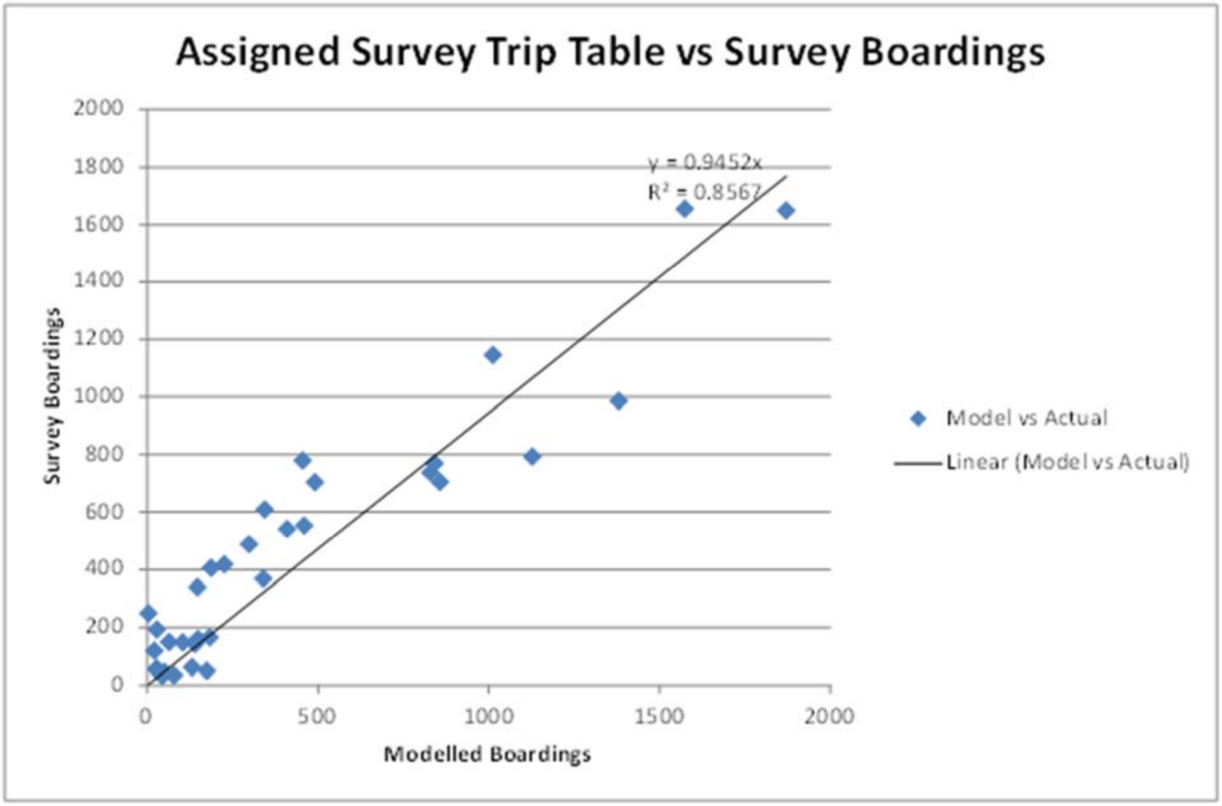
    b. Version 3 Adjustments - Increased max walk time from 10 to 20 minutes. Reasoning is that some survey trips were unable to be assigned. There are many reasons why that could be, but one is that they walked more than 10 minutes to/from the bus stop. This allowed more trip to be assigned, and also lowered the number of transfers (which were too high).

    c. Version 4 Adjustments - Tried assigning peak and off-peak trips separately, using their respective headways. This did not improve the assignment validation, and therefore will not be included at this time because of the added complexity. One reason to have separate peak and off-peak assignment would be to allow the model to differentiate between all-day routes and peak-only routes. The model currently only uses AM peak headways.

    d. Version 5 Adjustments - based on V3, with revised effective headway calc. Formula used to compute effective headway: (if AM_headway < 15 then AM_headway else (if

AM_headway < 30 then 15 + (AM_headway-15)*0.5 else (22.5 + (AM_headway-30)*0.33)))

The figure below provides the interim improved performance of the model, based on this initial set of assignment validation adjustments.



Estimation of Mode Choice Logit Model

The steps involved in estimating a mode-choice logit model included:

1. Constructed synthetic survey from person trip tables and the transit on-board O-D survey.
2. Used TransCAD logit model estimation routine to estimate 0-auto coefficient and mode specific constant (MSC) for the 8 purposes based on the synthetic survey.

3. Used 50% of the 0-auto coefficients because the levels were higher than expected values. Removed the effective headway calculations from walk-access since they seemed to make the results worse.

4. Iteratively ran the logit mode choice routine and adjusted MSCs to match the survey based calibration targets for linked trips. Excluded route 200 from targets since the model did not see it as a Park and Ride.

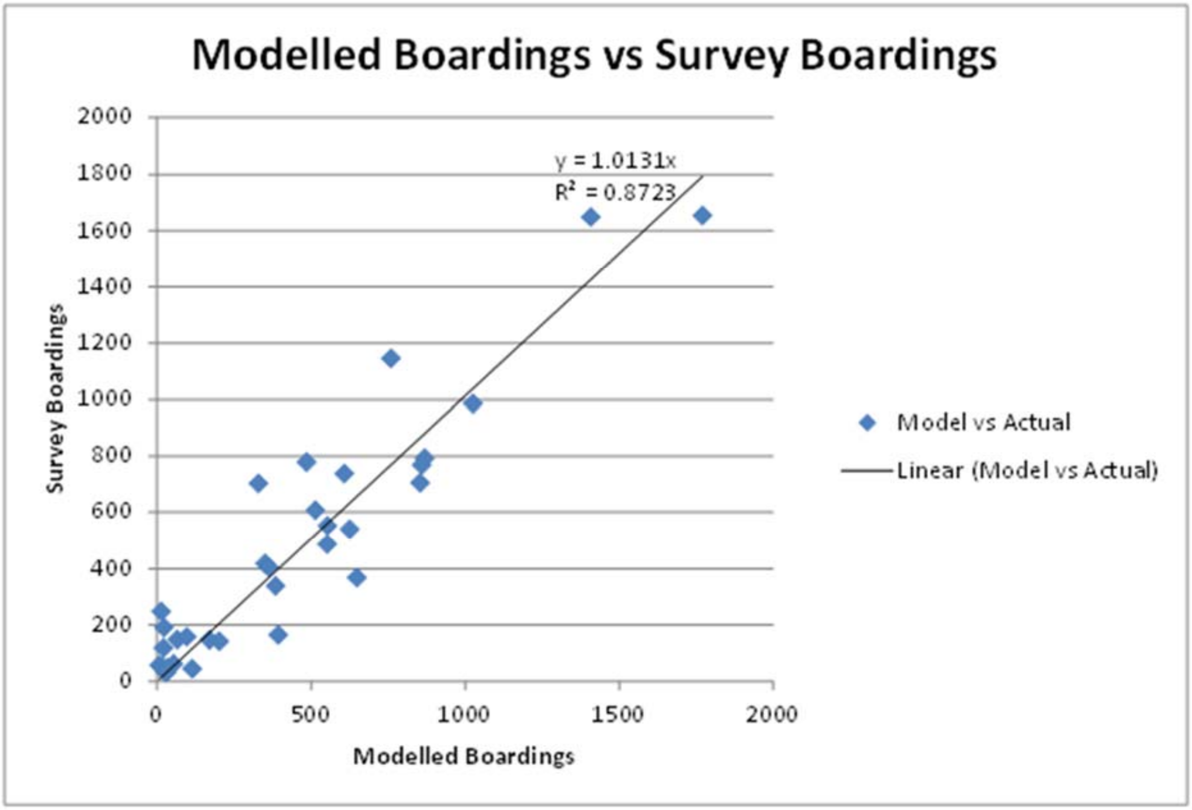
Linked Trip Calibration Targets

	Walk	Drive
HBW1	2574.7	106.0
HBW2	1524.2	167.4
HBW3	375.5	279.4
HBSH	589.2	36.0
HBSR	758.8	31.2
HBSch	2093.0	71.0
HBO	1065.5	60.5
NHB	1686.1	164.8

The table below provides the observed, original model (2012), and updated model (2016) boardings.

	Survey Boardings			Original Model Boardings			New Model Boardings		
Route	Walk	Drive	Total	Walk	Drive	Total	Walk	Drive	Total
1				39	0	39	54	3	57
2	1,504	150	1,654	1,026	19	1,045	1,732	38	1,770
3	710	28	738	385	6	391	592	16	609
4	738	55	793	592	235	827	735	134	869
5	585	23	608	295	2	297	502	11	514
7	713	66	779	410	9	419	476	10	486
8	396	21	417	224	2	226	333	18	351
9	137	11	148	22	1	22	62	3	65
11	469	17	486	289	7	296	524	28	552
13	917	68	985	891	20	911	953	72	1,025
14	655	49	705	728	4	732	839	16	854
15	643	60	704	275	7	282	286	43	329
16	136	10	146	89	3	93	160	11	171
18	1,525	123	1,648	1,230	13	1,244	1,375	34	1,409
22	117	25	141	99	0	100	187	15	202
24	503	37	540	231	10	241	607	19	627
25	111	7	118	2	0	2	20	0	21
26	232	16	247	3	0	3	14	0	14
30	1,087	58	1,145	762	9	770	741	19	760
32	349	19	368	422	8	431	629	20	649
34	33	0	33	30	0	30	24	3	27
35	526	26	552	331	4	334	543	11	553
41	372	33	405	109	6	115	356	6	362
43	326	12	338	130	10	140	374	11	385
48	43	2	44	77	0	77	115	0	115
55	731	38	769	523	113	636	605	254	860
92	41	124	164	31	255	286	8	386	394
93	18	13	31	77	2	78	22	8	30
94	23	34	57	29	0	29	6	2	8
95	33	17	50	93	3	96	13	3	16
96	54	7	61	18	0	18	7	47	54
97	36	122	158	30	1	31	12	85	96
98	44	4	48	30	0	30	25	8	34
200	30	161	191	0	0	0	23	0	23
Total	13,836	1,436	15,271	9,484	749	10,232	12,904	1,332	14,236

The figure below provides the updated goodness-of-fit with the logit choice implemented.



Addition of Transit Only Link Model Element

For the purposes of testing "transitway" alternatives for scenarios with routes on dedicated busways or buslanes, the model script was updated. The following provides a summary of how this new element works in the model.

1. For transit only links (no autos allowed) use a BASE_Code of "TRANSIT". This will set the capacity to 0 and disallow cars.
2. Code [Express Time] for Rail or BRT modes and [Bus Time] for streetcar.
3. The modes must be turned on in the modetable and coding must use the correct mode ID

Technical Memorandum

Date:	Monday, March 21, 2016
Project:	Metropolitan Area Travel Improvement Study
To:	MAPA Staff
From:	Jason Carbee, Eric Petersen, and Yunfei Zhang (HDR)
Subject:	Implementation of Income-based Trip Distribution

1. Introduction

HDR was asked to enhance the Metropolitan Area Planning Agency (MAPA) travel demand model. The over-riding goal was to improve the model's ability to inform analyses required for the Metro Travel Improvement Study (MTIS). Several tasks were suggested as part of a Travel Model Improvement Program (TMIP) Peer Review supported by the Federal Highway Administration. Two suggested enhancements that promised the clearest and most immediate improvement to model performance have been implemented: adding income segmentation into the trip distribution component and developing truck demand matrices. This technical memorandum will focus on upgrading the trip distribution component.

Income has long been regarded as having significant impact on travel behavior and increasingly travel demand models have introduced household income into demand segmentation. The state-of-the-practice is to include household income at several stages of the model, including trip distribution, auto ownership, trip distribution and mode choice.[1]

Higher income households generate more trips relative to lower income households, and in most regions they generate more motorized trips and fewer active trips. Even controlling for trips by travel mode, individuals from high income households make longer trips than those from low income households. Introducing household income in distribution of work trips allows the model to better capture the travel patterns observed in the region. While the non-work trip distribution could also be separated by income, that is considered a

[1] Household income was considered a key variable influencing auto ownership from the earliest models developed in the late 1960s. See Deutschman, Harold D. "Auto Ownership Revisited: A Review of Methods Used in Estimating and Distributing Auto Ownership." Highway Research Record 205 (1967). As travel modeling has advanced and computing power has increased the complexity of models and the amount of demand segmentation available in travel demand models, household income has been used in trip generation, distribution, mode choice and even occasionally auto assignment, particularly in networks with tolls. See for example Southworth, Frank. "Temporal versus other impacts upon trip distribution model parameter values." Regional Studies 17, no. 1, (1983): 41-47; Jara-Díaz, Sergio R. "Time and income in travel demand: towards a microeconomic activity framework." Theoretical Foundations of Travel Choice Modelling. Elsevier (1998); and Jara-Díaz, Sergio R., and Jorge Videla. "Detection of income effect in mode choice: theory and application." Transportation Research Part B: Methodological 23, no. 6 (1989): 393-400.

lower priority, as the peak period travel tends to be dominated by work trips. Nonetheless, this is a model enhancement that the region can consider implementing in a future model development cycle.

2. Data

2.1 2009 National Household Travel Survey

The first task was an examination of existing data available for model enhancement, specifically to introduce income into the trip distribution function. The data that best suits this project is the 2009 National Household Travel Survey (NHTS). MAPA purchased additional records (an Add-on sample) that brought the number of households in the 2009 NHTS up to 1,273. **Table 1** contains some general statistics about the MAPA region sample.[2] One interesting feature of the data is that the households and persons are sampled at approximately a 0.5% sample rate, but this drops to approximately 0.3% when looking at trip records. This low sample rate suggests at least some caution be used when drawing inferences from the NHTS data and that model results be checked against other external data sources when possible.

Table 1: Details of Omaha Add-on Sample from 2009 NHTS

	Unweighted	Weighted/ expanded	Sample rate
Household records	1273	282,906	0.45%
Households with valid income	1177	268,027	0.44%
Person records	2758	669,046	0.41%
Individual is 18+ year old	2259	534,087	0.42%
Trip records	10766	3,608,481	0.30%
Home-based work trips	1332	504,220	0.26%
Motorized HBW weekday trips	1195	433,152	0.28%

One surprising finding is that over 90% of the households in the Add-on sample had valid household income associated with the record. This is a higher response rate on the income question than is commonly observed (often 20-30% of households refuse to answer the income question). This higher response rate means more records are available for processing, which is beneficial for model development. Slightly over 80% of the person records were adults (18+). Trip records were not omitted or supressed if the trip was carried out by a child, but the majority of work trips (the focus of this model enhancement exercise) are made by adults.

The NHTS has 10,766 trip records, which expand to 3.6 million daily trips. To be consistent with the placement in the model system, the trip distribution is only applied to

[2] Note that some additional households in Council Bluffs, Iowa were also sampled as part of developing the add-on sample to be used for planning efforts in Metropolitan Omaha. 13.7% of households in the sample were from Iowa, though this percentage dropped to 10.4% after the household weights and expansion factors were applied.

weekday travel by motorized modes (Non-motorized modes are generated in an earlier pre-mode choice step and removed from the model system prior to distribution.) While not reported in the table, additional processing was required before model estimation could begin.

Another subset of the records were removed if the trips were long-distance trips (over 100 miles), if both ends of the trip could not be geocoded or if income was missing. The final expanded number of usable work trips was 386,482.

Determining the proper income brackets and developing the distribution targets is discussed in Section 3.1.

2.2 AirSage Survey Data

To support the MTIS study, MAPA and NDOR ordered a custom run of AirSage data for the Metropolitan Omaha region in 2014. This data is based upon mobile devices, particularly cell phones from a wide variety of service providers, and is processed to generate OD data for automobile trips.[3] In this particular case, AirSage averaged the records from March 2013 to generate typical weekday OD patterns by three trip types: home-based work, home-based other and non-home based trips. They geocoded the data into the current MAPA zone system, and then delivered two files: one comprises of 24-hour OD data (by the three trip purposes) and a peak hour file that allows planners to investigate the OD flows in the AM and PM peak periods. In this case, these periods were defined as 6:30-9:29 and 15:30-18:29. Given the placement of the distribution in the model system, the current model enhancements focused on the 24 hour flows. This was used as a validity check on the NHTS data, so that when the model reasonably replicated the NHTS, it was considered to be a reasonable representation of the region's travel demand patterns. The validation of the NHTS against the AirSage data is reported in Error! Reference source not found. in Section 4. It is worth noting that AirSage data does not contain any information on household income, so it can only be compared to the NHTS trip totals.

2.3 Development of sub-regional districts

In order to facilitate analysis and reporting of the data, particularly when looking at distribution patterns across the region, zones were grouped into sub-regional districts. It was decided to maintain the districts' consistency with an existing district grouping developed (with MAPA's input) on a previous effort to evaluate the AirSage data.

The districts for the income-based trip distribution are displayed in **Figure** . Districts 1-14 are internal, and the focus of the distribution submodel is naturally on internal travel. The downtown core of Omaha is District 1, and Districts 2-5 can be considered Central Omaha. Districts 7 and 8 are the western edge of Omaha . Districts 10 and 11 represent Council Bluffs, Iowa.

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[3] AirSage claims that they achieved approximately a 50% sample rate in Omaha, though this claim is extremely difficult to verify.

Districts 20-25 are external. A gap in the number scheme was left in case further differentiation of the internal districts was desired in the future.

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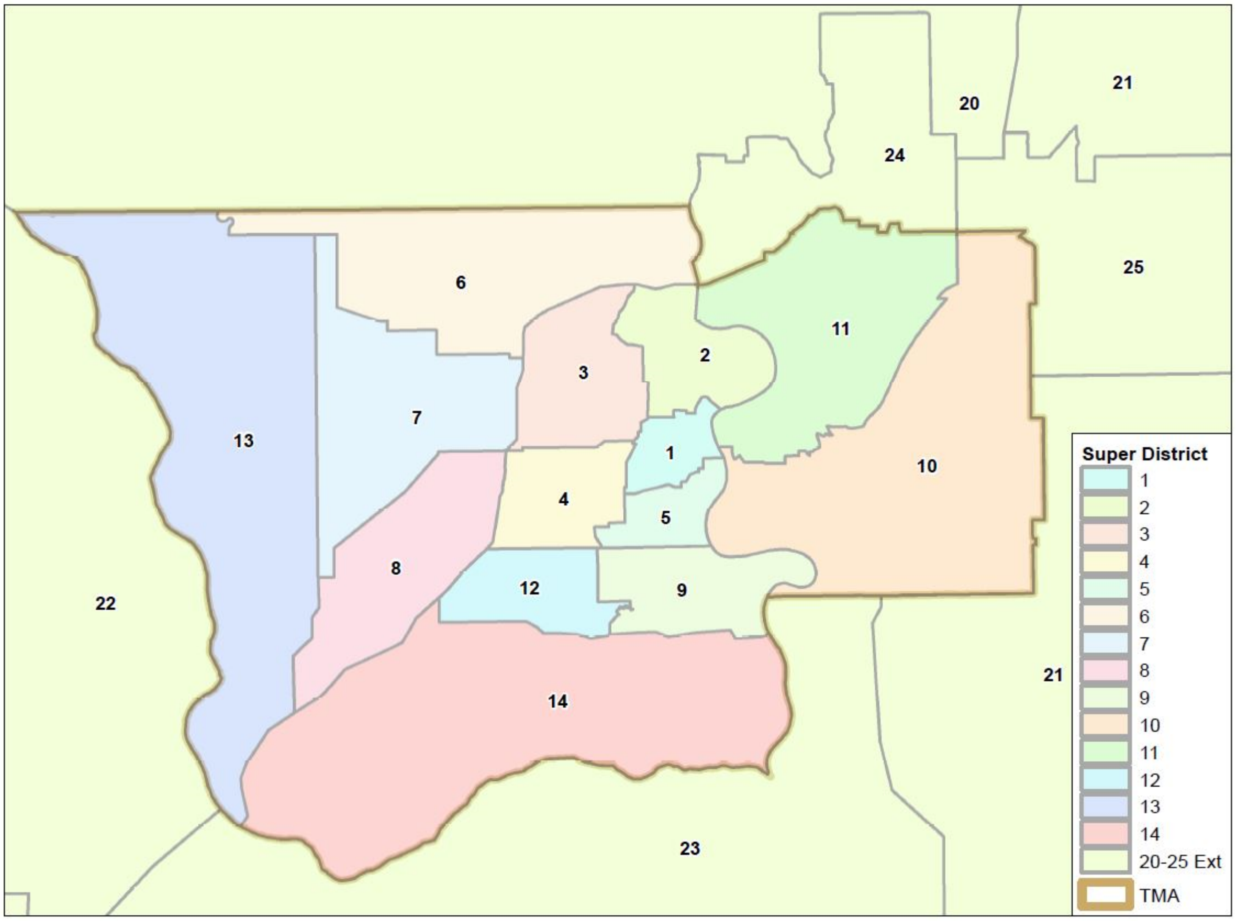

Figure 1: Districts for Income-Based Trip Distribution Model Development

3. Model development

3.1 Generation of Income Bands and development of distribution targets

The first step in introducing income into the MAPA model is deciding how income should be treated. As noted in Section 2.1, approximately 90% of the households in the 2009 NHTS Omaha Add-on sample provided a valid response to the question about household income. There were 18 levels of household income data reported (see **Table 2**).

A scheme with four income group categories was initially considered, but quickly determined that this grouping pattern did not lead to stable patterns. A scheme with two income group categories was then considered, splitting households into low/medium and medium/high (using a break point at $50,000), which is Income Group A below. It was decided that grouping households into three groups: low, medium and high household income, was a more natural grouping, although using 3 income groups would be dependent upon the NHTS data demonstrating the desired patterns.

Table 2: Composition of Income Groups

<table>
<tr><th>Code</th><th>Derived Total HH Income</th><th>Income Group A</th><th>Income Group B</th><th>Frequency *</th><th>%</th></tr>
<tr><td>-7</td><td>Refused</td><td colspan="2" rowspan="3"></td><td>10,046</td><td>4%</td></tr>
<tr><td>-8</td><td>Don't know</td><td>4,657</td><td>2%</td></tr>
<tr><td>-9</td><td>Not ascertained</td><td>176</td><td>0%</td></tr>
<tr><td>1</td><td>< $ 5,000</td><td rowspan="10">Income Bracket 1</td><td rowspan="7">Income Bracket 1</td><td>7,280</td><td>3%</td></tr>
<tr><td>2</td><td>$ 5,000 - $ 9,999</td><td>10,763</td><td>4%</td></tr>
<tr><td>3</td><td>$ 10,000 - $ 14,999</td><td>14,732</td><td>5%</td></tr>
<tr><td>4</td><td>$ 15,000 - $ 19,999</td><td>14,656</td><td>5%</td></tr>
<tr><td>5</td><td>$ 20,000 - $ 24,999</td><td>15,209</td><td>5%</td></tr>
<tr><td>6</td><td>$ 25,000 - $ 29,999</td><td>22,779</td><td>8%</td></tr>
<tr><td>7</td><td>$ 30,000 - $ 34,999</td><td>19,008</td><td>7%</td></tr>
<tr><td>8</td><td>$ 35,000 - $ 39,999</td><td rowspan="6">Income Bracket 2</td><td>17,391</td><td>6%</td></tr>
<tr><td>9</td><td>$ 40,000 - $ 44,999</td><td>11,486</td><td>4%</td></tr>
<tr><td>10</td><td>$ 45,000 - $ 49,999</td><td>15,987</td><td>6%</td></tr>
<tr><td>11</td><td>$ 50,000 - $ 54,999</td><td rowspan="8">Income Bracket 2</td><td>12,039</td><td>4%</td></tr>
<tr><td>12</td><td>$ 55,000 - $ 59,999</td><td>14,324</td><td>5%</td></tr>
<tr><td>13</td><td>$ 60,000 - $ 64,999</td><td>6,199</td><td>2%</td></tr>
<tr><td>14</td><td>$ 65,000 - $ 69,999</td><td rowspan="5">Income Bracket 3</td><td>13,649</td><td>5%</td></tr>
<tr><td>15</td><td>$ 70,000 - $ 74,999</td><td>6,389</td><td>2%</td></tr>
<tr><td>16</td><td>$ 75,000 - $ 79,999</td><td>13,209</td><td>5%</td></tr>
<tr><td>17</td><td>$ 80,000 - $ 99,999</td><td>21,381</td><td>8%</td></tr>
<tr><td>18</td><td>>= $ 100,000</td><td>31,543</td><td>11%</td></tr>
<tr><td>Total</td><td colspan="3"></td><td>282,906</td><td>100%</td></tr>
</table>

* Weighted household income distribution

Several income groupings were investigated. One potential grouping considered placing the break between low and medium income at $35,000, and placing the break between medium and high at $65,000. A third grouping was tested where the only difference was that the break between medium and high was placed at $70,000. These two groupings were very similar, but Income Group B (with the high income break at $65,000) outperformed the grouping with the high income bar set a bit higher ($70,000) and a smaller number of households in the high income category. To focus on the differences between grouping household income into two versus three categories, the difference between Income Group A and B is only presented, and the third grouping is not presented.

The trip length distribution (TLD) and key district-to-district flows were two key trip distribution calibration targets. Determining the appropriate income bands was essentially done simultaneously with the development of these targets, since once there was a reasonable pattern for TLD and key district-to-district flows based on income distribution, that income group was used and the statistics from the NHTS were used as the model targets.

Table 1 shows the TLD of the HBW trips for Income Group A and Income Group B, with long trips, non-motorized trips, and weekend trips filtered out from the NHTS data. It is clear that higher income households tend to make longer work trips for each income group, but it is an even more useful pattern to see that the work trips for medium income households fall between low and high income households, which is the expected pattern. **Figure** shows that higher income households have a higher tendency to travel outside their residential district for work (and thus likely they are making longer work trips), and in particular higher income households in western parts of the metropolitan area travel into the downtown core of Omaha (districts 1-5) for work. **Figure** repeats this pattern, again showing that medium income households' trip length patterns fall between low and high income households, which is the expected and desired pattern. Based on this analysis, an income distribution scheme with three categories was implemented for home-based work trips in the MAPA model trip distribution routine.

Table 3: Trip Length Distribution for each Income Group

	Mean (miles)	%	Minimum (miles)	Maximum (miles)
Income Group A				
1	8.44	45%	0.22	40
2	9.19	55%	0.33	82
Income Group B				
1	8.04	22%	0.22	39
2	8.67	33%	0.56	61
3	9.41	44%	0.33	82
Total	8.85	100%	0.22	82

* Weighted HBW trips
** Excluding trips that are longer than 150 miles, non-motorized trips, and weekend trips

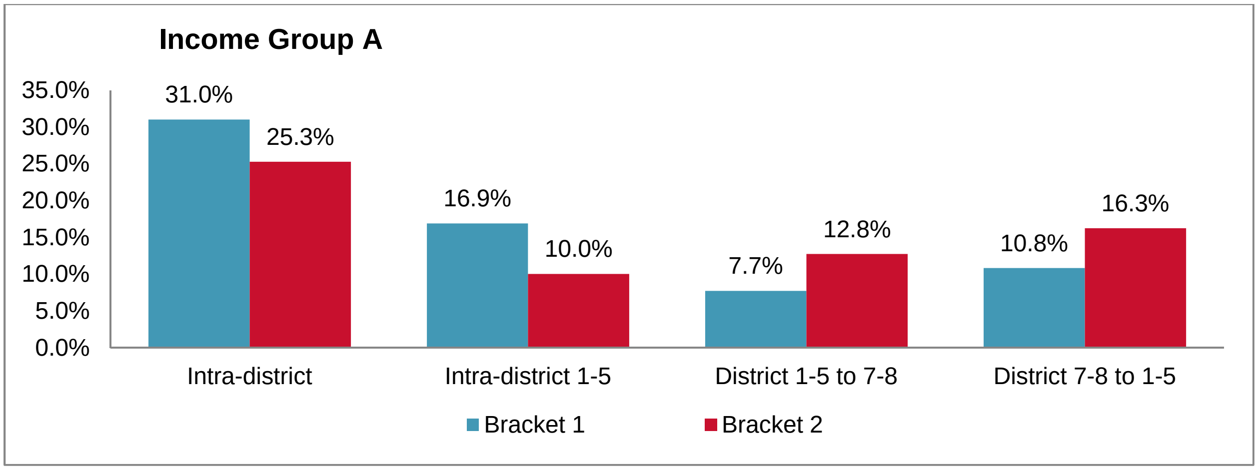

Figure 2: Key District-to-district Flow for Income Group A

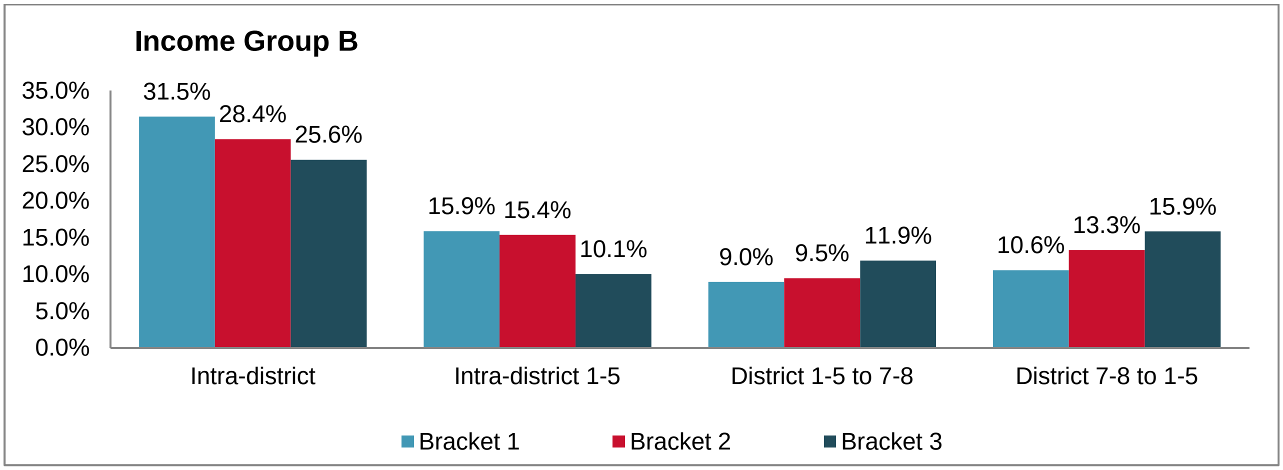

Figure 3: Key District-to-district Flow for Income Group B

3.3 Splitting Productions and Attractions by income

It is necessary to split HBW productions and attractions into 3 income groups in order to integrate the income groups later in the trip distribution step of the model. The HWB productions and attractions were developed from the work trips reported in the 2009 NHTS. The working assumption is that the proportional distribution of income groups for the productions and attractions at the district level will be the same in the base year (2010) and all future scenarios.

The following districts were pooled prior to generating the income factors, due to the relatively small number of cases and a desire to avoid "lumpy" distributions: 4 and 12, 6 and 7, and 13 and 14. Districts 15 to 25 represent all the external locations and are aggregated together more reasonable distributions of the productions and attractions. In addition, to avoid very small values in the demand matrices, any cell in **Table 4** where the proportion was below 5% was increased to 5% with the balance coming from the most populated category.

Table 4: Production and Attraction by Income Groups for HWB Trips

District	Production - HBWL	Production - HBWM	Production - HBWH	Attraction - HBWL	Attraction - HBWM	Attraction - HBWH
1	0.397	0.459	0.144	0.128	0.396	0.476
2	0.283	0.525	0.192	0.537	0.137	0.326
3	0.103	0.485	0.412	0.208	0.406	0.386
4	0.310	0.143	0.547	0.253	0.248	0.499
5	0.390	0.440	0.170	0.200	0.164	0.636
6	0.050	0.398	0.552	0.230	0.327	0.443
7	0.050	0.398	0.552	0.230	0.327	0.443
8	0.179	0.343	0.477	0.195	0.453	0.352
9	0.415	0.324	0.261	0.050	0.583	0.367
10	0.409	0.289	0.302	0.464	0.333	0.203
11	0.409	0.289	0.302	0.464	0.333	0.203
12	0.310	0.143	0.547	0.253	0.248	0.499
13	0.159	0.056	0.785	0.050	0.221	0.729
14	0.159	0.056	0.785	0.050	0.221	0.729
External	0.062	0.317	0.621	0.050	0.477	0.473

3.4 Adjustment of gravity model parameters

The friction factor matrix, which contains the friction factor for travel (either based on time or distance between each pair of zones) in the current MAPA trip distribution gravity model, uses the gamma function:

$$f\left(d_{ij}\right) = a \cdot d_{ij}^{-b} \cdot e^{-c\cdot(d_{ij})}$$

where $f\left(d_{ij}\right)$ is the friction factor between zone i and j;

d_{ij} is the travel time or distance between zone i and j;

and a, b, and c are parameters in the function.

The trip distribution model calibration procedure in TransCAD was first used, where the “TLD Maximum” number, i.e., the maximum value in the TLD, was changed. Based on the NHTS and AirSage Survey, the longest HBW trips for low, medium, and high income household were 39, 61, and 82 miles respectively (see Table 3). The outputs of this procedure were the parameters (a,b, and c) in the gamma function, which were then applied in the trip distribution model to generate the TLD. This method has limited effect on the TLD, since more than 99% trips in the MAPA model are within 25 miles.

An iterative process was then used to calibrate the trip distribution model:

a) Manually adjust the parameters (a, b, and c) in the Gamma Function;
b) Apply the trip distribution model and generate new TLD;

c) Compare the TLD with the target values (see Table 3). Based on the comparison, the parameters were then adjusted accordingly and the model was applied again.

The last step was to compare the observed (target) and modelled district O-D patterns and adjust the K-Factor matrix. The K-Factors are used to adjust the O-D matrix predicted by the gravity model, so that it can match the target or observed O-D flows more accurately. In this model, the K-Factor was increased from 1.0 to 1.1 for high income HBW trips from District 7 and 8 to District 1 and 2 in order to encourage more trips. In discussions between MAPA, HDR, and FHWA resource center staff, it was decided that this limited application of k-factros to high-income HBW trips was appropriate.

4. Model validation results

The validation targets were to match the average trip length (from the 2009 NHTS data) for home-based work trips by each income group within 0.25 miles. The validation of the distribution pattern would be based on key regional movements, which are reported in **Table 6**, namely:

- How many work trips remained within the district of origin
- How many remained within Central Omaha as a whole (Districts 1-5)
- How many work trips crossed the Missouri River between Iowa and Nebraska portions of the metro area
- How many work trips remained within the Council Bluffs area
- How many work trips originated from western portions of the metro area and then ended in either the downtown or Central Omaha. This last movement was quite significant with nearly 13% of all work trips in the region following this pattern.

The validation target was to replicate the overall percentage of each trip type within 5%. It was also important that the income patterns be reflected, so that if low income trips predominated in a category (such as internal Council Bluff trips), then the model also demonstrated the same pattern. A secondary goal was to match each trip type by each income group within 5%.

Error! Reference source not found. and Error! Reference source not found. show the target and modelled average trip distance and district O-D patterns. The average trip distance is very similar to the target values, where the distance travelled increases as the household income increases. The calibrated model is able to capture the variance in the O-D patterns, where higher income households tend to make less intra-district trips within Central Omaha (Districts 1 through 5) and make slightly more trips from District 7 and 8 into Central Omaha. Overall, medium and high income households originating in Districts 7 and 8 have similar patterns, but they are distinctly different from low income households. One of the most significant patterns observed in the NHTS data is the high proportion of low income households with work trips originating and ending in Council Bluffs, Iowa (Districts 10 and 11). The model was able to accurately replicate this split, as well as the relatively low number of medium income households with work trips in Council Bluffs and the very low proportion of high income households.

Table 5: Modelled and Target Average Travel Distance

Income Group	Target Average Distance (miles) *	Modelled Average Distance (miles) **
Low	8.04	7.92
Medium	8.67	8.46
High	9.41	9.50
Total	8.85	8.81

* Excluding trips that are longer than 150 miles, non-motorized trips, and weekend trips

** Motorized HBW trips only, and excluding external trips

Table 6: Modelled and Target District O-D Pattern Comparison of Motorized HBW Trips

	NHTS Target				AirSage	Modelled			
	Low	Medium	High	Total	Total	Low	Medium	High	Total
All intra-district	22.7%	24.6%	22.1%	**23.7%**	**16.5%**	22.1%	18.9%	15.5%	**18.1%**
Intra-district 1-5	10.4%	12.1%	9.6%	**10.5%**	**4.9%**	9.8%	8.1%	5.7%	**7.4%**
OD within 1-5	28.4%	31.7%	22.6%	**26.4%**	**22.2%**	28.9%	26.9%	18.1%	**23.4%**
Origin 7-8 into 1-2	2.5%	4.9%	4.9%	**4.3%**	**4.0%**	1.3%	4.6%	5.2%	**4.1%**
Origin 7-8 into 1-5	8.3%	13.9%	14.4%	**12.8%**	**12.1%**	5.9%	14.8%	17.3%	**14.0%**
Council Bluffs internal	12.0%	5.4%	1.6%	**5.2%**	**3.3%**	12.0%	4.1%	1.2%	**4.5%**
Crossing Missouri River Westbound	2.9%	1.9%	3.0%	**2.7%**	**4.1%**	6.5%	4.5%	5.6%	**5.4%**
Crossing Missouri River Eastbound	5.3%	2.2%	3.5%	**3.6%**	**4.0%**	2.9%	2.5%	2.0%	**2.3%**
Total River Crossing	8.2%	4.1%	6.5%	**6.3%**	**8.2%**	9.4%	7.0%	7.5%	**7.8%**

The AirSage data generally matched the NHTS data in terms of O-D patterns, with the exception of intrazonal trips. The most likely reason for this is that AirSage gathers data on travelers passively and does not survey travelers directly. Thus, they do not know trip purpose but infer it from an algorithm that tags locations that are repeated over the month of observations. It is not entirely clear what goes into this algorithm, but it is likely that shorter trips are more often classified as non-work trips than work trips, which would skew the sample towards longer work trips. A second hypothesis is that drivers are making more unreported stops on short trips whereas the longer distance deters them from making as many stops for fear of being late for work. If the stops are not reported in the NHTS then there would be more HBW records and not enough NHB records and this would disproportionately affect short trips. The AirSage data, in contrast, would have a more accurate split between work and non-home-based travel.

In Error! Reference source not found., the overall model results are quite similar to the total NHTS and all the modeled trip types are within 5% of the observed with the exception of intra-district trips for medium and high income households. Other observations include:

- Although the model does not generate quite as many intra-district trips as observed in the NHTS, the modeled results generally fall between the AirSage data and the NHTS, which may, in fact, be closer to reality.
- The overall model results are within 2% for trips with origin-destination in Council Bluffs, IA, for trips originating in Districts 7 and 8 and heading into the Central Core (Districts 1-2) or Central Omaha (Districts 1-5), and crossing the Missouri River in eastbound direction.
- The model is within 3% of internal Central Omaha and crossing the Missouri River in westbound direction. The model may still slightly over-represent river crossings (but by less than 1% when comparing in both directions) and this is very much in line with the AirSage data, which is slightly higher than the NHTS data.

The implementation of income into the HBW trip distribution function should be considered reasonably calibrated, particularly when intra-district trips fall between the NHTS and AirSage results. The trip lengths follow a meaningful pattern with high income households traveling further for work than low income households, and the District-to-District flows also follow the generally representative patterns, as observed in the 2009 NHTS data, with the biggest variation from observed being seen in work trips that cross the Missouri River.

The calibrated gamma function parameters are shown in **Table 7**. As can be seen in the table, the gravity parameters pivot off the original values prior to income being introduced into trip distribution. The low income households take a shorter value for (a) and a higher value for (b) and (c) actually is unchanged from the original model. Collectively, these changes have the effect of shortening trips. Medium and high income work trips have a lower value for (b) and (c) than before, which leads to slightly longer trips. The two are quite similar, though high income has an increased (a) value, which again leads to slightly longer work trips than medium income work trips.

The K-Factor matrix was very similar to the MAPA model with two changes. The vast majority of zone pairs do not have any K-Factors (they take a value of 1), except zone pairs that have a river crossing, as the model generally over-simulates trips crossing the Missouri River. The initial model used a value of 0.4 to discourage such trips, and for the low and medium work trips, this was lowered even further to 0.2 (this was stored in KFact_WBRv,mtx). However, the model somewhat under-simulated high income work trips in the eastbound direction, so a new K-Factor matrix was developed for high income HBW trips (KFact_WBRv3,mtx), where the K-Factor was increased to 1.5.

Table 7: K-Factor and Gamma Function Parameters

	Kfactor		a		b		c	
	Original	Updated	Original	Updated	Original	Updated	Original	Updated
HBW-low income	KFact	KFact_WBRv	1000	500	0.50	0.60	0.05	0.05
HBW- medium income		KFact_WBRv		1000		0.35		0.035
HBW- high income		KFact_WBRv3		1500		0.35		0.035
HBSH	KFact	KFact	1000	1000	1.50	1.50	0.06	0.06
HBSR	KFact	KFact	1000	1000	1.50	1.50	0.06	0.06
HBSch	KFact	KFact	1000	1000	2.00	2.00	0.06	0.06
HBO	KFact	KFact	1000	1000	1.50	1.50	0.06	0.06
NHB	KFact	KFact	1000	1000	1.00	1.00	0.075	0.075

4. Future extensions

Based on the success of implementing income into the home-based work trips, there is a strong argument that in the next round of enhancements, that the home-based non-work trips also be treated separately by income group, using this same classification scheme. Longer term improvements might include taking the income classification and using it for trip generation and/or mode choice components.

Date:	**Tuesday, March 22, 2016**
Project:	**Metropolitan Area Travel Improvement Study**
To:	**MAPA Staff**
From:	**Jason Carbee, Rhys Wolff, Yunfei Zhang, Eric Petersen (HDR)**
Subject:	**MAPA Truck Demand Module Development and Calibration**

Introduction

This memorandum outlines the key assumptions made and procedures executed by HDR in creating a truck module for the 2010 MAPA TransCad travel demand model, as well as a summary of the calibration results. The model estimates truck volume by origin-destination (O-D) for the entire MAPA (Omaha – Council Bluffs Metropolitan Area Planning Agency) Region, broken down into four time periods (AM peak period, midday, PM peak period, and night) and two truck types (light/medium and heavy).

Details of the time period definitions are given in **Table 1**. Light/Medium trucks are defined as FHWA classes 5 to 7 (single unit), and Heavy trucks are defined as classes 8 to 13 (multi-unit). Some commercial vehicles will also fall into FHWA class 3 (four-tire) but these are not included in the model, because of the difficulty in differentiating these from passenger vehicles. The development of the truck model is structured to fit into the existing MAPA model framework, using the same Traffic Analysis Zone (TAZ) system and road network. **Figure 1** shows a map of the study area, and **Figure 2** shows the internal TAZ and external station locations. There are 808 internal zones and 27 external stations in the model.

The overall truck model development process included:

- Review of existing truck count data and development of a relatively consistent dataset for development and validation of the MAPA truck model.
- Assessment of truck trip generation rates from other studies, and testing and fitting of those rates to the MAPA region.
- Development of a base year set of truck volume flows by O-D pair using O-D Matrix Estimation (ODME).
- Implementation of a forecasting routine that pivots from the base year truck volume flows according to changes in forecasted socio-economic data, based on the MAPA-tailored truck trip generation rates.

Data Input

Several data sources were used to generate a single set of link-based counts, including count stations maintained by the Omaha – Council Bluffs Metropolitan Area Planning Agency (MAPA), the Nebraska Department of Roads (NDOR), and the Iowa Department of Transportation (Iowa DOT).

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The data includes internal counts on the road network within the model area, and external station counts. Some were categorized into four time periods: am, midday, pm, and night (but not by truck type), and some counts were split by truck type (but not by time period). The only counts that included information on both time period and truck type were the external station counts maintained by MAPA. The breakdown of each time period, consistent with the overall model, is shown in **Table 1**. Where splits were not explicitly included in the counts, they were estimated using the method described in the next section.

Table 1: Time Period Breakdown

Period	Start Time	End Time
AM	6:30 AM	8:29 AM
Midday	8:30 AM	3:29 PM
PM	3:30 PM	6:29 PM
Night	6:30 PM	6:29 AM

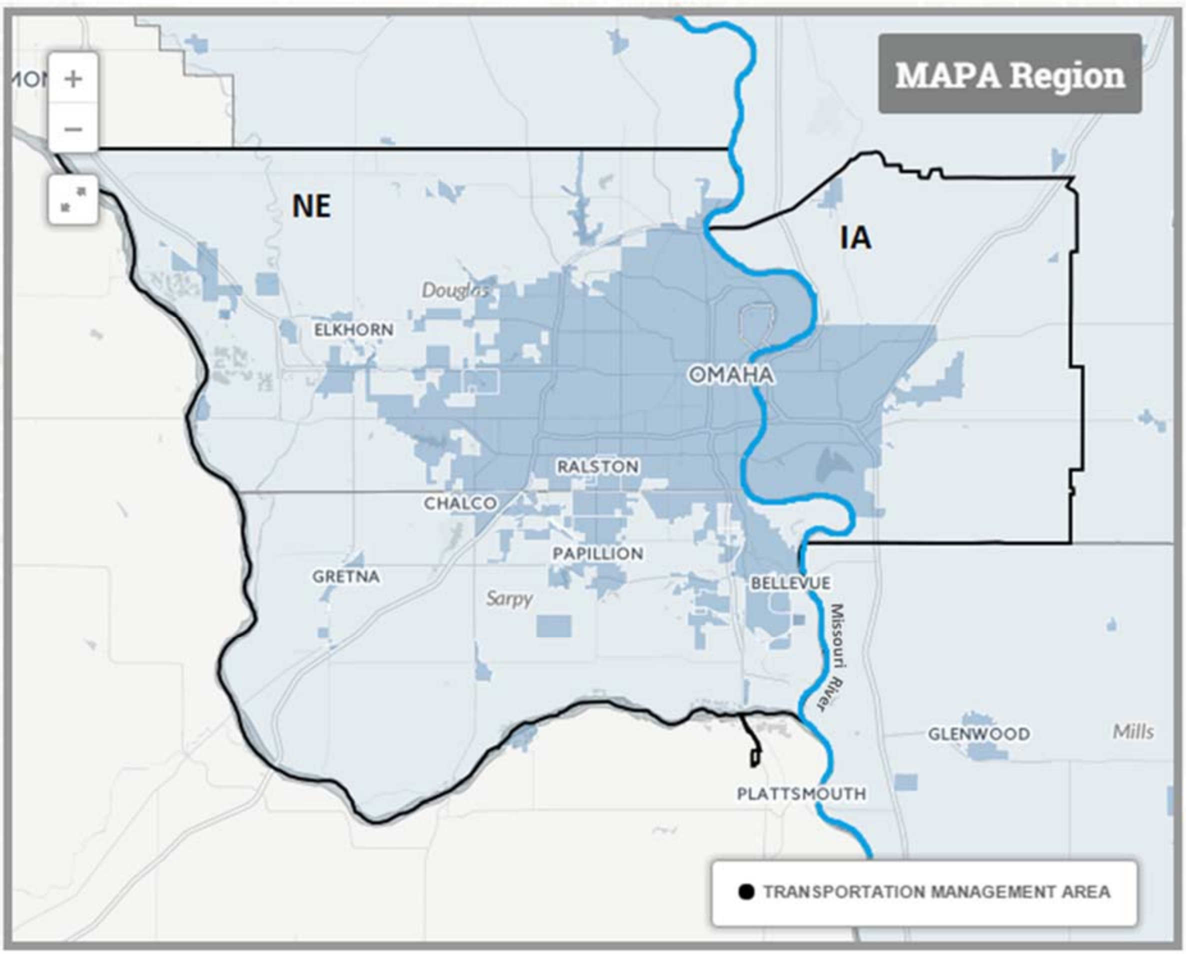

Figure 1: Study Area, MAPA Region

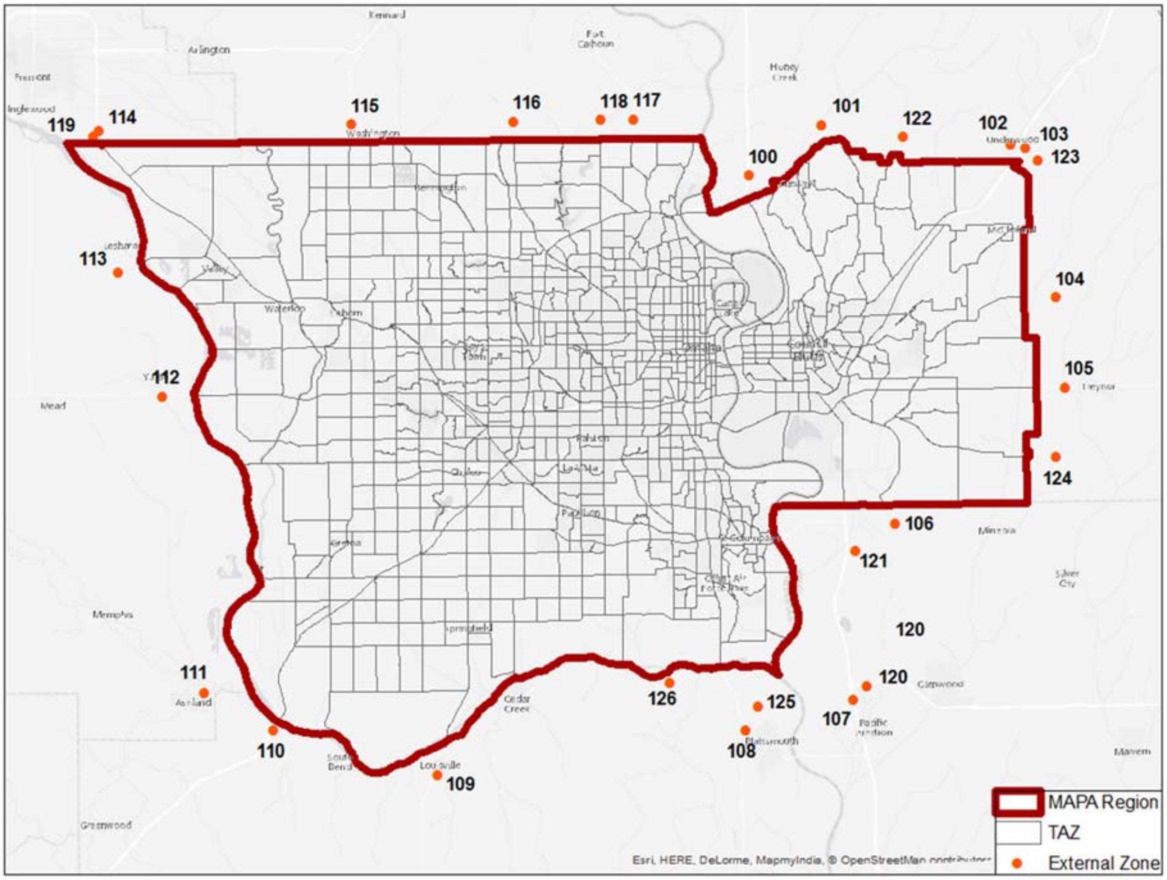

Figure 2: TAZ and External Stations

The data provided by MAPA, NDOR, and Iowa DOT included observed Average Daily Traffic (ADT) and Truck volumes for both directions of travel. MAPA also provided the smoothed Annual Average Weekday Traffic (AAWT) and included a breakdown by time period. The external station truck volumes were further broken down into light/medium and heavy trucks. **Table 2** shows a summary of the data sources with the level of detail available from each source.

A few external counts provided by MAPA were marked as “bad counts”. They were classified as such because of one or more of the following reasons:

1) Significant imbalance between daily outbound and inbound trips. Since the truck count is 24-hour, the numbers of trucks coming in and going out of the study area should be close to each other.

2) The numbers were too high or low comparing to the counts at nearby locations or similar road classes, or generally appeared unrealistic to those familiar with the area.

Table 2: Internal and External Count Data Source

ID	Count	Source	Level of Detail					Comment / Aciton
			Total Traffic Volume	Total Truck Volume	Directional Split (2)	Time Periods Split (4)	Truck Type Split (2)	
Internal Link Counts								
Int-1	Smoothed AAWT	MAPA	x					Used as primary source for ADT, source Ext 1 and Int-2 were used to split out truck types and time periods
Int-2	ADT and Truck Count	MAPA	x		x	x		Source Ext 1 was used to split out truck types
Int-3	ADT and Truck Count	NDOR	estimated or actual	estimated or actual				Source Ext 1 and Int-2 were used to split out truck types and time periods
External Gateway Counts								
Ext-1	ADT and Truck Count	MAPA	some marked as "Bad Counts"	some marked as "Bad Counts"	x	x	x	Primary source for external ADT and truck volume
Ext-2	Total ADT	DOT	x		x			Secondary source for external ADT and truck volume, Source Ext-1 was used to split out truck types and time periods
Ext-3	External Truck Count	MAPA	x	x				External-to-external truck volume

On review of the counts during the assignment process, some exceptions were made to these rules of priority for selecting counts at individual locations where the counts appeared unusually high or low compared with adjacent locations, making it difficult for the model to match the numbers. In these cases an alternative source was substituted or (if the count was an estimated NDOR number) the location was removed from those used for validation. The table also discusses the processing required to use the data for truck modeling purposes.

Preparing the External Counts

The total number of trucks at external stations provided by MAPA was used as a primary source of data to develop the initial truck trip tables. The NDOR or Iowa DOT truck volume, if available, was used if the MAPA truck counts were marked as "bad counts" that were too low or too high. If there was no corresponding NDOR / Iowa DOT volume, the closest internal count was used to represent the external station. While ideally the daily counts should be balanced, when inbound and outbound flows were imbalanced in the data the number of daily inbound and outbound trucks was adjusted so that the ratio fell between 40:60 and 60:40. The counts were further split into two truck types and four time periods based on the count provided by MAPA. Figure 3 shows the counts at external stations, separated into inbound and outbound flow. Stations with the highest truck flows were TAZ 100, 103, and 110, all of which represent major Interstates such as I-80 and I-29.

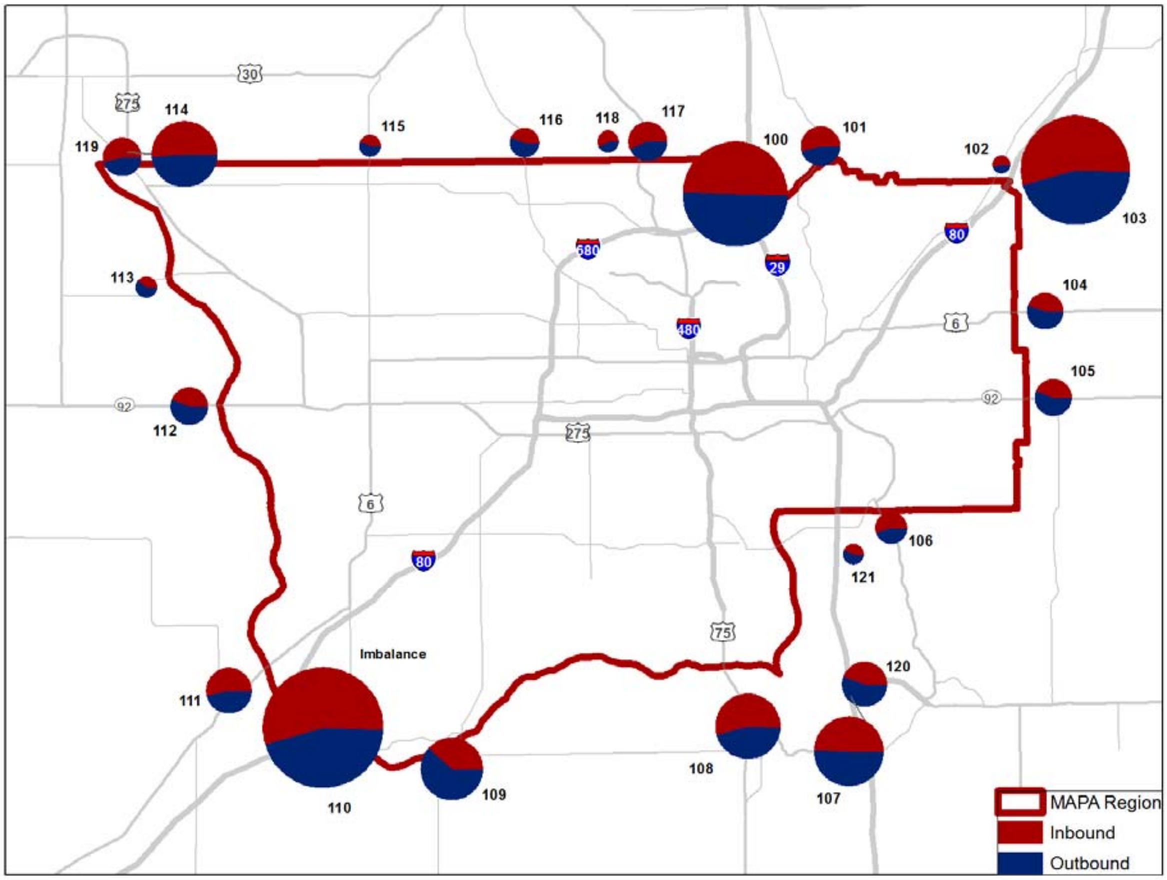

Figure 3: Truck Inbound and Outbound Counts at External Stations

Preparing the Internal Counts

Since multiple data sources of the internal truck volumes were provided as detailed in **Table 2**, a hierarchy of data sources developed was decided based on the quality of the data and the level of details. **Figure 4** describes the steps of this procedure.

Step	Procedure	Source and Priority
Step 1	Total AADT	1. Smoothed AAWT 2. NDOR ADT, actual 3. MAPA total ADT 4. NDOR ADT, estimated
Step 2	Truck %	1. NDOR truck volume / NDOR ADT, actual 2. MAPA truck volume / ADT 3. NDOR truck/NDOR ADT, estimated
Step 3	Total Truck Volume	AADT (from Step 1) * Truck % (from Step 2)
Step 4	Truck split %, by direction and by time periods (AM, MD, PM, NT)	1. MAPA total truck by direction and time periods at the link segment 2. Average direction/time period split by road class
Step 5	Truck split % by medium and heavy truck	1. Internal truck split along major highways or on bridges across the Missouri River 2. External truck split
Step 6	Final Truck Volume by direction by time periods by medium/heavy truck	Total Truck Volume * Truck split % (from Step 4) * Truck split % (from Step 5)

Figure 4: Procedures for preparing the internal truck volume count

The primary source for the average daily traffic was the smoothed AAWT provided by MAPA (step 1). The truck volume was then calculated based on the truck percentage provided by NDOR and MAPA (step 2 and 3). Counts near the Highway 80 and Highway 680 interchange were closely examined since a large number of counts were provided from multiple sources, and there were some internal inconsistencies among them. Based on the counts at adjacent locations and professional judgments, the total AADT was used instead of the primary source smoothed AAWT, or the count at that location was removed.

Figure 5 shows a map of the total truck counts on the network. The truck count is the highest on Interstate 80 and Interstate 680.

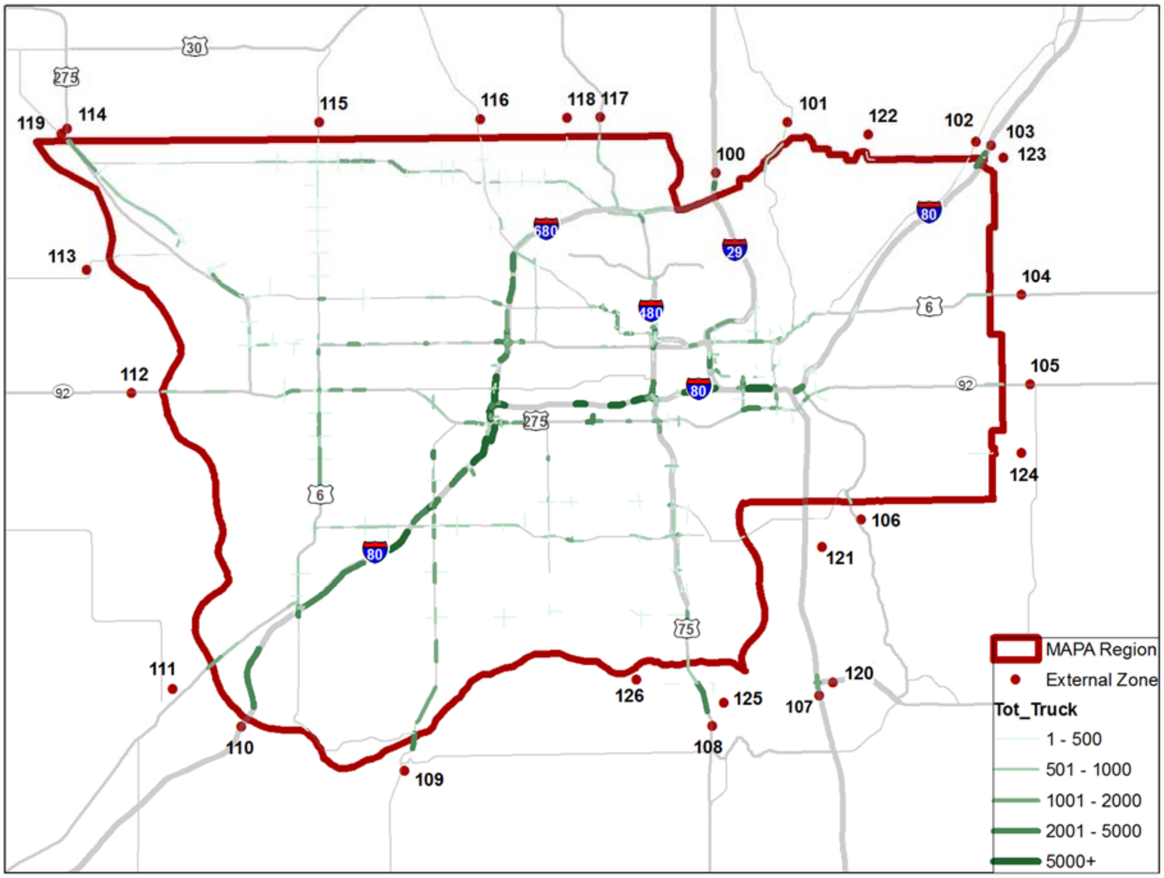

Figure 5: Total Internal Truck Count

The total truck volume was then split into two directions and four time periods. The split was based on the counts provided by MAPA as summarized for time periods in **Table 3**. Three types of road class were used: Interstate / highway, major or minor arterial and local one-way street.

Table 3: Truck Split by Time Period

Road Class	AM	Midday	PM	Night
Expressway / Highway	11%	43%	16%	29%
Major/Minor Arterial	13%	42%	15%	30%
One way street	13%	42%	15%	30%
Total	12%	43%	16%	30%

The last step was to split the truck volume by truck type, i.e. into light/medium and heavy trucks. MAPA provided medium and heavy truck splits at selected internal locations, and the ones located along major highways or on bridges across the Missouri River (the Nebraska-Iowa state boundary) were used to further adjust the truck split (see **Figure 6**) for those specific locations, given their relative importance to truck travel in the model area. In these cases, the individual truck type splits recorded at these locations were used. When the internal truck split was not available, an approximation was developed based on the MAPA external truck count split. To do this, several methods of categorizing the link network were tested, including using the ADT, daily truck volume, truck percentage, and the road classification (local or Interstate or highway). Based on the external truck count split, the following classification scheme provided a reasonable balance between restricting the number of categories (for simpler processing) and capturing the important variance between different groups:

- Interstate or Highway,
- non-Interstates / non-Highways with ADT greater than 20,000,
- ADT between 10,000 and 20,000, and
- ADT less than 10,000.

The light/medium and heavy truck split target percentages are shown in **Table 4**. In general, Interstates, Highways and roads with higher volume have a higher heavy truck percentage, and light/medium trucks are more likely to utilize local streets. In this regard the splits make sense as heavy trucks are most likely to use major roads. These percentages are based on a cross-referencing of observed splits with the characteristics of the classified count location, and then these percentages are applied to all counts with similar characteristics and volumes.

Table 4: Light/Medium and Heavy Truck Split

	Category	Medium Truck %	Heavy Truck %
1	Interstate or Highway	45%	55%
2	ADT > 20, 000	45%	55%
3	ADT 10,000-20,000	50%	50%
4	ADT < 10,000	75%	25%

For future enhancements of this model, the splits could be improved in coordination with a classified count program to replace the average splits with location-specific numbers across the network. However, this approximation aims to make the best use of the available data while recognizing that medium and heavy trucks often have different flow patterns, particularly when time period of travel is taken into account.

In addition to the internal truck counts, the external station counts were added to the links that are connected to external zones in order for them to play a role in the truck O-D estimation.

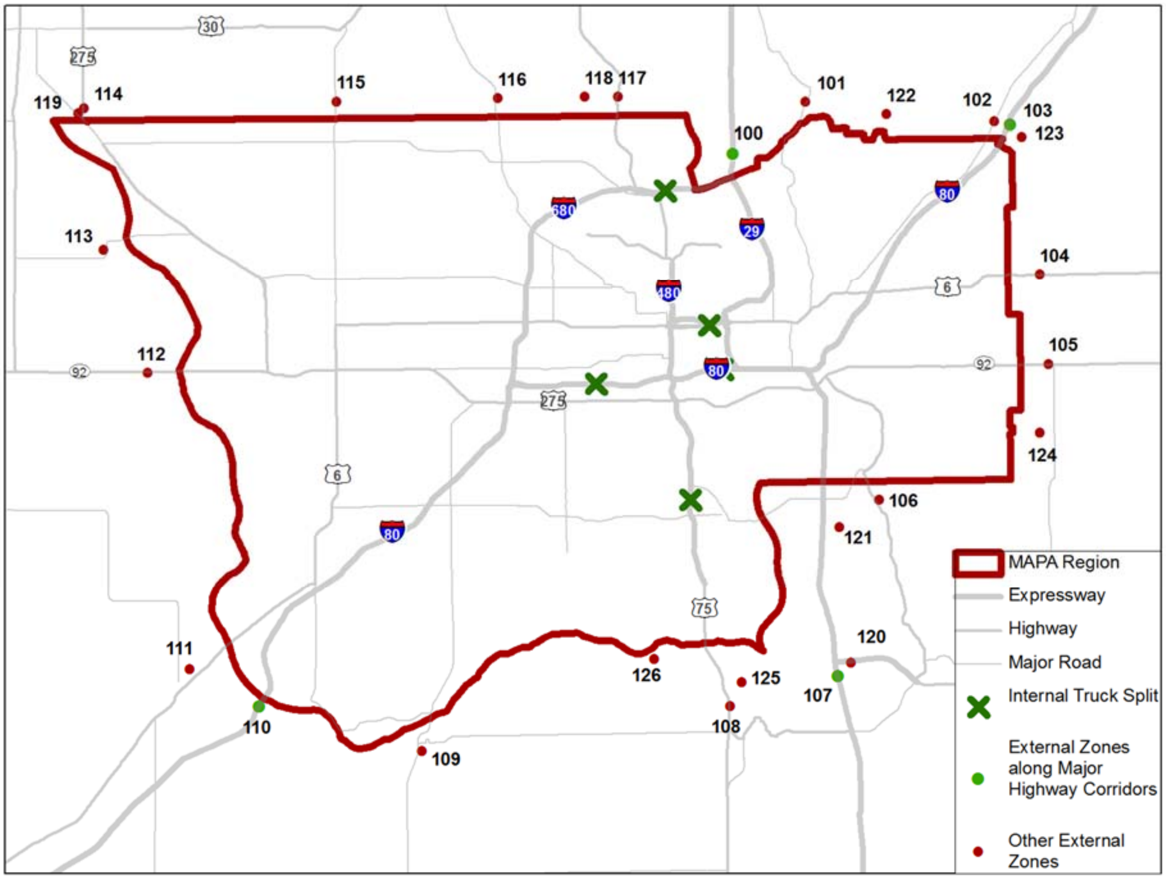

Figure 6: Locations with Additional Internal Medium and Heavy Truck Split

Trip Rate Research

There was no information directly available (such as from a shippers' survey or a license plate study that would reveal OD data) on truck generation in the Omaha metropolitan area, so several external sources were reviewed to identify relationships between land use and truck trip generation. These included:

- **NCHRP Truck Trip Generation Synthesis 298** (2001). This provided multiple tables in an extensive appendix of trip generation rates by employee and truck type, although mostly collected 20 years or more ago.
- **The Quick Response Freight Manual II** (QRFM, Cambridge Systematics, 2007), provided examples of daily trip rates by employee type for both single-unit trucks and combination trucks, based on survey information from Phoenix.

- The FHWA **Freight Analysis Framework** (FAF) database provided information on commodity flows to and from metropolitan Omaha (excluding Iowa), but at a very aggregate level.
- NCHRP Reports 384 (2008) and 739 (2012) were also reviewed, but provided more of an overview to freight trip modelling than specific examples of rates.

The trip generation rate sources indicate a wide variation in rates, and it should be noted that the comparison is only approximate because of differences in employment categories and truck type classification used by each location. Numbers compared between the QRFM, and a series of numbers from Synthesis 298, are shown in **Table 5** below.

Table 5: Daily truck trip rates by number of households or employees by category

Land use characteristic	QR Manual[1]		NCHRP 298 (multiple)[2]		NCHRP 298 (MAG)[3]		NCHRP 298 (SCAG)[4]		Average	
	Med	Hvy	Med	Hvy	Med	Hvy	Med	Hvy	Med	Hvy
Number of households	0.099	0.038			0.069	0.013	0.009	0.002	0.059	0.018
Retail workers	0.253	0.065			0.133	0.037	0.096	0.036	0.161	0.046
Office/Service workers	0.068	0.009	0.014	0.014	0.021	0.003	0.014	0.003	0.029	0.007
Manufacturing workers							0.058	0.039	0.058	0.039
Transportation workers							0.046	0.158	0.046	0.158
Manufacturing, wholesale and transportation workers	0.242	0.104	0.120	0.203					0.116	0.126

The averages are based on taking the mean of the available sources for each category. When these were aggregated to the MAPA model land use categories, the approximate rates are shown in **Table 6.**

[1] Quick Response Freight Manual II (2007), Table 4.1
[2] NCHRP Synthesis 298 (2001), Section C3,Table D-1
[3] NCHRP Synthesis 298 (2001), Section C5
[4] NCHRP Synthesis 298 (2001), Section C7

Table 6: Daily truck trip rates, MAPA model categories

Land use characteristic	Medium	Heavy
Household	0.059	0.018
Retail/Commercial Employment	0.161	0.046
Service/Office Employment	0.029	0.007
General/Industrial Employment	0.116	0.126

These rates were customized for the MAPA model area based on count data, using the process discussed in the rest of the memo. However, certain conclusions based on the research were used to help formulate the model, including:

- Based on the low rates shown in **Table 6,** the service/office category was expected to have minimal impact on truck travel. As such, it was dropped from consideration for inclusion in the model. This was also confirmed by regression analysis at the trip rate generation stage comparing the service/office land use to numbers of trucks generated per zone, where there was no significant relationship observed.
- “General/industrial” category (including manufacturing, wholesale, and transportation jobs) employment generates significant numbers of both medium and heavy truck trips.
- Retail/commercial employment appears to generate the highest number of medium truck trips, and also a significant, though lower, number of heavy truck trips.
- Households also have a low impact on truck rates. However, recognizing that residential areas do generate some truck trips (such as for deliveries and construction), a small residential value has been included in the forecasting model so that purely residential areas will generate non-zero numbers of trucks.

These findings were used to help with preparing the seed matrix and subsequent validation of the model trip rates.

Methodology: O-D Matrix Estimation

Truck volumes by O-D were generated using the O-D Matrix Estimation (ODME) function in TransCad. This is an iterative process that switches back and forth between the matrix estimation stage and traffic assignment stage. The procedure requires an initial estimation of the O-D matrix, i.e., the seed matrix, as well as observed truck counts on the network links. The output of this procedure includes a matrix file containing the estimated O-D demand, as well as a table file that contains the estimated link flow volume. Steps involved in preparing the seed matrix are described in the next section.

Trucks typically follow certain shortest paths, such as major roads and designated “truck routes”, and rarely change their routes despite the variations in travel time. For this reason, two simplifications were adopted. First, the network capacity was set to represent the capacity of the entire facility, which is significantly higher than the truck volume (as trucks are rarely over 25% of observed demand). By retaining the entire link capacity, network congestion will essentially have no impact on the truck assignment (routing) for this particular subroutine (which is not true for the assignment algorithm in the final model). Second, the single mode ODME was used, which means the O-D matrix was estimated separately for each truck type and time period, and there were no interactions between truck types (light/medium and heavy).

Preparing the Seed Matrix

The seed matrix was used as a starting point for the balancing procedures in TransCad's O-D Matrix Estimation process (ODME). The flows were then adjusted to the observed demand on links, but a more realistic seed matrix does reduce the number of iterations required by the ODME procedure. The basic structure of the seed matrix is shown in

		Destination	
		Internal	External
Origin	Internal	internal regional demand	internal to external
	External	external to internal	through trips

Figure 7**Error! Reference source not found.**. It included Internal-Internal, External-Internal and Internal-External trips, and External-External trips (sometimes called through trips as they pass entirely through a region). The seed matrix depends on two factors: the total demand and the distribution of demand.

		Destination	
Orig in		Internal	External

	Internal	internal regional demand	internal to external
	External	external to internal	through trips

Figure 7: Structure of the O-D Seed Matrix

The inbound and outbound demand at each external station was provided by MAPA and NDOR (see **Table 2**). For each inbound and outbound demand, information from the 2013 MAPA *External Travel Survey* was used as the starting point to the process, and were subsequently adjusted based on the balancing to internal and external locations.

		Destination	
		Internal	External
Origin	Internal	internal regional demand	*Medium:95% of Ext. Inbound Demand* *Heavy: 90% of Ext. Inbound Demand*
	External	*Medium:95% of Ext. Outbound Demand* *Heavy: 90% of Ext. Outbound Demand*	*Medium: 5% of Ext. In/Outbound Demand* *Heavy: 10% of Ext. In/Outbound Demand*

Figure 8: External-Internal, Internal-External, and External-External Demand

The total demand of the Internal-Internal trips was assumed to be proportionate to the total external trip demand. The total internal demand for light/medium trucks was assumed to be a multiple of 2.5 of the total of External-Internal and Internal-External demand (based on professional engineering judgment), while the total internal demand heavy trucks was assumed to be 0.4 times of the total of External-Internal and Internal-External demand. These initial estimates of internal truck traffic by truck type were used to set the scale of the seed matrix for each truck type. The final internal truck traffic (by truck type) emerges from the ODME procedure.

The distribution of the internal seed matrix was based on the employment information in each Traffic Analysis Zone (TAZ). There are three employment types in the MAPA model: general industrial, retail and commercial, and service and office. It was assumed the light/medium and heavy trucks O-D were dependent on the general industrial and retail/commercial employment in each TAZ. The retail/commercial employment was assumed to generate 5 times more medium trucks and the same number of heavy trucks, comparing to the general industrial employment. Service/office employment was not expected to generate significant numbers of truck trips.

The distribution of the external-external trips was based on the MAPA External Travel Survey Summary Report.

Table 7 shows major external to external truck percentages (above 3%) and the total truck volumes. The locations of these zones are highlighted in **Figure 6**.

Table 7: External to External Trip Distribution (by external station pairs)

	100	103	107	110
100			13%	4%
103				20%
107	13%			
110	4%	20%		

Major External-external Truck Volume	12,796
Major External-external Truck %	73%
Total External-external Truck Volume (including other external station pairs with less than 3% of total demand each)	17,436

Post-processing the Estimated O-D Matrix and Assignment

The estimated O-D demand for external zones was further adjusted in order to match the observed volume. The demand from TAZ 120 to 102 was reduced by 90%, and the adjustment factors used for TAZ 102 are shown in **Table 8**.

Table 8: Adjustment Factor for External Zone 102

	Adjustment Factor
Heavy, AM	9%
Heavy, MD	26%
Heavy, PM	47%
Heavy, NT	2%

After adjusting the estimated O-D matrix, each matrix was assigned on the network using similar settings as the current auto vehicle assignment in the MAPA model[5].

Base Year Calibration Results

Our target was to calibrate flows to within a root mean square error (RMSE%) of 0.30, or 30%, compared with observed counts.

A comparison of the observed and estimated truck volume to and from external stations is shown in **Table 9**. Overall the estimated truck volume at external stations is 2% higher than the observed volume, with most locations ranging from 96% to 101% of the observed volume. The model tends to over-generate higher truck volumes along major interstates and highways (such as stations 107

[5] The current auto vehicle assignment uses the Stochastic User Equilibrium (SUE) and the congestion function developed by the Bureau of Public Roads (BPR). The truck model, however, treats this as a free-flow assignment (i.e., congestions will not have any impact) since the capacity was set to be the capacity of the whole facility.

and 110), and the performance is worse at locations with low numbers of observed trucks (such as stations 102, 116, 120, and 121).

Table 10 and **Table 11** show the comparison between the estimated and observed link volume. They were aggregated into super districts (SD), which were developed by HDR and MAPA based on the districts as shown in **Figure 9**. The assigned traffic volume is very similar to the count with every SD ranges from 94% to 107% of the assigned volume. **Figure 10** shows the assignment results for the entire network (sum of both truck types and four time periods).

Figure 11 shows the ratio between the total assigned truck volume and the observed volume, for links with volume higher than 50. While most ratios are between 0.81 and 1.20, indicating the assigned volume is close to the observed volume, it is more problematic for links on Highway 680 just north of the Highway 80 and Highway 680 interchange. This problem will likely be addressed with more accurate and consistent counts, so that TransCAD will be able to match the volumes on adjacent links.

The RMSE for external stations is shown in **Table 12**. The overall RMSE percentage is 0.24, which is below the 0.30 target value. Each RMSE for the light/medium truck type is lower than 0.30, while the heavy truck night RMSE is the only individual case slightly above this target at 0.35. This may because of a higher number of through trips in this class and time period, which were difficult to quantify in the model.

Table 9: External zone volume comparison by truck type and time of day

TAZ	Observed									Estimated									Estimated / Observed
	Light / Medium Truck				Heavy Truck				Total	Light / Medium Truck				Heavy Truck				Total	
	AM	Midday	PM	Night	AM	Midday	PM	Night		AM	Midday	PM	Night	AM	Midday	PM	Night		
100	314	912	330	730	325	1,366	486	1,552	6,015	314	911	330	730	330	1,375	490	1,551	6,031	100%
101	57	251	116	140	27	115	45	80	831	59	260	120	146	28	117	46	82	858	103%
102	6	13	5	23	4	44	18	6	119	13	52	25	15	4	44	19	7	179	150%
103	330	1,476	635	875	369	1,506	544	548	6,284	359	1,637	700	906	380	1,513	510	531	6,534	104%
104	57	187	122	142	24	97	35	51	716	59	192	125	145	24	98	36	54	733	102%
105	64	263	137	168	13	60	33	16	754	65	266	140	169	12	56	30	14	752	100%
106	126	176	131	95	4	23	9	4	568	126	176	131	95	4	23	9	4	568	100%
107	170	754	320	420	173	670	234	259	3,001	148	667	285	369	153	603	209	217	2,651	88%
108	288	685	273	344	66	418	136	127	2,337	288	685	273	344	67	418	136	125	2,336	100%
109	191	614	274	310	51	220	56	81	1,796	240	763	379	290	58	286	58	56	2,130	119%
110	242	1,480	616	1,386	480	2,204	871	1,697	8,977	170	1,172	547	1,420	414	1,814	796	1,620	7,953	89%
111	78	490	132	174	41	132	41	60	1,149	78	490	132	174	41	132	41	60	1,148	100%
112	36	152	46	44	66	174	72	187	777	36	150	46	44	66	175	72	187	776	100%
113	25	110	37	23	8	43	9	5	260	25	110	37	23	8	43	9	5	260	100%
114	93	380	158	223	113	467	167	264	1,864	134	504	212	265	153	636	208	271	2,383	128%
115	28	92	37	28	12	38	14	11	261	29	93	37	29	13	38	14	10	263	101%
116	23	84	31	72	18	62	27	54	371	12	80	37	87	23	98	45	96	478	129%
117	140	282	196	150	5	45	11	14	843	140	281	195	150	5	44	11	14	840	100%
118	18	120	30	42	10	33	11	15	278	18	118	29	42	9	30	10	13	269	97%
119	67	221	151	160	24	103	39	56	822	67	220	151	160	24	103	39	56	820	100%
120	120	421	171	208	58	204	68	144	1,393	62	432	224	118	26	165	47	48	1,122	81%
121	1	54	19	18	8	21	7	12	141	17	97	26	38	9	30	10	13	240	170%
Total	**2,476**	**9,216**	**3,967**	**5,776**	**1,900**	**8,047**	**2,934**	**5,242**	**39,558**	**2,459**	**9,356**	**4,181**	**5,759**	**1,851**	**7,840**	**2,844**	**5,034**	**39,324**	**99%**

Table 10: Link volume by super district comparison by truck type and time period

Super District	Observed									Estimated								
	Light / Medium Truck				Heavy Truck				Total	Light / Medium Truck				Heavy Truck				Total
	AM	Midday	PM	Night	AM	Midday	PM	Night		AM	Midday	PM	Night	AM	Midday	PM	Night	
1	1,983	2,060	7,497	7,969	2,223	2,418	4,976	5,286	34,412	2,131	2,163	8,177	8,432	2,419	2,482	5,417	5,391	36,612
2	1,226	1,095	3,782	3,608	1,190	1,131	2,650	2,497	17,179	1,162	1,010	3,583	3,369	1,126	1,059	2,511	2,328	16,149
3	2,450	2,661	8,503	9,269	3,491	3,856	5,778	6,271	42,278	2,556	2,765	8,607	9,394	3,601	4,030	5,883	6,386	43,220
4	3,738	4,600	13,748	17,134	4,738	5,846	9,564	11,880	71,248	3,659	4,468	13,381	16,590	4,586	5,553	9,280	11,402	68,919
5	2,267	2,459	8,599	10,298	2,771	3,276	5,815	6,860	42,348	2,215	2,465	8,394	10,118	2,729	3,227	5,683	6,523	41,354
6	2,197	1,241	7,118	3,971	2,688	1,583	4,771	2,473	26,041	2,157	1,254	6,983	4,024	2,646	1,592	4,706	2,533	25,897
7	2,326	2,526	8,174	8,901	3,087	3,353	5,458	5,893	39,717	2,214	2,371	7,973	8,523	3,024	3,212	5,306	5,633	38,257
8	3,472	3,835	13,520	14,984	5,018	5,604	9,413	10,445	66,290	3,609	3,975	13,713	15,100	5,189	5,732	9,789	10,690	67,799
9	1,255	1,126	3,908	3,340	1,269	1,045	2,762	2,365	17,071	1,257	1,148	3,982	3,433	1,307	1,081	2,801	2,407	17,416
10	3,683	3,363	13,407	12,772	5,186	4,863	9,554	9,027	61,855	3,624	3,145	13,267	11,990	5,107	4,358	9,310	7,223	58,023
11	2,749	2,143	9,451	7,535	3,519	2,846	6,740	5,371	40,355	2,976	2,185	10,030	7,682	3,765	2,931	7,254	6,029	42,852
12	1,384	1,403	4,607	4,727	1,678	1,751	3,287	3,378	22,217	1,290	1,314	4,412	4,574	1,561	1,636	3,112	3,213	21,113
13	2,153	1,319	7,492	4,737	2,756	1,755	5,264	3,303	28,780	2,213	1,382	7,683	4,950	2,849	1,865	5,343	3,351	29,635
14	2,888	2,457	10,406	8,856	3,857	3,271	7,305	6,205	45,245	2,868	2,436	10,445	8,853	3,894	3,277	7,358	6,207	45,338
Total	33,773	32,288	120,211	118,102	43,471	42,599	83,337	81,255	555,036	33,931	32,081	120,629	117,033	43,802	42,036	83,754	79,317	552,582

Table 11: Estimated/observed link volume by super district by truck type and time period

Super District	Light / Medium Truck				Heavy Truck				Total
	AM	Midday	PM	Night	AM	Midday	PM	Night	
1	107%	105%	109%	106%	109%	103%	109%	102%	106%
2	95%	92%	95%	93%	95%	94%	95%	93%	94%
3	104%	104%	101%	101%	103%	105%	102%	102%	102%
4	98%	97%	97%	97%	97%	95%	97%	96%	97%
5	98%	100%	98%	98%	98%	99%	98%	95%	98%
6	98%	101%	98%	101%	98%	101%	99%	102%	99%
7	95%	94%	98%	96%	98%	96%	97%	96%	96%
8	104%	104%	101%	101%	103%	102%	104%	102%	102%
9	100%	102%	102%	103%	103%	103%	101%	102%	102%
10	98%	93%	99%	94%	98%	90%	97%	80%	94%
11	108%	102%	106%	102%	107%	103%	108%	112%	106%
12	93%	94%	96%	97%	93%	93%	95%	95%	95%
13	103%	105%	103%	104%	103%	106%	102%	101%	103%
14	99%	99%	100%	100%	101%	100%	101%	100%	100%
Total	100%	99%	100%	99%	101%	99%	101%	98%	100%

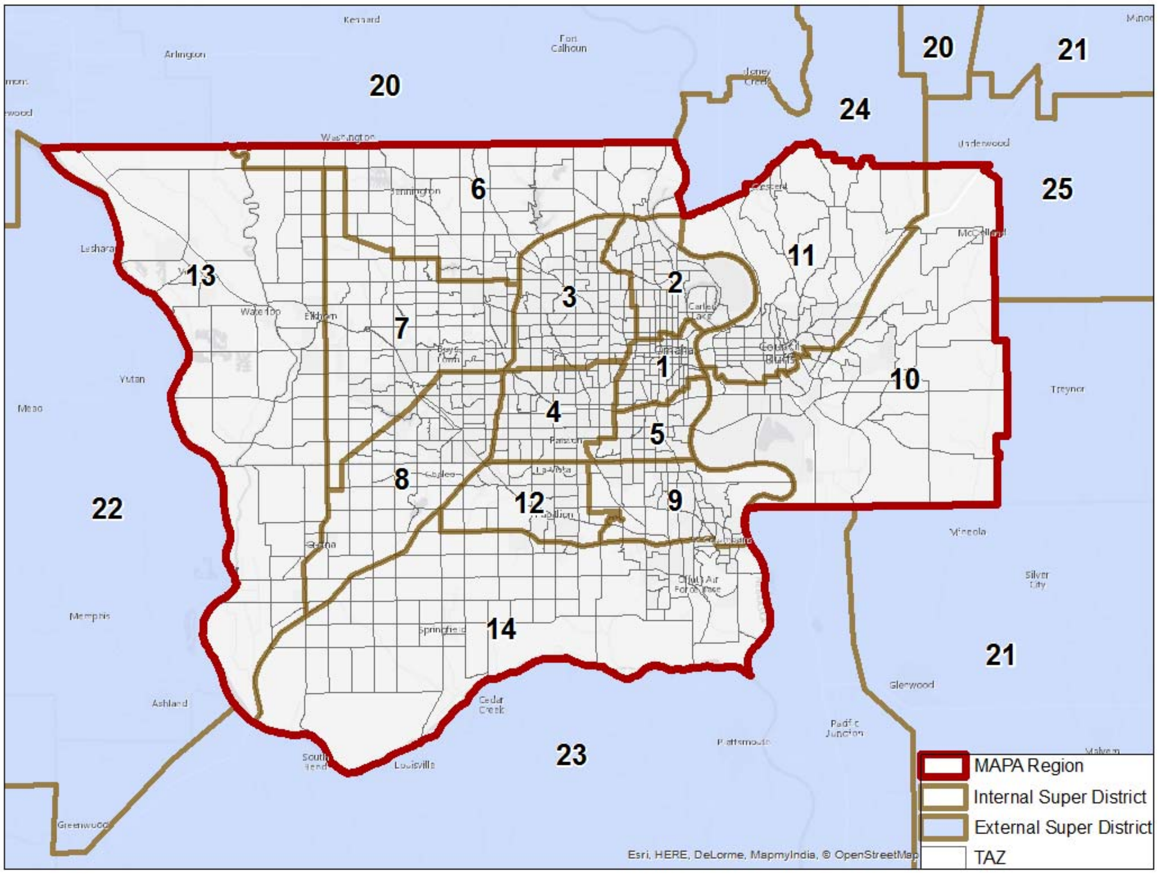

Figure 9: Location of Super Districts

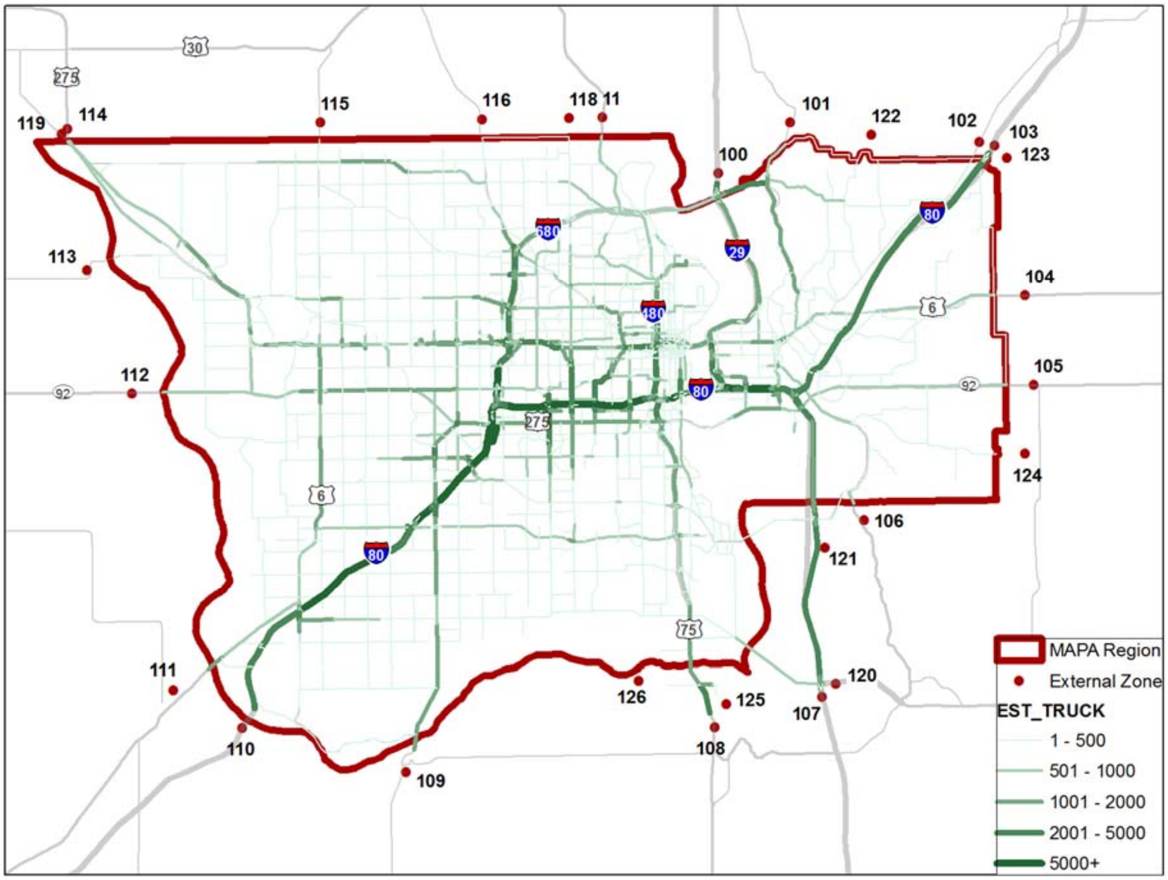

Figure 10: Total Truck Volume Assignment

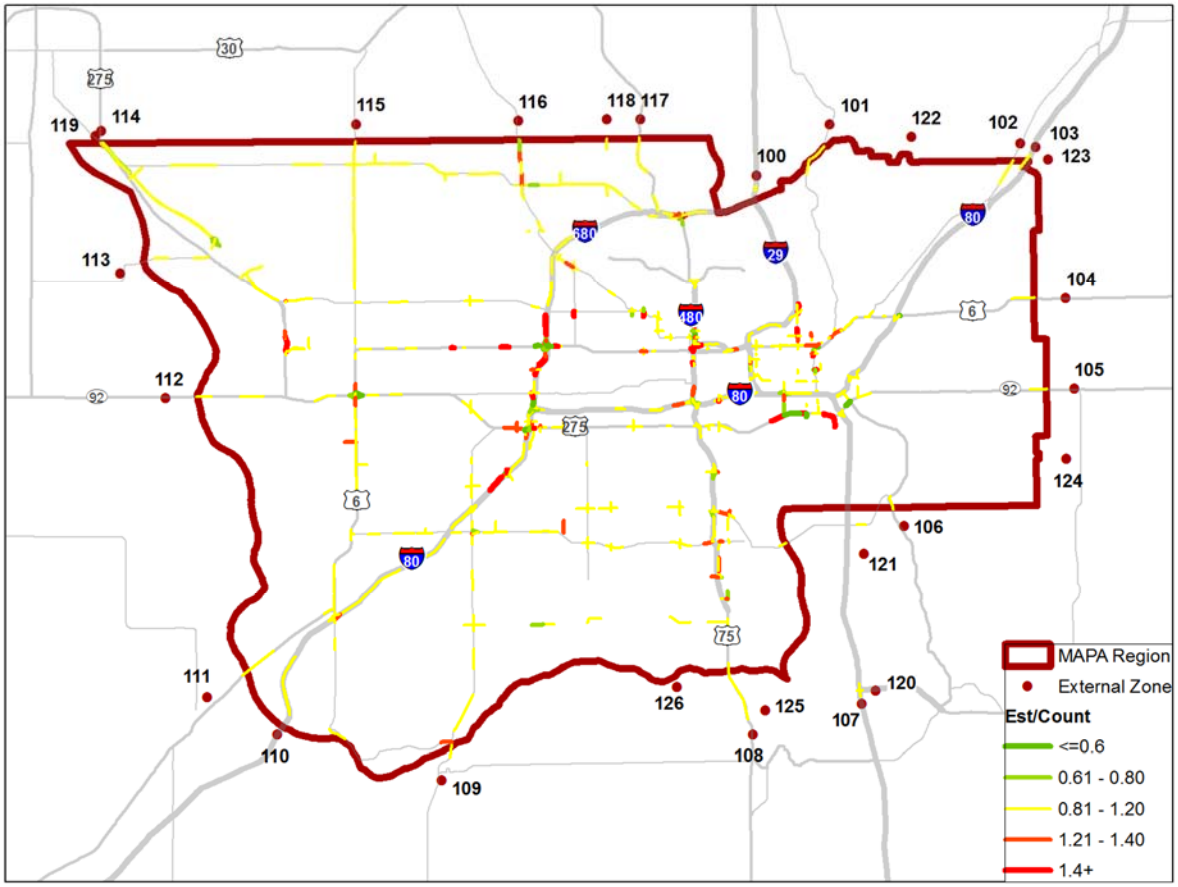

Figure 11: Ratio of Estimated Volume / Observed Volume

Table 12: Root Mean Square Error (RMSE) by Truck Type and Time Period

Truck Type	Time Period	RMSE %
Medium	AM	0.29
	Midday	0.26
	PM	0.28
	Night	0.26
Heavy	AM	0.30
	Midday	0.28
	PM	0.30
	Night	0.35
Total		**0.24**

Truck Trip Rates

The final step was developing truck trip rates specific to the MAPA region based on the input socio-economic data and the ODME-developed truck matrix. The first stage in preparing truck forecasts was developing a zone aggregation to group zones with very low land use with other adjacent zones. This aggregation was used to develop time-of-day factors by grouped zone and to determine the overall relationship between land use and truck trips, to avoid trip / job proportions potentially being skewed by very small numbers. This process resulted in 561 grouped zones, each representing between 1 and 10 contiguous zones. This was not applied to any of the external stations.

The next stage involved comparing the number of daily light/medium and heavy truck trips generated by (originating in) each internal grouped zone with the land use characteristics of that grouped zone. Regression analyses indicated that:

- The general/industrial and retail/commercial land use employment in the MAPA area have a significant relationship with the number of truck trips generated (for both classes).
- The service/office land use category is not significant
- The number of households is marginally significant.

This is consistent with the findings reported in the Quick Response Freight Manual and NCHRP Synthesis 298. A further investigation as to whether the relative influence of each land use category varies by time of day did not indicate any particular variation by time period, so truck rates were generated at the 24-hour level and demand was then split, for each grouped zone and truck class, based on the observed base year time period proportions.

The daily trip rates by land use type for new demand in a zone are given in **Table 13**Error! Reference source not found.**.**

Table 13: Trip rates for future demand by TAZ

Truck type	General/Industrial Employment	Retail/Commercial Employment	Households
Light/medium	0.114	0.228	0.053
Heavy	0.150	0.104	0.039

Truck trip forecasts are based on three attributes:

- The base year number of daily trips generated by the zone. This takes into account individual zone characteristics that are not captured by the broad land use categories, and ensures that a zone that generates a lot of observed truck trips despite not having high employment will continue to generate an equivalent number in future;
- Time of day and origin/destination splits. These are calculated and applied for each zone grouping.
- Estimated new demand. These are calculated based on the rates given above applied to the forecasted (future) land use.

External trips do not have rates associated with them as they are not connected to land use for a given geographical area; however, it is expected that external flow growth will be proportional to the growth in internal employment. As such, it is recommended that external trip end forecast numbers be developed by factoring the base year trips by the overall growth ratio in internal trips.

Future 24-hour internal truck volumes generated by zone for light/medium trucks (LT) and heavy trucks (HT) are thus calculated with the following equations, where F represents future year and B base year, and the results are constrained to a minimum value of zero (so that even if employment should decline in a zone in future, negative trucks will not be generated):

$$\mathrm{LT}_F = \begin{bmatrix} \mathrm{LT}_B + 0.114 * (GenInd_F - GenInd_B) + 0.228 * (RetCom_F - RetCom_B) \\ +0.053 * (Hhld_F - Hhld_B) \end{bmatrix}$$

$$\mathrm{HT}_F = \begin{bmatrix} \mathrm{HT}_B + 0.150 * (GenInd_F - GenInd_B) + 0.104 * (RetCom_F - RetCom_B) \\ +0.039 * (Hhld_F - Hhld_B) \end{bmatrix}$$

The volumes will then be factored for each time period using a frataring (bi-proportional updating) method in TransCad to convert zone-level trip-end growth to overall OD growth recognizing the base year distribution. External demand totals by external station will be based on factoring the totals proportionally to the growth in internal land use (so if internal trip ends grow by 20% relative to the base year, external trip ends will also grow by 20%). External-internal and internal-external flows will then be fratared to the new totals. In the absence of any updated information on external-external trips, it is suggested that the same growth rate be applied to these.