Northwest Arkansas Regional Travel Demand Model Development

Model Development and Validation Report

Prepared for the
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TABLE OF CONTENTS

I. OVERVIEW

This report presents model development procedures used to develop the Northwest Arkansas Regional Travel Demand Model. Covering all of Washington and Benton counties, this two-county regional model utilizes a GIS-based travel demand modeling software, TransCAD. Using TransCAD's GIS techniques, the Northwest Arkansas model incorporates extensive geographic and traffic operational databases into the highway network and the traffic analysis zone (TAZ) GIS layer for use in the modeling process. Peak-period modeling capabilities are also embedded in this model through time-of-day (TOD) models. The *2004 Northwest Arkansas Household Travel Behavior Study* was fully analyzed to derive key modeling components such as trip generation rates, trip length frequency distributions, time-of-day distributions and vehicle occupancy rates.

The Northwest Arkansas model is structured to implement "four-step" processes – trip generation, trip distribution, mode share and trip assignment. Based on this structure, the model runs in two phases – "initial" assignment and then subsequent "feedback" assignments. It incorporates a feedback loop that takes link congested speeds estimated from the first four-step processes (i.e., "initial" assignment) and feeds the congested speeds back to subsequent model runs. With the feedback routine, trips are distributed and assigned on the network in a more effective and realistic manner since trip destination and route choices are determined based on congested network condition.

Major features of the Northwest Arkansas TransCAD model are summarized as follows:

- **Study Area.** The model fully covers Benton and Washington counties. Trips external to this study area (i.e., external-internal or external-external trips) are captured by 31 external stations.

- **Network and TAZ Development.** The Northwest Arkansas regional highway network was developed from NARTS and AHTD GIS and roadway data sources by NARTS staff. Thorough network review was conducted by Bernardin, Lochmueller & Associates and Alliance Transportation Group. The network includes extensive geometric and operational link attributes. Traffic signals were also coded in the network to estimate delays associated with this control device. Consistent with the network details, TAZs were appropriately defined throughout the study area to be bounded by the modeled roadway network with a minimum of network passing through any zone. Each TAZ is characterized by more than 40 zonal attributes.

- **Improved Estimation of Free-Flow Speeds.** Instead of using posted speed limits as a surrogate for free-flow speeds, free-flow speeds were estimated based on a procedure similar to that developed for the Indiana Statewide Travel Demand Model (ISTDM). The new procedure was developed from speed surveys conducted for *the I-69 Evansville-to-Indianapolis Study*. Based on the speed surveys, the relationship between free-flow speeds and several determining factors such as posted speed, access control and area type was identified for each facility type. This relationship was expressed in various forms of nonlinear regression models.

- **Improved Estimation of Link Capacities.** Geometric and operational link data were utilized for improved estimation of link capacities. A new methodology to estimate directional peak-hour capacities was developed based on the *Highway Capacity Manual 2000* (HCM 2000). This methodology derives various capacity adjustment factors from bi-factor nonlinear regression formula. The estimated peak-hour capacities were then converted to peak and off-peak period capacities.

- **Traffic Signal Delays.** Delays associated with traffic signals were estimated to adjust directional link free-flow speeds and capacities. The HCM 2000 method of calculating vehicle delay that takes into consideration green time and progression effect was adopted.

- **Trip Generation Design.** Simply speaking, travel demand modeling is the process of translating different types of trips into vehicular traffic on the network. Trip production and attraction models were developed for each of these trip purposes through various statistical analyses using trip data from the *2004 Northwest Arkansas Household Travel Behavior Study*.

- **Trip Distribution Model.** During the development of the Northwest Arkansas model, unique friction factor tables were calibrated to survey data for each of the trip purposes, including truck trips.

- **Time-of-Day Models.** The Northwest Arkansas model consists of three time-of-day (TOD) models: morning peak, evening peak and off-peak periods. Most modeling factors that are unique to each time period were derived from the *2004 Northwest Arkansas Household Travel Behavior Study*. Compared to a single daily model, the TOD modeling generates a more accurate travel model by treating each period uniquely.

- **Truck Models.** Travel patterns of trucks are different from those of passenger cars, thus it is desirable to have a separate truck mode in the model. In each of the four step processes, the Northwest Arkansas model maintains a separate truck model to address the unique travel characteristics of trucks. Truck trips are separately generated and distributed. Then, they are assigned to the network for each TOD simultaneously with the corresponding passenger car assignments.

- **Feedback Loop.** Link free-flow speeds derive the first phase of the model run, or initial assignment. It is used for network skimming, trip distribution and route choice. Following the first phase, link congested-speeds are estimated and used to redistribute trips in subsequent model runs, or feedback assignments. The final assignment results are obtained from the feedback assignment.

- **Post-processors.** The Northwest Arkansas model is equipped with several post-processors. These post-processors report (1) calibration statistics through a program "CAL_REP", (2) a variety of performance measures of the model through a program "POST_ALT". These post-processors are embedded in the model user interface.

- **User-friendly Travel Model Geographic User Interface (GUI).** Using TransCAD's programming capability, GISDK script a user friendly model interface was designed to run the model by automating the entire modeling and post-processing procedures. The first part of the interface elicits from the user all necessary inputs to the model, including the highway network, the TAZ database and the location of model component files. The remaining parts consist of several modules including "initial" and "feedback" model runs and post-processing. Detailed descriptions of the model GUI are provided in the *Model Users Guide*.

The first part of this report is devoted to describing the model coverage area and the model input GIS databases. Then, the new speed and capacity estimation procedures are explained in detail. Modeling components of the Northwest Arkansas model are described with associated tables and figures. Later, model validation results are presented with key performance measures such as loading error, VMT error, and percent root mean square error. Post-processors developed for the model are also described.

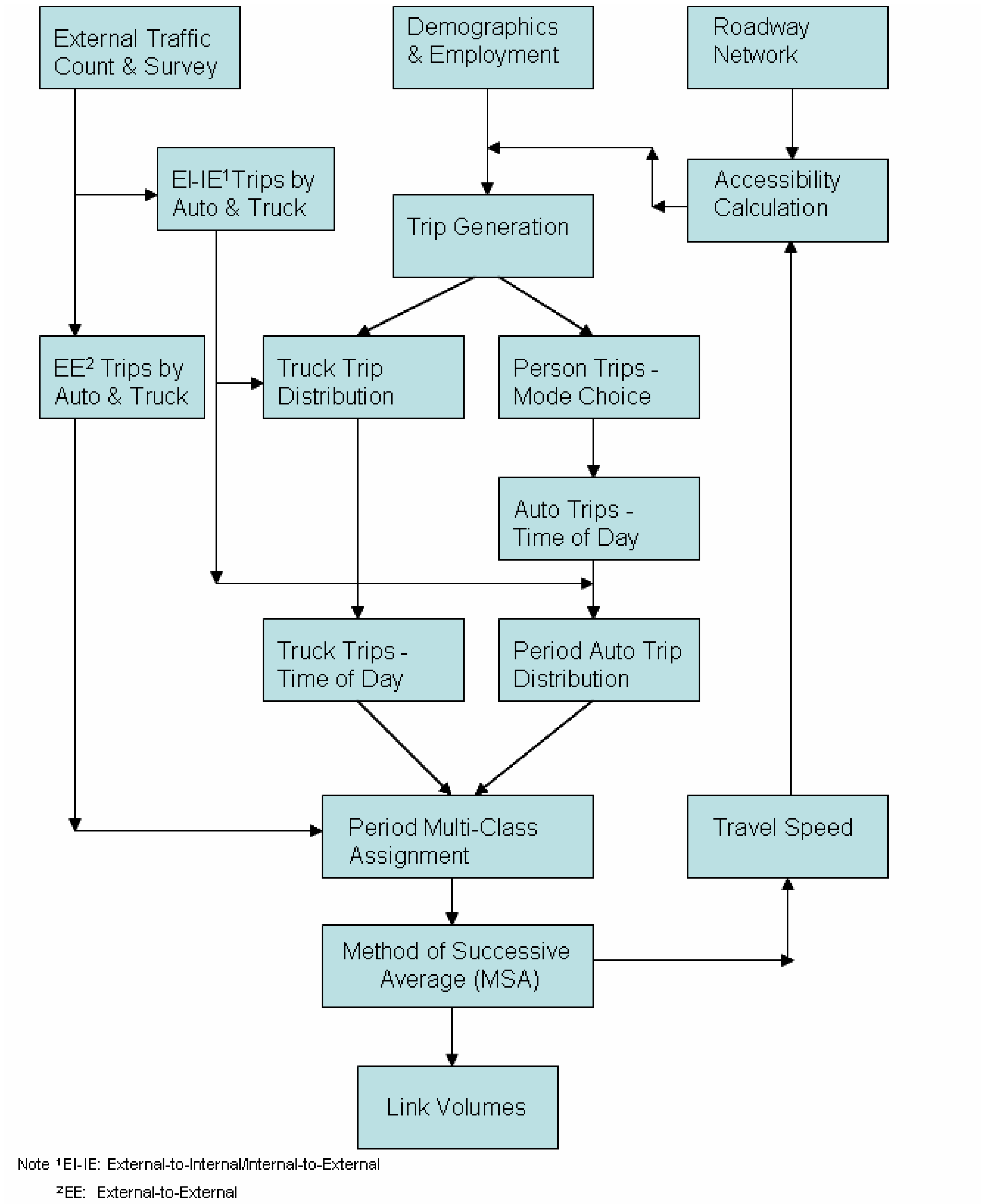


Figure 1. Flow Chart of Model Process

II. MODEL AREA

The model area of the Northwest Arkansas regional model covers both Benton and Washington Counties. All roadway classes which include Interstates, major and minor arterials, major and minor collectors, and some local roads are represented in the model's coverage area. The zone structure of these counties are detailed to address diverse and intense socioeconomic activities in these core counties

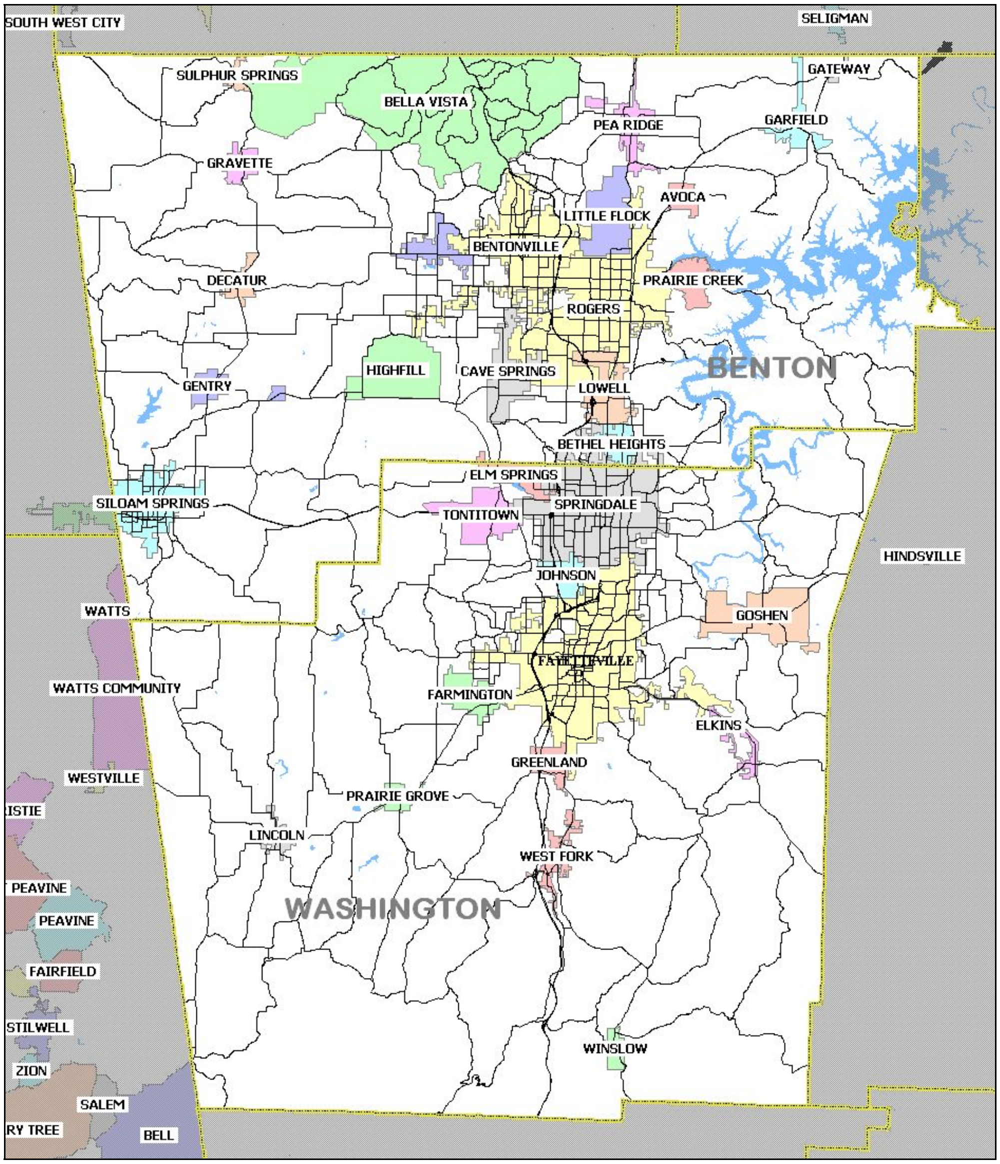


Figure 2. Northwest Arkansas Regional Travel Model Study Area

III. NETWORK AND TAZ DEVELOPMENT

A substantial effort was undertaken on the Northwest Arkansas regional model network to create a TransCAD-based network that included all necessary highways (arterials, collectors and significant local roads) to be analyzed along with the highway attributes. The highway network for the base year of 2005 was created by NARTS staff from various GIS data sources.

Centroid connectors in the network for Benton and Washington counties were provided by NARTS. These centroid connectors were thoroughly examined for placement and connectivity. Questions regarding centroid connector locations were identified and corrected where necessary.

The newly-developed TransCAD base year network consists of 5,943 roadway links and 1,699 centroid connector links. Of the 5,943 links, forty-three percent of the roadway links are classified as urban facilities, nine percent are classified as suburban, nine percent are classified as major employment district, and thirty-nine percent are classified as rural Figure 3 shows the base-year highway network color-coded by federal functional class.

The Northwest Arkansas model network includes more geometric and operational features than most urban area models. The TransCAD network includes link attributes for interstates, U.S. highways, state highways and some local roads. These link attributes are derived from: (1) AHTD (2) geographic information system (GIS) layers provided by the NARTS; and (3) local planning and engineering staff knowledge of the street/road system in the study area counties. Tables of the link attributes can be found in the *Model Users Guide*.

The incorporation of geometric and operational data was one of the major improvements made in the Northwest Arkansas regional model. These detailed data on the roadway characteristics provided valuable information for estimating various inputs (such as capacities and speeds) to the subsequent modeling processes.

Using traffic signal layers provided by the NARTS and from AHTD, traffic signals locations were coded into the network link attributes. In addition, the approach to the traffic signal location was categorized by its priority relative to the priority of the crossroad. This categorization is based on the fact that the mainline is given preferential signal schemes (such as a higher green time and longer signal phases) than the crossroad. Multiple signals were also coded in the network to consider the progression effect on a series of traffic signals closely located on a link of the same roadway. The traffic signals along with signal priorities and multiple signals were used to accurately estimate delays on approaching links and to adjust speeds and capacities based on the delays.

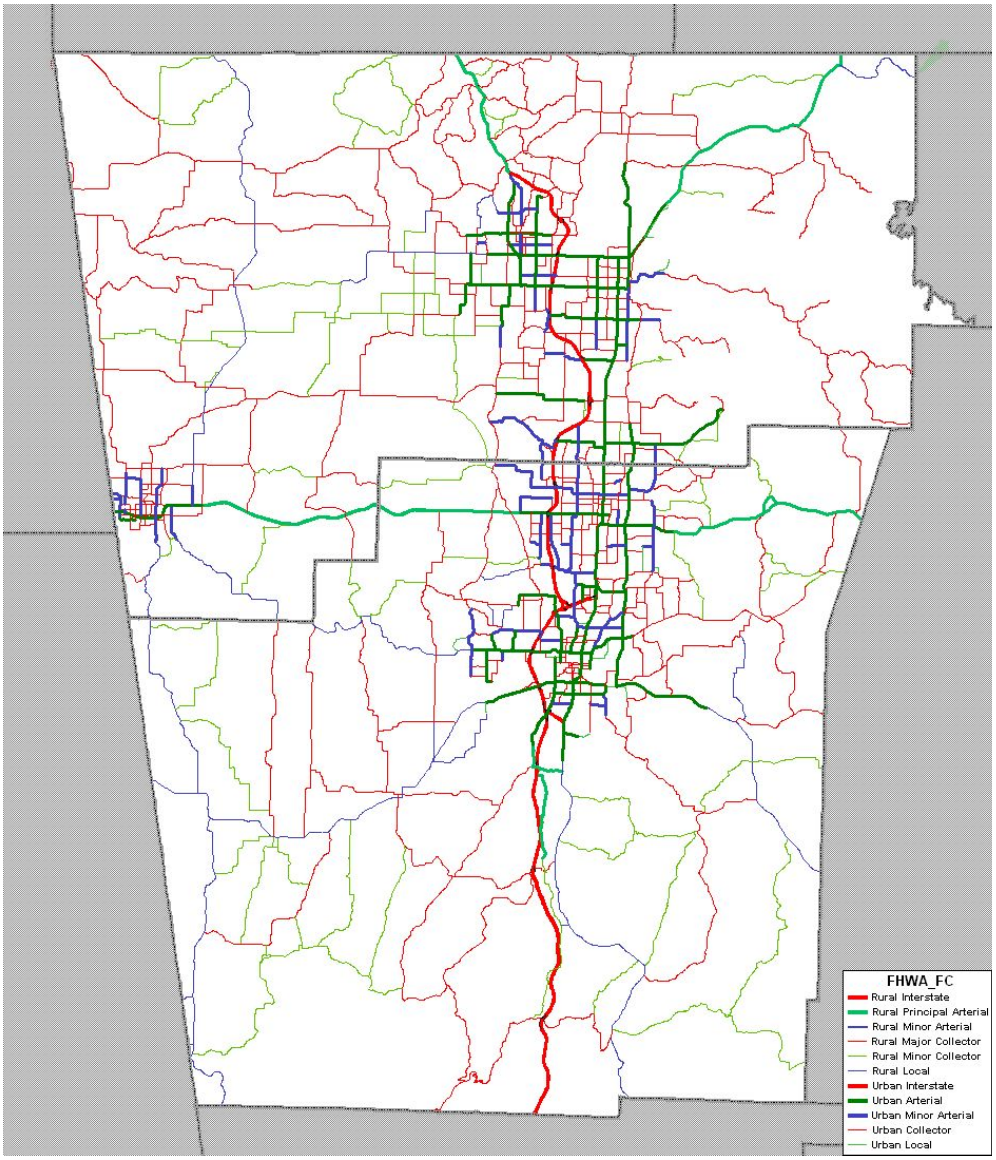


Figure 3. Northwest Arkansas Highway Network

The study area of the Northwest Arkansas regional model was disaggregated into a number of traffic analysis zones. The TAZ layer of the model consists of a total of 776 zones. Demographic and employment features of the Northwest Arkansas model area are reported for each of the 681 internal zones for use in trip generation. There are also 64 dummy zones available for adding zonal detail for sub-area or corridor studies. The remaining 31 zones are used as external zones.

Each zone is characterized by extensive zonal attributes. The attributes include land area, county name/number, TAZ number and detailed categorization of population, households, vehicle ownership, mean household income, school enrollment, university enrollment and employment by economic sector.

For details about network and TAZ data attributes, refer to the *Model Users Guide*.

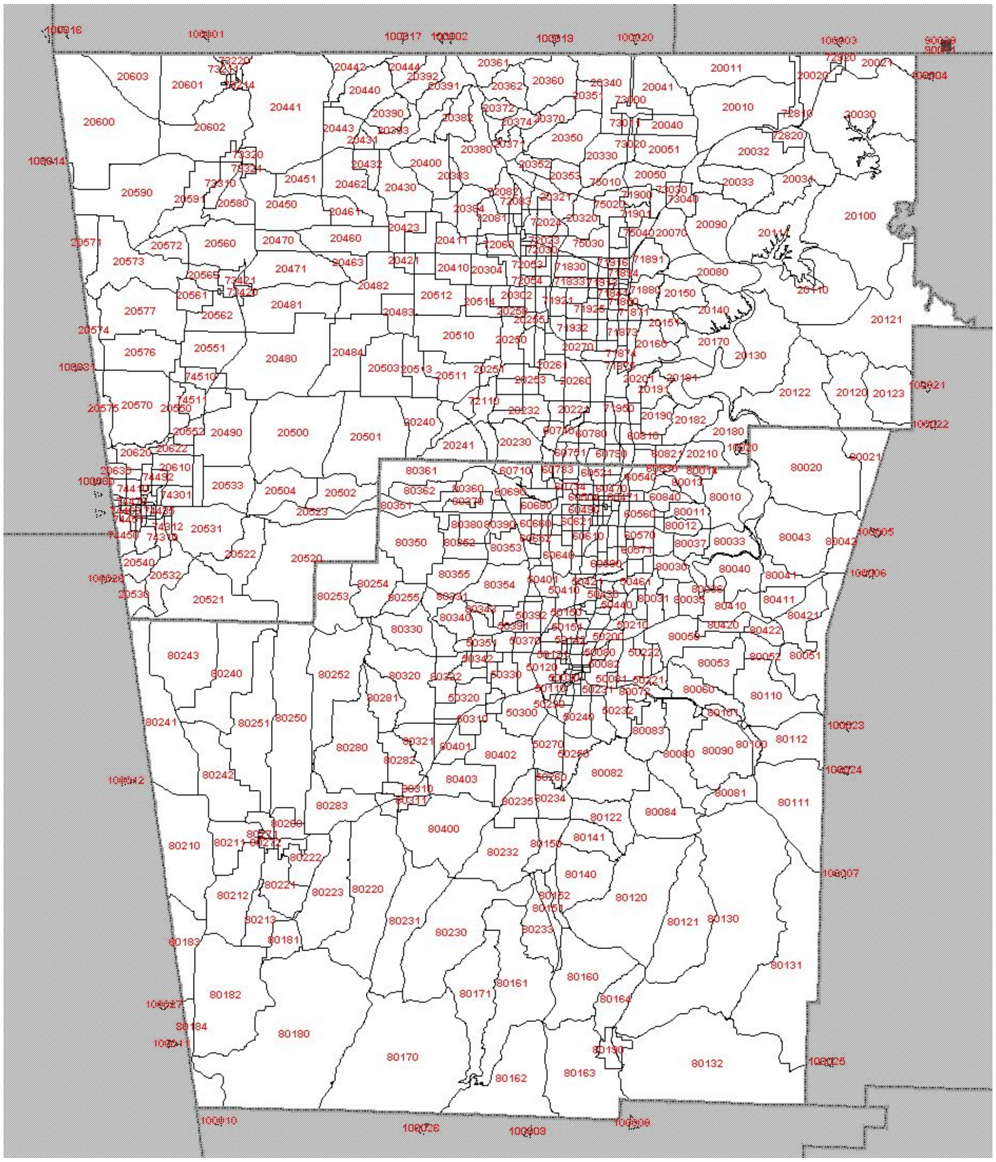


Figure 4. Northwest Arkansas TAZs

IV. FREE-FLOW SPEED ESTIMATION

By definition, "free-flow" speed is the speed that occurs when traffic density (vehicles per lane mile) and traffic flow (vehicles per hour) are zero. Thus, factors determining free-flow speed only include the geometrics of the road and the posted speed without any influences by traffic, weather or accidents. Free-flow link speeds are used in most elements of the assignment procedures including network skim, trip distribution and trip assignment.

The importance of using correct free-flow speeds cannot be overstated. Most travel models use posted speed limits as a surrogate for free-flow speeds. This common practice under-represents the true free-flow inputs to the travel model, and results in a significant over-estimation of travel times.

The Northwest Arkansas model borrows a new free-flow speed estimation procedure developed for the new Indiana Statewide Travel Demand Model (ISTDM). The previous method adopted for the ISTDM and other urban models including the Lexington Area Travel Demand Model and the Evansville Regional Travel Demand Model relied on a detailed speed table that determines free-flow speeds based on the roadway's area type, functional class, posted speed and number of lanes. This table was constructed from various statistical analyses on field data collected from an extensive speed survey which was done at 64 urban and rural locations in southwestern 26-county area in Indiana. Using the speed table, more realistic free-flow speeds could be input to the above mentioned models.

The new speed estimation procedure further improves the previous method. The previous method is heavily dependent on the roadway's functional class definition. However, definition of the functional class is somewhat judgmental and can lead to incorrect interpretation of actual geometric and functional roadway conditions. On this ground, the new procedure utilizes roadway's facility type instead of relying on its functional class.

To develop the new procedure, the 26-county field survey was revisited and reanalyzed to investigate any relationships between facility type and free-flow speed. The facility type was determined based on area type, total number of lanes, median type (divided vs. undivided), directionality (one-way vs. bi-directional), and access control type (full, partial or none). For each unique facility type, observed speeds that represent free-flow conditions were compared with their respective posted speed limits. The relationship between the observed free-flow speeds and the posted speeds was then formulated by curve fitting these two data items using nonlinear regressions.

Table 1 lists the nonlinear formula developed for major facility types. The speeds for other minor variations in facility type such as one-way streets were derived from these formula based on similarity in geometric and functional characteristics of the roadway.

Table 1. Free-Flow Speed Estimation Formula

Area Type	Free-Flow Speed [1, 2]	Condition	Note
2-lane 2-way undivided highways			
Rural	$0.009751 \cdot PSPD^2 + 30.03397$	$25 \le PSPD \le 55$	No or Partial Access Control
	25	PSPD < 25	
Suburban	$117.640917 \cdot PSPD^{0.0015+0.001279 \cdot PSPD} - 98.065483$	$25 \le PSPD \le 55$	
	25	PSPD < 25	
Urban	$6.189 + 0.9437 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	PSPD < 25	
2-lane 2-way divided highways			
Rural	$\left(0.000017 \cdot (PSPD - 72.323105)^2 + 0.019702\right)^{-1} + 19.835323$	$25 \le PSPD \le 55$	No Access Control
	25	PSPD < 25	
Suburban	$3.180682 \cdot PSPD^{0.857638} - 84.105587 \cdot e^{-41.803252/PSPD}$	$25 \le PSPD \le 55$	
	25	PSPD < 25	
Urban	$\left(0.119687 - 0.023365 \cdot \ln(PSPD)\right)^{-1} + 0.373821 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	PSPD < 25	
Multilane undivided highways			
Rural	$\left(0.000017 \cdot (PSPD - 72.323105)^2 + 0.019702\right)^{-1} + 19.835323$	$25 \le PSPD \le 65$	
	25	PSPD < 25	
Suburban	$3.180682 \cdot PSPD^{0.857638} - 84.105587 \cdot e^{-41.803252/PSPD}$	$25 \le PSPD \le 55$	
	25	PSPD < 25	
Urban	$\left(0.119687 - 0.023365 \cdot \ln(PSPD)\right)^{-1} + 0.373821 \cdot PSPD$	$25 \le PSPD \le 55$	
	25	PSPD < 25	
Multilane divided highways			
Rural	$2.836165 \cdot PSPD - 0.071256 \cdot PSPD^2 + 0.000744 \cdot PSPD^3$	$25 \le PSPD \le 50$	No or Partial Access Control
	$16.0359 + 0.8223 \cdot PSPD$	$50 < PSPD \le 65$	
	25	PSPD < 25	
Suburban	$\left(0.000071 \cdot (PSPD - 64.166165)^2 + 0.035258\right)^{-1} + 9.061039 \cdot \ln(PSPD)$	$25 \le PSPD \le 55$	
	25	PSPD < 25	
Urban	$\left(0.081714 - 0.016217 \cdot \ln(PSPD)\right)^{-1}$	$25 \le PSPD \le 55$	
	25	PSPD < 25	
Full access controlled highways			
	64.00	PSPD = 55	
	67.06	PSPD = 60	
	70.21	PSPD = 65	
	73.30	PSPD = 70	

Note: [1] Free-flow speeds in mph, [2] PSPD: Posted speeds in mph

V. CAPACITY ESTIMATION

The common practice applied in most travel models ascribes a roadway capacity based on a simplified link-capacity system that in many cases over or underestimates the true capacity of the roadway. Peak-hour roadway capacities of the Northwest Arkansas regional network were estimated based on the *Highway Capacity Manual 2000* (HCM 2000) procedure. In this new procedure, detailed link data on geometric and operational characteristics incorporated in the network link attributes were used for improved estimates of link capacities. First, all links in the model area were set to "maximum hourly service flows" as specified in HCM with respect to their functional class. Then, the maximum service flows were adjusted to "hourly service flows" based on several of limiting factors. These capacity reduction factors included: right-shoulder lateral clearance, heavy vehicles, driver population, lane width, number of lanes, interchange density, median type, access points, and directional distribution.

A significant effort was given to develop these limiting factors from HCM 2000. For each of these factors, the manual provides adjustments (or reductions) in free-flow speed that reflect negative effect of the factor. The reductions are determined based on geometric features of the roadway. For instance, for adjustments for lateral clearance for freeways, two geometric variables (right-shoulder lateral clearance and number of lanes) are cross-referenced to estimate the reduction in free-flow speed. These adjustments are then applied to base free-flow speed to obtain *actual* free-flow speed that takes into consideration unique physical conditions of the roadway. For example, Exhibit 23-5 in HCM 2000 shows reductions in free-flow speed for varying right-shoulder lateral clearance for basic freeway segments.

As the first step to derive the capacity reduction factors, a possible range of free-flow speed was set based on facility type. In the above example for freeways, free-flow speeds from 55 mph to 75 mph in an increment of 2.5 mph were used. For each combination of these preset free-flow speeds and the geometric variables, a ratio of the reduced free-flow speed to the original free-flow speed was calculated. This process resulted in a two-dimensional table (i.e., one dimension containing a range of free-flow speed and the other containing the geometric variables), which was populated with the ratios, or free-flow speed reduction factors. Under the assumption that the maximum service flow can be adjusted to the service flow with the same reduction percentage as the speed reduction factor, these free-flow speed reduction factors were used to estimate hourly service flows.

The two-dimension table can be represented in a 3-dimension space as exemplified in Figure 5. The factors in this space were then generalized by curve fitting the factors using bi-factor nonlinear regression technique. As an example, Table 2 lists curve-fitted formula for capacity reduction factors for lateral clearance. This procedure was applied to other capacity limiting factors such as adjustments for access point densities, lane widths, etc.

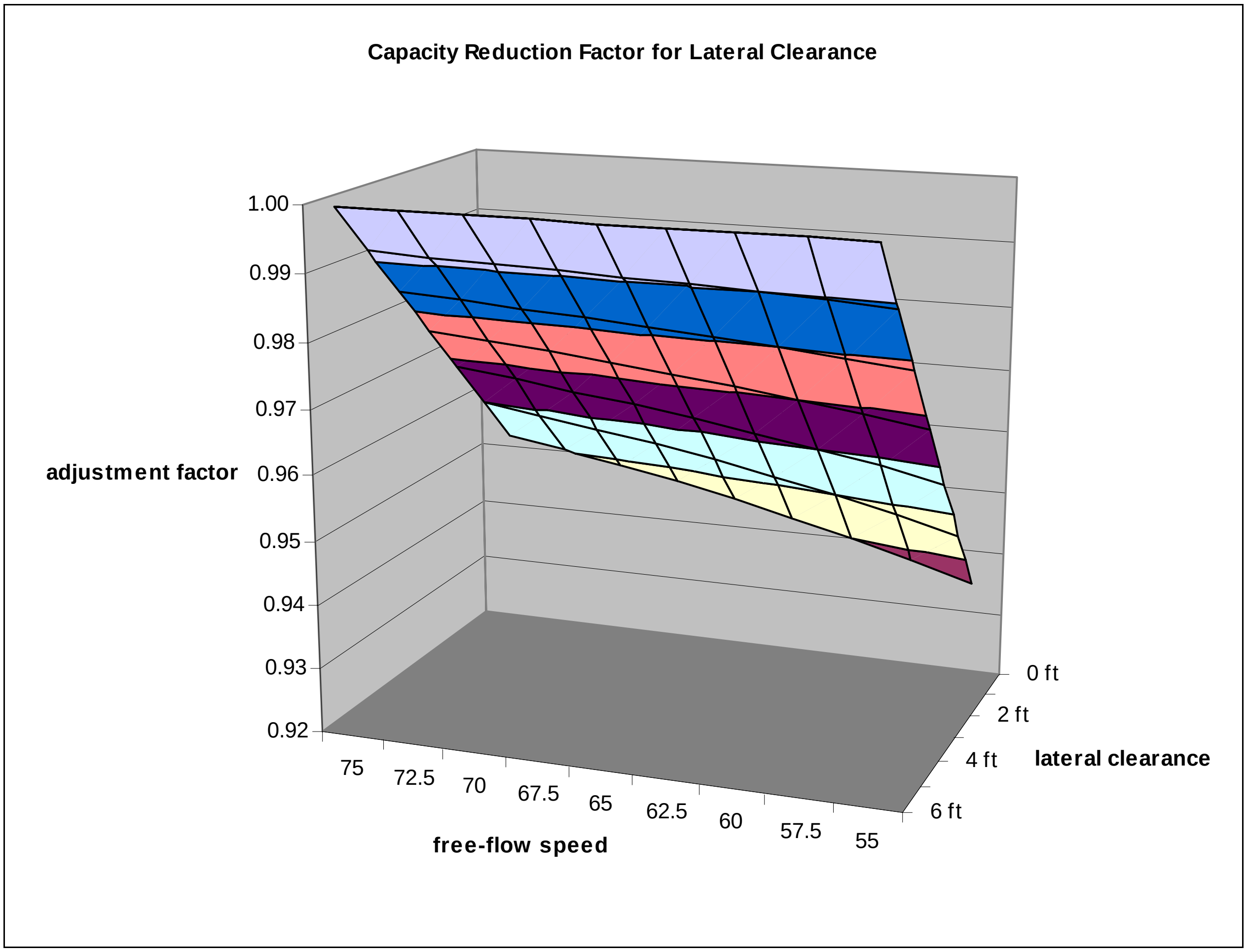


Figure 5. Capacity Reduction Factors for Lateral Clearance (Basic Freeway Segments)

Table 2. Capacity Reduction Factors for Lateral Clearance

Class	Reduction Factor [1]	Note
Interstates and Freeways		
2 lanes in one direction	$\frac{-6.00001+\text{RSLC}}{0.0001+1.66667\cdot\text{FSPD}}+1$	Min. 0.9345
3 lanes in one direction	$\frac{-5.99999+\text{RSLC}}{-0.00084+2.50001\cdot\text{FSPD}}+1$	Min. 0.9564
4 lanes in one direction	$\frac{-6.00001+\text{RSLC}}{-0.00002+5\cdot\text{FSPD}}+1$	Min. 0.9782
≥5 lanes in one direction	$\frac{-6.00002+\text{RSLC}}{0.00371+9.99994\cdot\text{FSPD}}+1$	Min. 0.9891
Multilane Highways		
4 total lanes	$\frac{1095.74797+\text{FSPD}}{1280.33942+6.53454\cdot\text{RSLC}^2}+0.03975\cdot\text{RSLC}$	Min. 0.8800
6 total lanes	$\frac{1485.4381+\text{FSPD}}{1660.34815+3.0981\cdot\text{RSLC}^2}+0.02166\cdot\text{RSLC}$	Min. 0.9133
Two-lane Highways		
Shoulder width < 2 ft	$1.20306\cdot\text{FSPD}^{(0.27207=0.08633\cdot\ln(\text{LW})}-\frac{7.09882}{\text{LW}}$	Min. 0.8400
Shoulder width < 4 ft	$1.43621\cdot\text{FSPD}^{(0.26354=0.09366\cdot\ln(\text{LW})}-\frac{8.06484}{\text{LW}}$	Min. 0.8800
Shoulder width < 6 ft	$1.58362\cdot\text{FSPD}^{(0.24881=0.09472\cdot\ln(\text{LW})}-\frac{8.34158}{\text{LW}}$	Min. 0.9125

Note: [1] RSLC: right-shoulder lateral clearance (ft), FSPD: free-flow speed (mph), LW: lane width (ft)

The Northwest Arkansas model consists of three different time-of-day models; thus, each of the time periods is analyzed with roadway capacities that are specific to the respective time period. The peak-hour capacity obtained using the nonlinear curve fitting methods was then converted to peak-period capacities by multiplying appropriate number of hours in each time period. In this model, morning and evening peak periods were defined as 3 hour spans. The remaining hours were defined as an off-peak period.

The peak-period capacity was then converted to directional capacities. Changes in directional capacities by time period were estimated according to changes in lane usage by time-of-day. The capacity for the off-peak period was obtained by applying K-factors to the directional peak-hour capacity. The K-factors were used by area type based on the recommendation in the *Florida's Level of Service Standards and Guidelines Manual for Planning, FDOT, 1995*.

VI. DELAYS ON INTERRUPTED FACILITIES

Free-flow speeds and roadway capacities estimated in the previous steps were adjusted to account for delays associated with traffic signals. The adjustment was made directionally according to the methodology described below.

Traffic signals were entered in the network as link attributes with designations of approach prioritization and multiple signals. If the approach to the signalized intersection is a higher functional class than crossroad, it was coded as “high” priority. If it is on par with the crossroad, it was assumed to have “equal” priority. If it is a lower functional class than the crossroad, it was given “low” priority. The number of multiple upstream signals were coded to account for progression effect as a result of signal coordination.

The speed and capacity adjustment for traffic signal delay followed a HCM methodology that uses the following equation:

$$d = 0.5C\left(1 - \frac{g}{C}\right)^2 \cdot PF$$

where,

d = delay per vehicle,
g = effective green time,
C = cycle length, and
PF = progression adjustment factor.

Delay estimated from the above equation was added to the free-flow speed-based link travel-time to come up with an “adjusted” free-flow travel time. Based on the fact that the mainline road is given a higher priority than the lower-class crossroad, varying green time ratios (g/C) were assumed by the priority code of the signal approach. HCM provides the progression adjustment factor as a function of the green time ratio and the arrival type. The arrival type for the signal approach was assumed based on multiple signals coded in the network. With the assumed green time ratio and the arrival type, an appropriate progression factor in HCM was sought and used to estimate signal delay of the approach.

The capacity reduction methodology was based on travel-speed reductions resulting from delays on the flow-interrupted facilities. The service flow rate is a function of the travel time along a road segment. Increasing signal densities effectively reduces travel speeds, and, in turn, reduces the amount of traffic flow that is possible. The reduction in service flow was calculated by dividing the maximum service flow approximate based on free-flow speed by the maximum service flow approximates based on speeds with traffic signal delays.

These speed and capacity adjustments due to traffic signals were made directionally. Thus, signal approach lane(s) and lane(s) in the other direction were estimated with different speed and capacity values.

VII. NORTHWEST ARKANSAS TRAVEL MODEL COMPONENTS

The Northwest Arkansas Travel Demand Model is built upon a model of the population of Northwest Arkansas. Fundamentally, it is people that make trips, and within a travel demand model, trip making and ultimately traffic volumes on roadway segments and VMT in a region are driven by the people who live and work there. All travel demand models in the U.S. are based on Census data about the population of the model area.

The way in which Census data is used in various models differs widely. In some of the oldest and simplest models, trip making and other aspects of travel demand like mode choice are based on the number of people or households in each traffic analysis zone and their aggregate or average characteristics (average automobiles owned per household, etc.). However, this very simple approach inevitably results in a variety of errors because it is not able to capture the complexities of the people and behaviors involved. Many of the behaviors involved, such as trip-making, are not linearly related the variables used to predict them. Although trip making can be represented simply by an average trip rate, for instance 0.48 home-based shop/personal business trips per person from the Northwest Arkansas Regional Transportation Survey, a household with one person will produce 0.92 trips on average while a household with four or more people will produce an average of only 1.71 such trips. There are a number of reasons for these sort of nonlinearity, but for instance, it stands to reason that just because a household had more people does not necessarily mean that it needs to make more trips to buy groceries each week; they may simply buy more groceries in a single trip.

The traditional way of dealing with these nonlinearities in travel behavior is to segment the population and use averages specific to each segment. So, for instance, based on the average number of persons per household, predict the number of one person households, two person households, etc., and apply a trip rate specific to each type of household. Typically this is done using two variables, such as number of persons per household and number of vehicles per household. This approach is called cross-classification. There are several difficulties with this approach. The most notable is that it severely limits the number of variables that can be used to explain trip making, mode choice and other aspects of travel behavior. The limitations of the traditional approach have motivated the development of alternative approaches.

The common alternative to the traditional approach which has been experimented with in research and practice is activity-based modeling. In activity-based modeling, average characteristics of the population from Census data are used to build a simulated population which has the same average attributes as the real population. Then, each simulated person or household makes choices hopefully similar to the real choices people make about what to do, where to do it and how to get there. The two main drawbacks of activity-based modeling are that they are simulation based or probabilistic models rather than deterministic models (which complicates the comparison of results for different alternatives) and that they require many more component models which in turn require more data to estimate and considerably more computer power and time to run.

The Northwest Arkansas model takes an intermediate approach. It begins by building a synthetic population of simulated households, very much like an activity based model, but then uses a more traditional, trip-based rather than activity-based framework for modeling people's travel. Using a synthetic population, however, allows even trip-based models to incorporate many more variables and capture many of the advantages, increased realism and increased sensitivity to more policy variables, offered by activity-based models without the disadvantages of the complexities of simulation modeling or long run times. For instance, the Northwest Arkansas model will respond to an increase in households with seniors (age 65+) and predict less work trips, but more shop trips, less trips by foot or bike, and more trips during the middle of the day and less during the peak hours. Traditional models do not offer this kind of sensitivity. Activity-based models offer this and more, but at much greater cost in run time and development cost. The Northwest Arkansas disaggregate deterministic approach offers this sort of additional sensitivity at no greater cost than a simpler traditional model.

A. SYNTHETIC HOUSEHOLD GENERATION

The Northwest Arkansas model is built upon a disaggregate representation or simulation of the population of the Northwest Arkansas. This synthetic population of households contains a simulated household in each TAZ for each real household in that TAZ and the average characteristics of the simulated households are the same as the average characteristics of the real households. For instance, in the base model, TAZ number 60560 has 1,667 households with an average household size of 3.15 persons and an average 1.77 vehicles per household. In household generation, the model will create 1,667 simulated households which have these averages. However, there may not be exactly the same number of three person households in the model as in the real population.

The generation of the synthetic households is a heuristic process. The process guarantees the reproduction of the aggregate zonal attributes and does not allow illogical/impossible households (e.g., a household with three workers and two people); however, it is partially a simulation and stochastic or probabilistic in nature. Therefore, if household generation is run twice for the same TAZ layer, the simulated population may be slightly different. There will be the same number of households in each zone with the same average characteristics (and in fact, there will be same number of three person households and of two vehicle households) but there may be not be exactly the same households (there may not be exactly the same number of three person households with two vehicles).

The results of these differences in household generation (for the same TAZ layer) should be very small on the overall results of the model. However, when it is most important to be able to compare the results of the model – for instance, when testing alternative alignment concepts for a possible new bypass – all stochasticity or randomness can be eliminated by using the same synthetic population, ensuring the alternative model runs are perfectly comparable and there are no hidden biases due to random differences.

The household attributes and possible simulated values they can take are shown in Table 3. The model predicts the number of persons, workers, children (under 18), and vehicles in each household as well as to which income group (quintile) the household belongs and whether there are any seniors (age 65+) in the household.

Table 3. Household Attributes and Categories

Attribute:	Number of Persons	Number of Workers	Number of Children	Seniors Present?	Income Group	Number of Vehicles
Categories:	1 2 3 4 5 6	0 1 2 3 4	0 1 2 3 4	0 (No) 1 (Yes)	1 (under $20k) 2 ($20k-$40k) 3 ($40k-$60k) 4 ($60k-100k) 5 (over $100k)	0 1 2 3 4

The household generation model begins by predicting for each zone the number of households of each level of each attribute (the number of one person households, two person households, etc., the number of zero worker households, the number of one worker households, etc.). This process is deterministic, beginning with an initial estimate based on stratification curves and then doing some simple "one-opt" swapping to ensure that the average is reproduced. When this is complete, the model has generated the total households of in each of the 28 single attribute categories. The model then creates simulated households one at a time. First it chooses the number of persons, then workers, children, whether there are seniors, the income group, and finally the number of vehicles. Each time it makes a choice (chooses that there are two workers, for instance) it decreases the number of households of that category remaining to be created for the zone. The probability of each choice depends on the attributes already chosen for that household and on the remaining number of households of the various levels of the attribute being chosen. Each part of this process is explained in more detail in the following sections.

1. <u>Generation of the Categorical Totals for Each Attribute</u>

This first step predicts, for each zone, the total number of households of each category of each attribute. The process is heuristic, but wholly deterministic. It has two steps, beginning with initial estimates of the number of households in the major categories on stratification curves developed from CTTP and *Northwest Arkansas Regional Transportation Survey* data. It then shifts one household at a time from one category to the next until the overall average of the households matches the average value for the zone.

a. Initial Estimation by Stratification Curves

Stratification curves were developed for five zonal attributes: household size, workers per household, vehicles per household, children under 18 years per household, and household income. (There is no need to create a curve for senior status since the attribute has only two categories.)

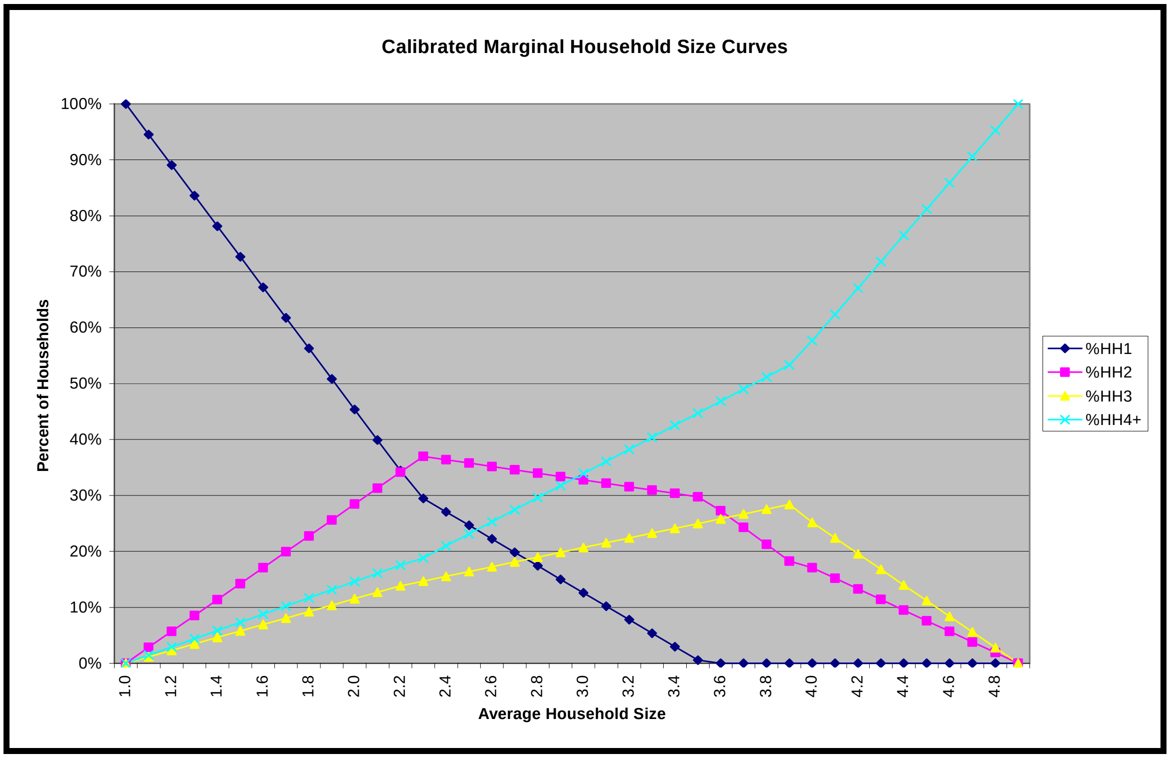
The data for these attributes and categories was extracted from the Census for Transportation Planning Package (CTPP) data. The CTPP data is available for each census zone. Therefore, the Northwest Arkansas model data was aggregated from the model TAZs to the census zone structure to determine census zone attribute averages. The CTPP data was used to determine the marginal distribution (in percentage of households) of each zone around the regional average. (Put more simply, the model's zonal data is more accurate for each TAZ, but only available as an average. The CTPP data, however, is divided into the categories necessary for developing the stratification curves.)

The zonal average was plotted against percentage of households by category. Mathematical relationships were then estimated for each category using the trend line analysis available in Microsoft Excel. The trend line analysis presents an equation for each size category that relates the attribute average to the percentage of households in that size category.

The trend lines were then evaluated using the R-Squared method of statistical relevancy to determine the three "best fit" equations. The category with the worst fit was calculated as a residual instead of using the trend line equation. That is, the category with the worst fit curve was calculated by subtracting the percent households from all the other categories from 100 percent.

Trend lines were calculated assuming linear, quadratic, and cubic equations. In each case, the cubic equation relationship provided the best fit. However, many of the cubic equations were nearly linear in nature or did a poor job of accurately predicting values on the margins of the value range. For these reasons, the more simple linear relationships were generally used to develop the stratification curves.

The trend line analysis equations for each category of each attribute are presented in tables below together with graphs of the resulting curves (using the residuals). The dependent variable (appearing as x in the equations) is the zonal average for the attribute (zonal avg. persons per household, zonal avg. workers per household, etc.) except for income. The dependent variable for income is a unit-less index corresponding to the ratio of the zonal average income to the regional average income. An index value of 1.0, therefore, shows a zone with an average income equal to the regional average and a zonal income index of 2.0 shows a zonal average income that is twice the regional average. This way the model is not improperly biased by inflation.

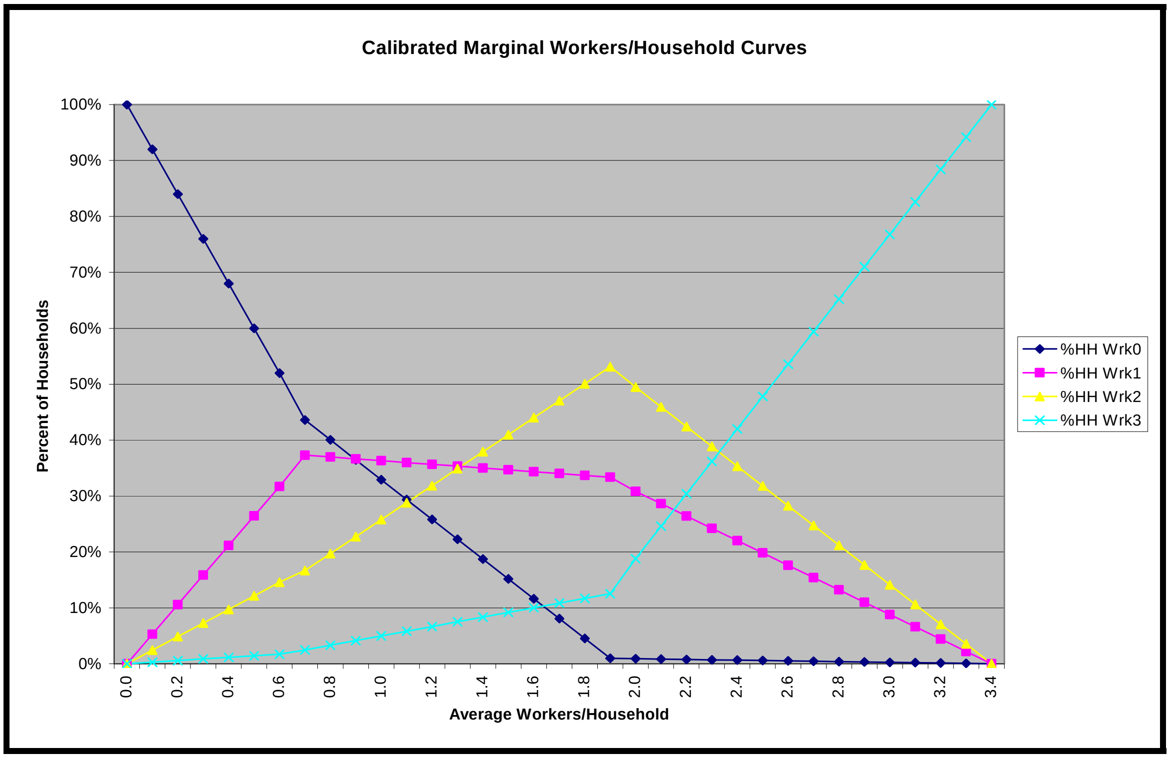


Size Category	Linear Equation	R-Squared*	Residual Equation
1 Person/HH	%HH1 = -0.2411x + 0.8493	0.4184	
2 People/HH	%HH2 = -0.0602x + 0.5087	0.0287	%HH2 = 1 - %HH1 - %HH3 - %HH4
3 People/HH	%HH3 = 0.0857x - 0.0502	0.1053	
4+ People/HH	%HH4 = 0.2157x - 0.3078	0.3748	

* The closer the R-squared value is to 1.0, the better the fit of the curve.

Figure 6. Marginal Household Size and Equation

The number of households by household size was extracted from Table 62 of Part 1 of the CTPP data corresponding to Benton and Washington Counties. The CTPP data divided the household size into 1 person, 2 people, 3 people, 4 people, and 5 or more people. The data for 4 person households and 5 or more households were combined to create the category of 4 or more people.



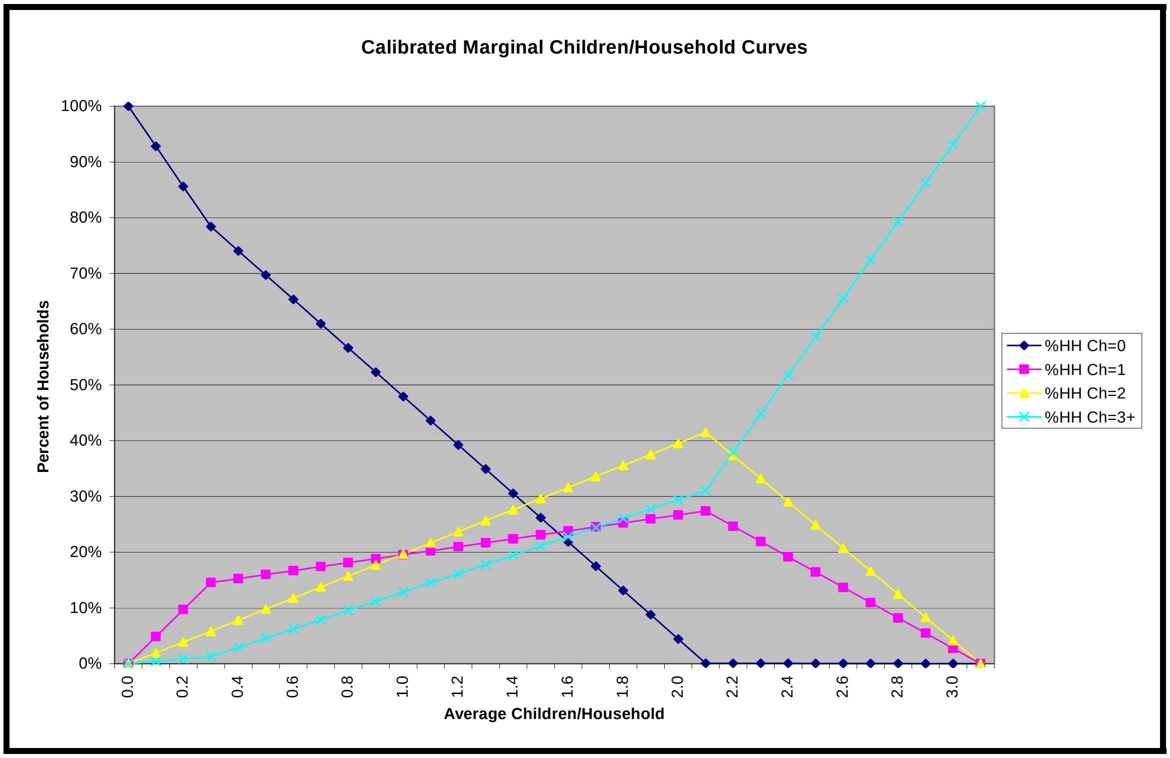
Size Category	Linear Equation	R-Squared*	Residual Equation
0 Workers/HH	%HH Wrk0 = -0.3551x + 0.6844	0.3214	%HH Wrk1 = 1 - %HH Wrk0 - %HH Wrk2 - %HH Wrk3+
1 Worker/HH	%HH Wrk1 = -0.0328x + 0.396	0.0030	
2 Workers/HH	%HH Wrk2 = 0.3039x - 0.0462	0.2050	
3+ Workers/HH	%HH Wrk3+ = 0.084x - 0.0342	0.0643	

* The closer the R-squared value is to 1.0, the better the fit of the curve.

Figure 7. Average Worker/household and Equation

The number of workers per household was extracted from Table 62 of Part 1 of the CTPP data corresponding to Benton and Washington Counties. The CTPP data divided the workers per household into 0 workers, 1 worker, 2 workers, 3 workers, and 4 or more workers. The data for 3 workers per household and 4 or more workers per household was combined to create the category of 3 or more workers per household.

The number of children per household was derived from information gathered from the *Northwest Arkansas Regional Transportation Survey* conducted by MORPACE International in the fall of 2004. Respondents for the survey were limited to household residents of Benton and Washington Counties. Results of the survey included the number of children (aged 18 years and younger) in each household. From this data, the households were divided into four categories: 0 children, 1 child, 2 children, and 3 or more children.



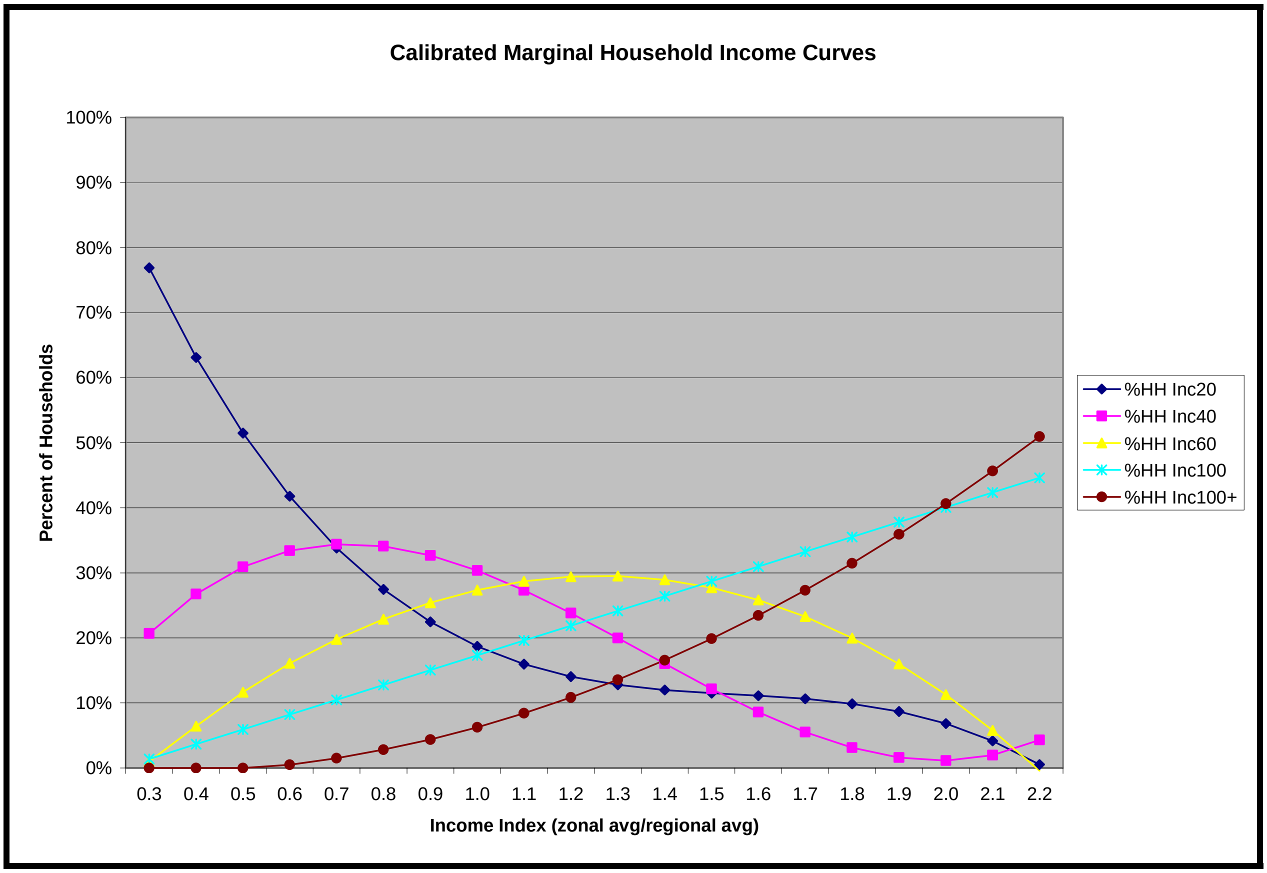
Size Category	Linear Equation	R-Squared*	Residual Equation
0 Children/HH	%HH Ch0 = -0.4351x + 0.9145	0.7384	%HH Ch1 = 1 - %HH Ch0 - %HH Ch2 - %HH Ch3+
1 Child/HH	%HH Ch1 = 0.0713x + 0.1241	0.0305	
2 Children/HH	%HH Ch2 = 0.1983x - 0.0014	0.3154	
3+ Children/HH	%HH Ch3+ = 0.1655x - 0.0372	0.4402	

* The closer the R-squared value is to 1.0, the better the fit of the curve.

Figure 8. Average Children/Household and Equation

Because the number of surveyed households could not equal the amount of households included in the CTPP data set, the household size distribution reported from the survey will not match that of the CTPP. Some household sizes will be under reported and some will be over reported. To correct for this phenomenon, each household in the survey was assigned a "weight." The weights can be applied to each household so that the survey distribution will match that of the population.

Each surveyed household was located in the CTPP TAZ structure using latitude and longitude coordinates of the household, provided in the survey data. The latitude and longitude coordinates were derived from the reported addresses. Any households that could not be located by latitude and longitude (due to an ambiguous address, for instance) or were located outside the study area were omitted from the stratification analysis. The total weighted households were then summed for each TAZ (along with the children per household size categories) and an average number of children per household calculated for each TAZ.

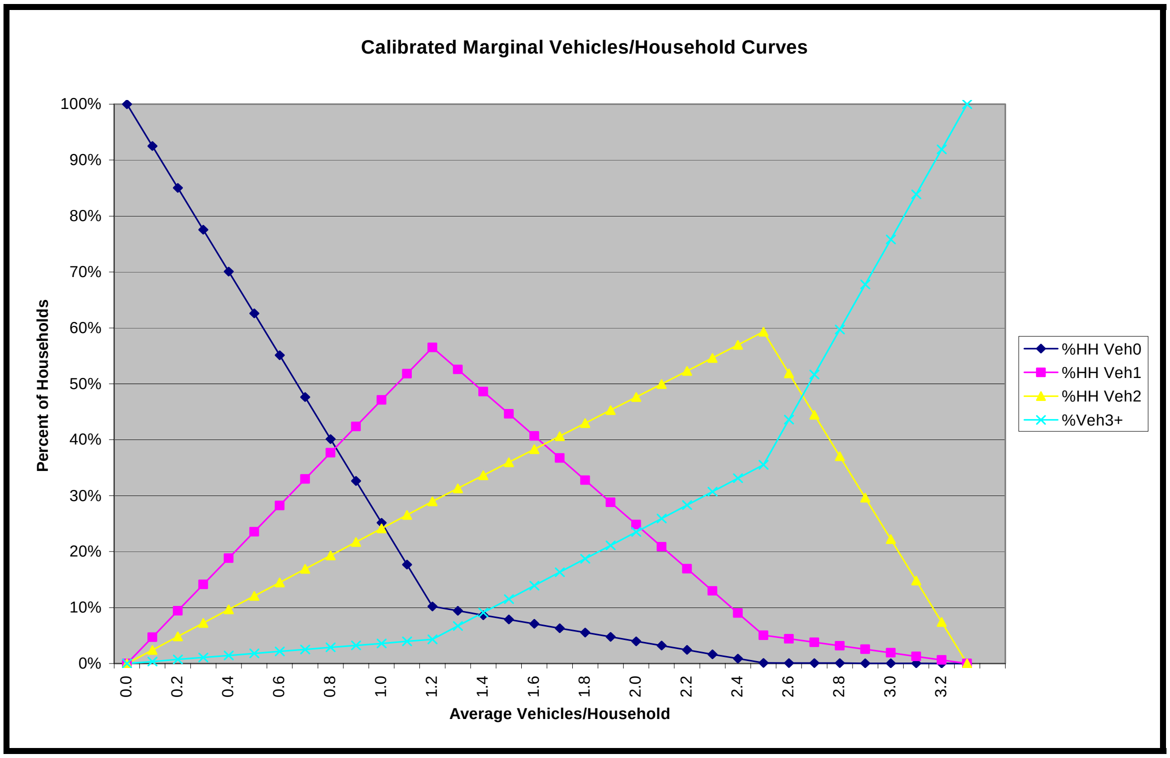


Income Category	Linear Equation		R-Squared*	Residual Equation
< $20,000	%HH Inc20 =	-0.3233x3 + 1.5082x2 - 2.3863x + 1.3983	0.7135	
$20,000 - $40,000	%HH Inc40 =	0.3399x3 - 1.3418x2 + 1.4235x - 0.1082	0.3176	
$40,000 - $60,000	%HH Inc60 =	-0.2507x2 + 0.6192x - 0.1226	0.1663	%HH Inc60 = 1 - %HH Inc20 - %HH Inc40 - %HH Inc60+
$60,000 - $100,000	%HH Inc100 =	0.2275x - 0.0543	0.4448	
$100,000 +	%HH Inc100+ =	0.143x2 - 0.0851x + 0.0047	0.7891	

* The closer the R-squared value is to 1.0, the better the fit of the curve.

Figure 9. Income Index and Equation

The household income was extracted from Table 64 of Part 1 of the CTPP data corresponding to Benton and Washington Counties. The CTPP data divided the household income into numerous categories, which were combined to create the ranges used for this analysis: less than $20,000/year, $20,000-$40,000/year, $40,000-$60,000/yr, $60,000-$100,000/yr, and greater than $100,000/year.



Size Category	Linear Equation	R-Squared*	Residual Equation
0 Vehicles/HH	%HH Veh0 = -0.0776x + 0.1952	0.1166	%HH Veh0 = 1 - %HH Veh1 - %HH Veh2 - %HH Veh3+
1 Vehicle/HH	%HH Veh1 = -0.3959x + 1.0403	0.5388	
2 Vehicles/HH	%HH Veh2 = 0.2334x + 0.0096	0.1876	
3+ Vehicles/HH	%HH Veh3+ = 0.2402x - 0.2451	0.3037	

* The closer the R-squared value is to 1.0, the better the fit of the curve.

Figure 10. Average Vehicle/Household and Equation

The number of vehicles per household was extracted from Table 63 of Part 1 of the CTPP data corresponding to Benton and Washington Counties. The CTPP data divided the vehicles per household into 0 vehicles, 1 vehicle, 2 vehicles, 3 vehicles, and 4 or more vehicles. The data for 3 vehicles per household and 4 or more vehicles per household was combined to create the category of 3 or more vehicles per household.

b. Secondary "1-opt" Swapping to Preserve Zonal Averages

Although the stratification curves provide a good initial estimate of the number of households in each attribute category, the resulting averages will not necessarily agree exactly with the input value from the zone, particularly if the last category is always considered as having its minimum value (4+ person households as having 4 people, 3+ vehicle households as having 3 vehicles, etc.). Therefore, in order to guarantee that the averages are reproduced in the synthetic population, or from another perspective, that total persons, vehicles, etc., are not created or lost, a simple heuristic is employed. The technique, commonly known generally as "1-opt" swapping in optimization science, simply moves one household at a time from one category to the next until the average of the synthetic households agrees with the zonal average. This also results in a more realistic synthetic population by allowing the creation of larger households (with more than four persons or more than three vehicles or children). Because the swapping is a simple, deterministic, rule-based procedure, the combined application of the stratification curves and the "1-opt" technique will always produce the same number of households in each category every time it is applied to the same TAZ layer data.

The only cases in which the attributes of the synthetic population may differ from the zonal attributes are if there is a basically illogical combination of attributes – such as more workers (or children) per household than persons per household for a given zone. This can actually happen, and does for two zones in the base model, when there are workers (or children) among the group quarters (institutionalized) population. In these rare cases, the children or workers in group quarters do not appear in the synthetic household population and do not generate trips.

2. <u>Selection of Combinations of Attributes for Individual Simulated Households</u>

After the total number of households of each attribute category have been determined for a zone by the stratification curves and swapping, the household generation model creates the simulated households for that zone one at a time. For each household, Monte Carlo simulation is used for each attribute to choose to which category the household will belong. The model first chooses the number of persons, then workers, children, whether there are seniors, the income group, and finally the number of vehicles. Each time it makes a choice (chooses that there are two workers, for instance) it decreases the number of households of that category remaining to be created for the zone. The probability of each choice depends on the attributes already chosen for that household and on the remaining number of households of the various levels of the attribute being chosen. Once the total number of households of a particular category have been created for a zone, the probability of remaining households in that zone belonging to that category is set to zero. The probabilities of a household belonging to a category for one attribute depend on the previously chosen attributes in two different ways. Rules are used to prevent impossible/illogical combinations of attributes, and probabilistic models are used capture the correlations between attributes such as workers and income or income and vehicle ownership.

a. A Priori Rules for the Combinations of Household Attributes

In a simulation framework based solely on probabilities, even highly improbable combinations could occur. Rules are therefore also introduced to set probabilities absolutely to zero to prevent illogical combinations of attributes. The following two rules are applied in the generation of households.

- The number of workers must be less than or equal to the number of persons.
- The number of children must be less than or equal to the number of persons minus one. (In other words, there must be at least one adult in every household.)

Other unlikely combinations of household attributes are generally not strictly impossible, but simply improbable.

b. Models of the Conditional Probabilities

Synthetic households are created by number of persons, i.e., first all of the single person households are created for a zone, followed by the two person households, and so forth. This process is deterministic. However, for choice of the remaining household attributes is probabilistic (except where the a priori rules apply). The probability of a household belonging to an attribute category is conditioned both on the (remaining) share of households belonging to that attribute category in that zone and on certain other previously chosen attributes for that household.

Workers

The probability of a household having a particular number of workers depends on both the number of persons in the household (as a function of the relevant rule) and on the percentage of households with that number of worker in that zone. The initial probability of membership in each category of workers is set to the percentage of households with that number of worker in that zone. The probabilities of any categories which violate the rule preventing more workers than people or of any category for which all the households have already been created are set to zero. The probabilities are then re-normalized so that they sum to one.

Children

The probability of a household having a particular number of children is basically computed in the same fashion as the probability of workers, except for the difference in their a priori rules and that the probability of any categories which result in children working (children plus workers greater than persons) is factored down by 98% based on the relative infrequency with which working children were observed in the household survey.

Seniors

The probability of a household having seniors (age 65+) depends on the number of persons, workers and children. The (un-normalized) probability is a simple piecewise function of the percentage of households with seniors, segmented on the number of non-worker, non-children (defined as Max[persons – workers – children,0]). The parameters of this function are presented in the table below.

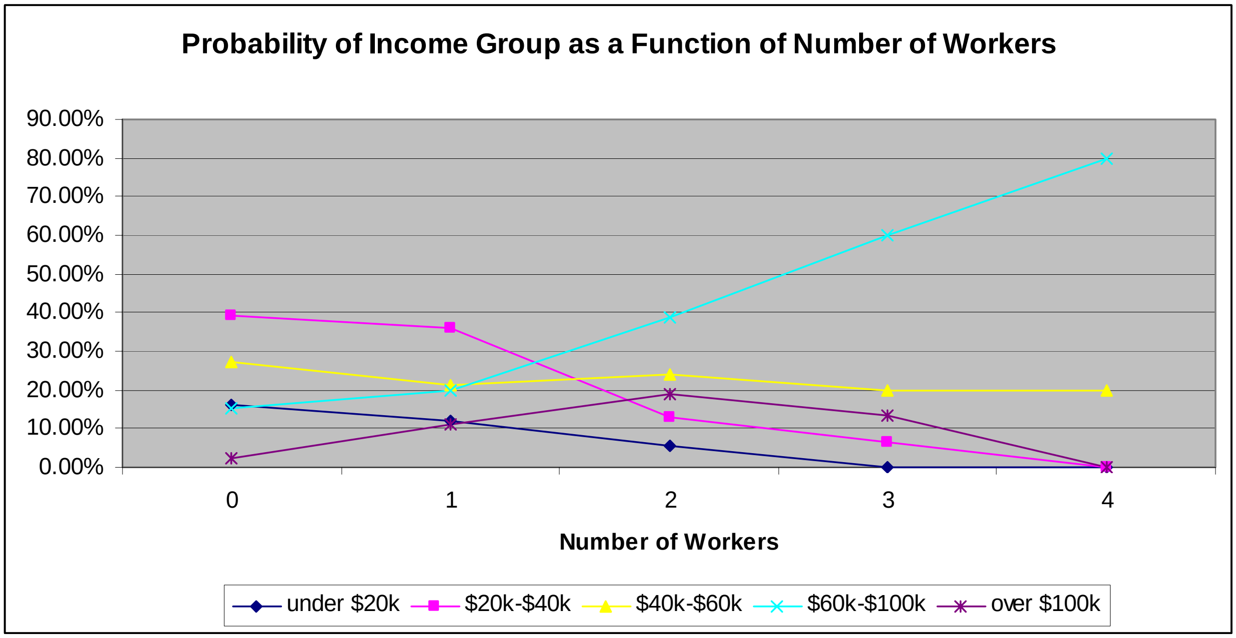
Table 4. Probability of Senior in Households

Un-normalized Conditional Probability of Seniors in the Household	
Zero non-worker, non-children	0.2193*Percentage of Households w/ Seniors
One non-worker, non-children	1.1592* Percentage of Households w/ Seniors
Two or more non-worker, non-children	2.6263* Percentage of Households w/ Seniors

These probabilities are overridden when the total number of senior households or non-senior households in a zone is reached. From that point on, all remaining households must belong to the other category.

Income Group

The probability of a household belonging to a particular income group depends on the number of workers in the household. The initial probabilities are shown in the table and graph below. If all of the households of a particular income group have already been created for that zone, the probability of that group is set to zero and the probabilities are re-normalized.



		Workers				
		0	1	2	3	4
Income	1	0.1631	0.1203	0.0539	0.0000	0.0000
	2	0.3913	0.3609	0.1275	0.0667	0.0000
	3	0.2717	0.2105	0.2402	0.2000	0.2000
	4	0.1522	0.1993	0.3872	0.6000	0.8000
	5	0.0217	0.1090	0.1912	0.1333	0.0000

Figure 11. Probability of Income Group

Vehicles

The number of vehicles owned by the household is chosen last because the probability of a household owning a particular number of vehicles depends on the household's income group as well as the number of persons in the household. The initial probabilities for one, two and three plus vehicles are given by regression equations displayed in the table below and were developed from the household survey. The probability of zero vehicles is then the residual. The 3-D graphs which follow show the probabilities for each category of vehicle ownership. The probability of three plus vehicles is divided into the probability of three vehicles and the probability of four vehicles proportional to the number of remaining households in each category. As in the case of income, all of the households of a particular vehicle ownership group have already been created for that zone, the probability of that group is set to zero and the probabilities are re-normalized.

Table 5. Probability Equation Parameters

	Constant	Number of Persons	Persons Squared	Income Group	R-Squared	
0 VEH	0.1941	-0.0211		-0.0314	0.058	Residual: 1-1VEH-2VEH-3+VEH
1 VEH	0.9079	-0.0747		-0.1339	0.202	
2 VEH	-0.2800	0.2713	-0.0447	0.1052	0.111	
3+ VEH	-0.1496	0.0686		0.0515	0.115	

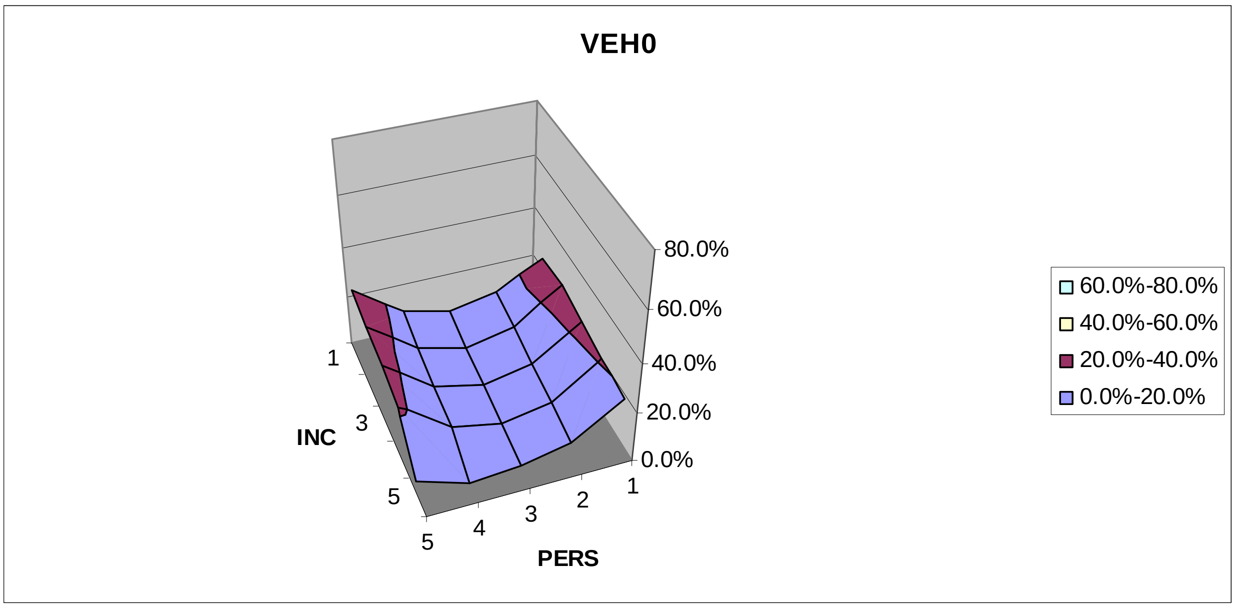


Figure 12. Probability of a Household without Vehicle

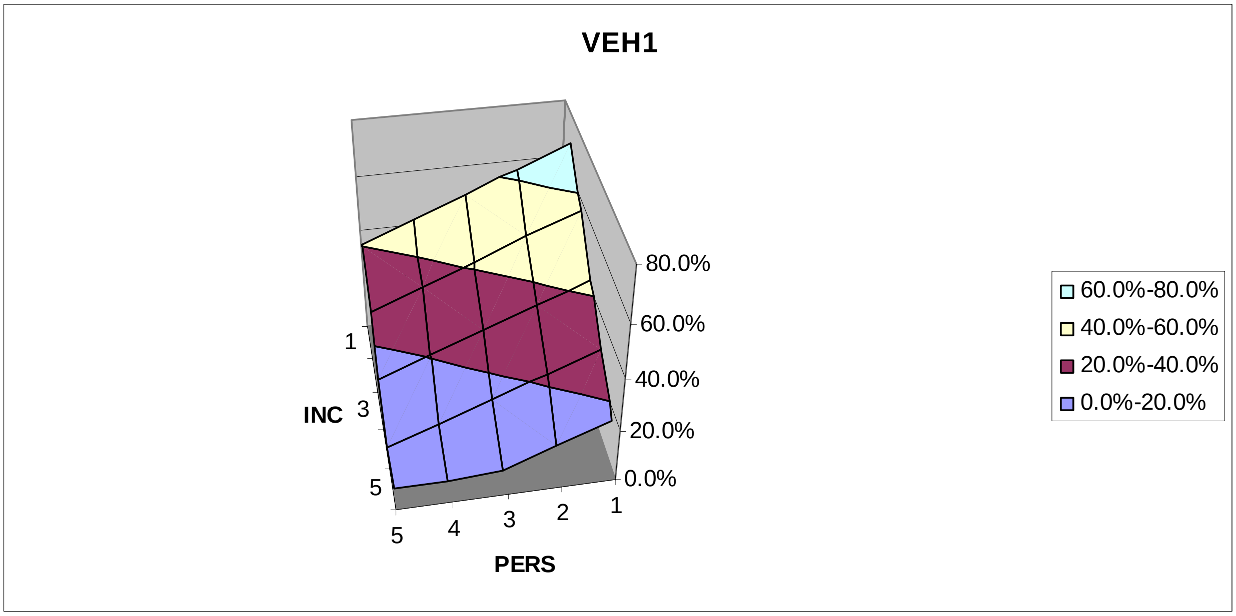


Figure 13. Probability of a Household without One Vehicle

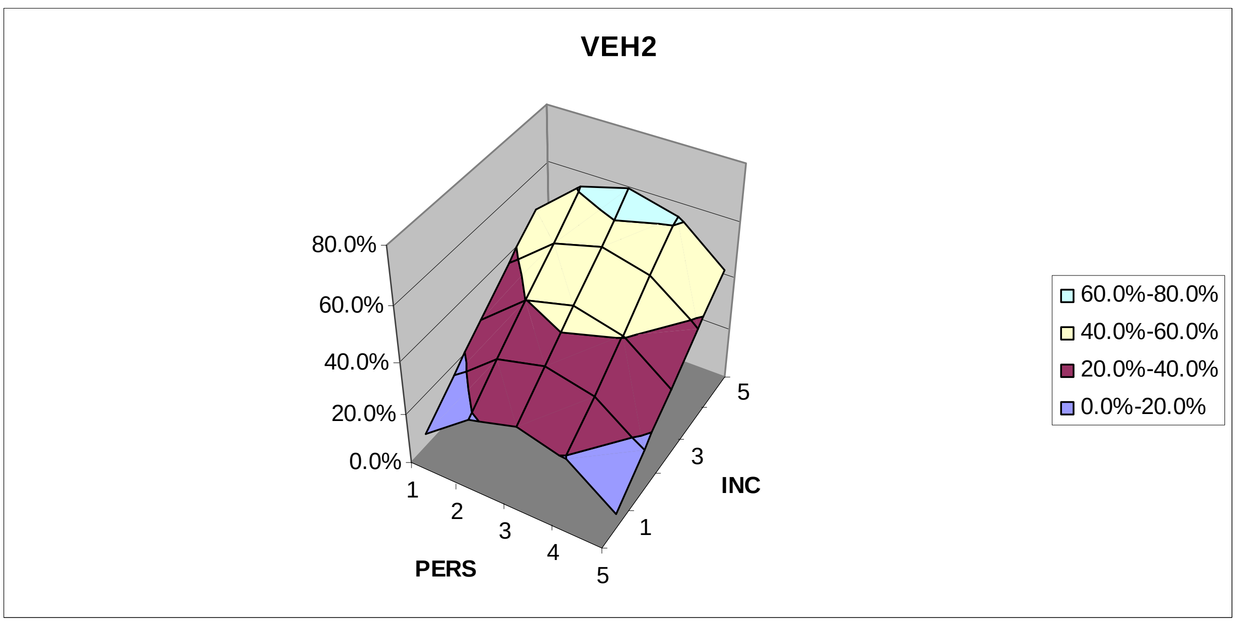


Figure 14. Probability of a Household without Two Vehicles

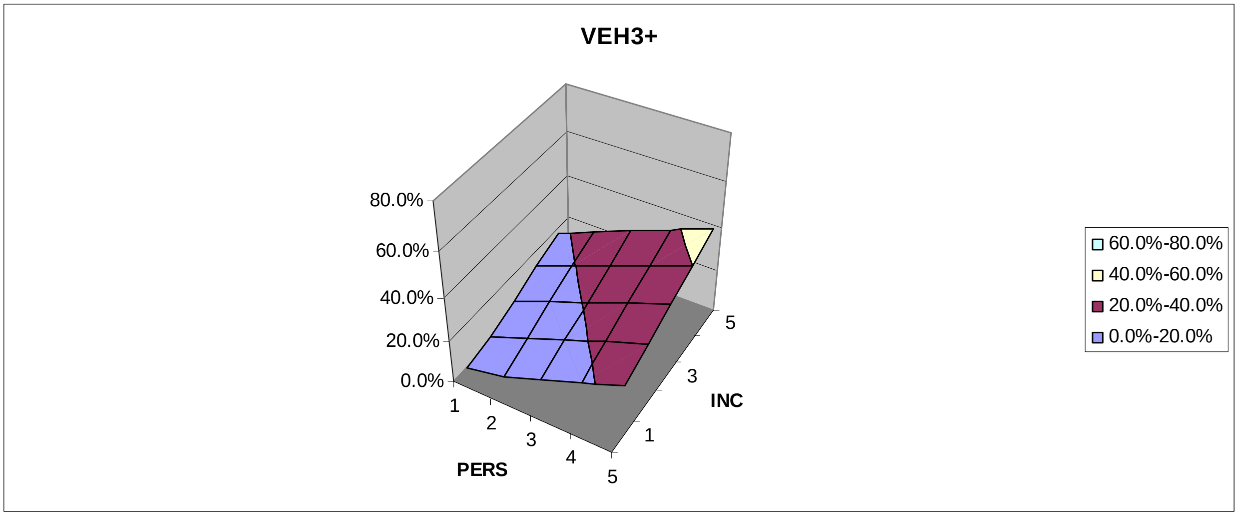


Figure 15. Probability of a Household without Three or More Vehicles

c. Monte Carlo Simulation

Once the conditional probabilities have been computed (and the rules applied), the choice of a household's membership in a particular category of an attribute is made using the process of Monte Carlo simulation. Monte Carlo simulation is both simple to apply and widely used for probabilistic modeling in many disciplines. First, the (conditional) probabilities for the categories of an attribute are expressed as cumulative probabilities. For instance, if the worker probabilities for a certain household with two people are 20% probability of zero workers, 50% probability of one worker, 30% probability of two workers and zero probability of three or four workers, then the cumulative probability of zero workers is 0.20, of one worker is 0.80 and of two workers is 1.00. A (pseudo-)random number between zero and one is then drawn by the computer. The household then belongs to the first category with cumulative probability greater than the draw. If the draw, in the given example were 0.235 it would be a one worker household, or if the draw were 0.989 it would be a two person household, etc.

B. ACCESSIBILITY VARIABLES

Accessibility variables influence a variety of travel behavior. A person who lives near many stores is likely to make more shopping trips than a person who lives in the countryside far from stores. A person is more likely to go a bank which is conveniently located near a commercial strip which may have other destinations they wish to visit than a bank with few other potential destinations nearby. Both of these effects can contribute to types of induced demand when improvements are made to the network. Traditional travel demand models generally ignore these effects, but it has become increasingly common to include accessibility variables in activity-based models as a way of linking the various choices involved in trip-making. However, there is nothing about accessibility variables which requires an activity-based framework.

The Northwest Arkansas model incorporates accessibility variables in both its trip generation and destination choice models. Based on the *Northwest Arkansas Regional Transportation Survey* data, it was possible to demonstrate that accessibility variables had a statistically significant effect on the number of home-based shop/personal business and home-based other trips and the destination choice probabilities of all trip purposes except home-based work and home-based school. The most appropriate accessibility variables were therefore incorporated into the relevant trip generation and destination choice models.

Three accessibility variables were ultimately used. Accessibilities were calculated to total employment, to retail employment and to non-basic employment. Accessibilities to enrollment and to general population were also tested, and while statistically significant, were highly collinear with the employment accessibilities and offered no additional explanatory power and were therefore ultimately not used in the model.

There are several mathematical forms for accessibility variables. The accessibility variables used in the Northwest Arkansas model are of the logit logsum form. This mathematical form has justification based on utility theory and arguably allows an interpretation of the destination choice models as nested destination choices, as a simplified way of modeling certain aspects of trip chaining behavior. The general formula for the accessibility variables is given below:

$$Accessibility(x) = \ln\left(\sum_{z \in zones} Emp_z e^{-c(time_{xz})}\right) \quad \forall x \in zones$$

where c = 0.11 for total employment or 0.20 for retail or non-basic employment and $time_{xz}$ is the shortest path time from zone x to zone z.

Maps of the accessibility variables based on the base year network and employment data are shown below. Accessibilities for future scenarios will differ based on differences in employment and the network.

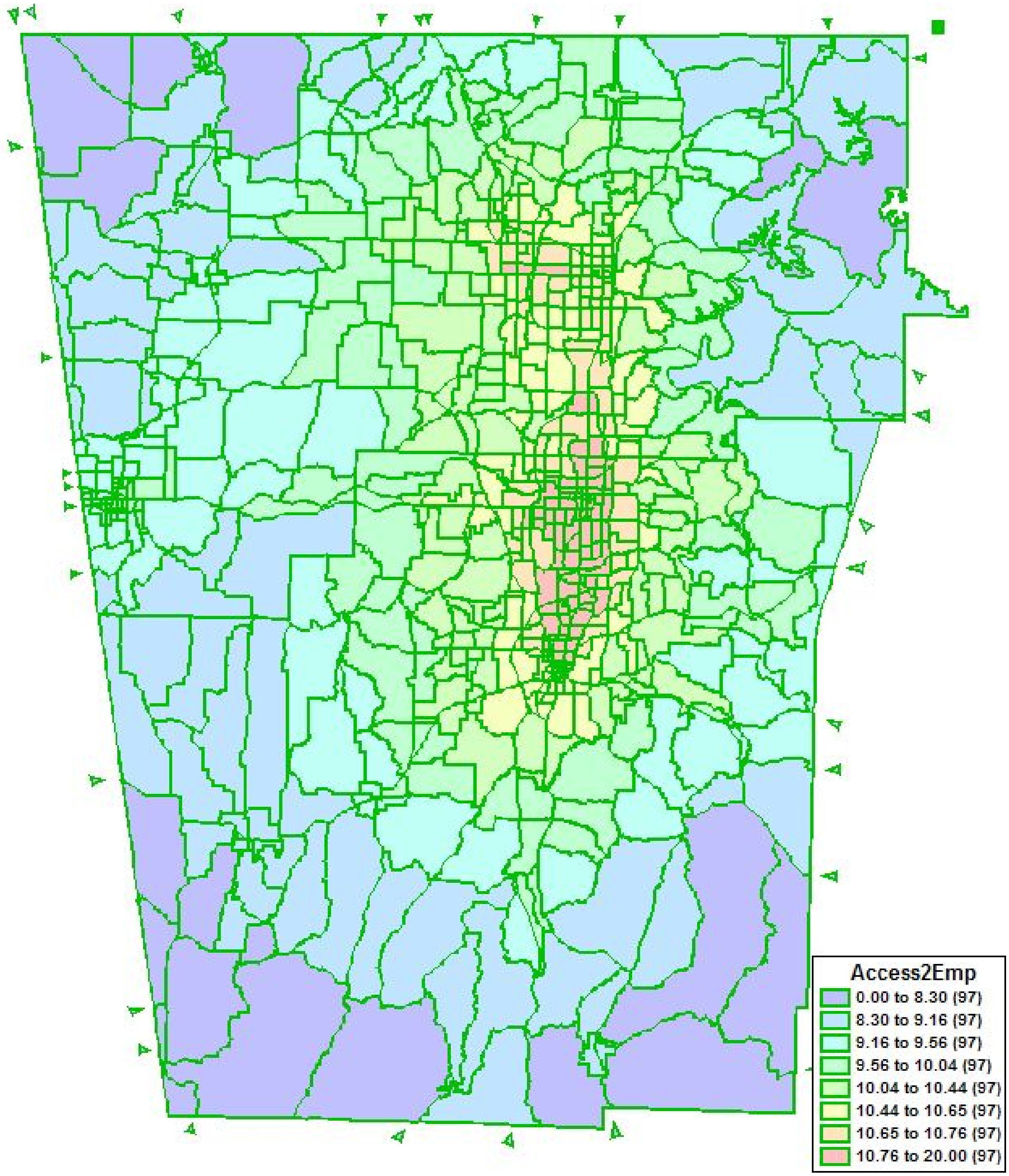


Figure 16. Accessibility to Employment Locations

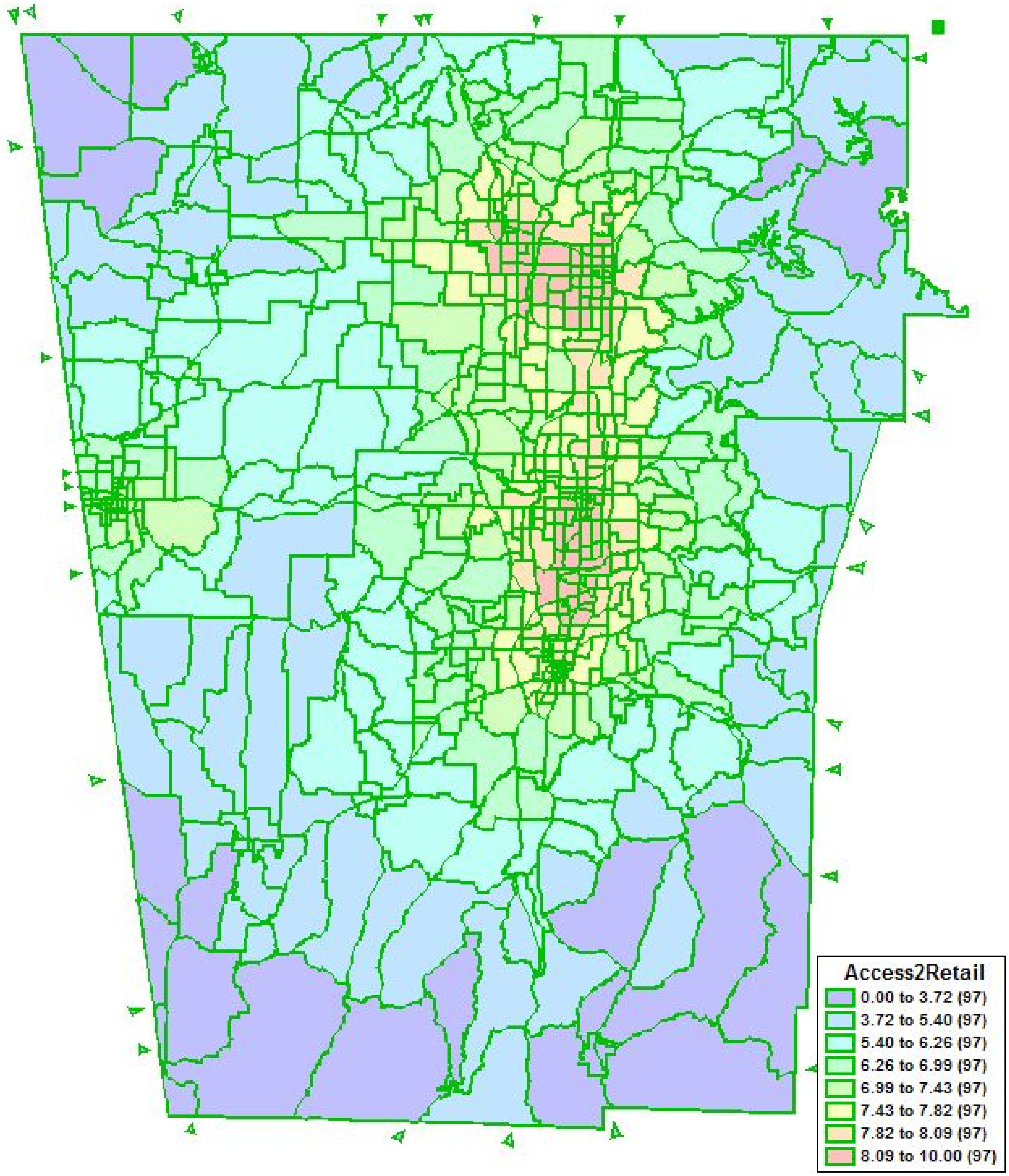


Figure 17. Accessibility to Retail Locations

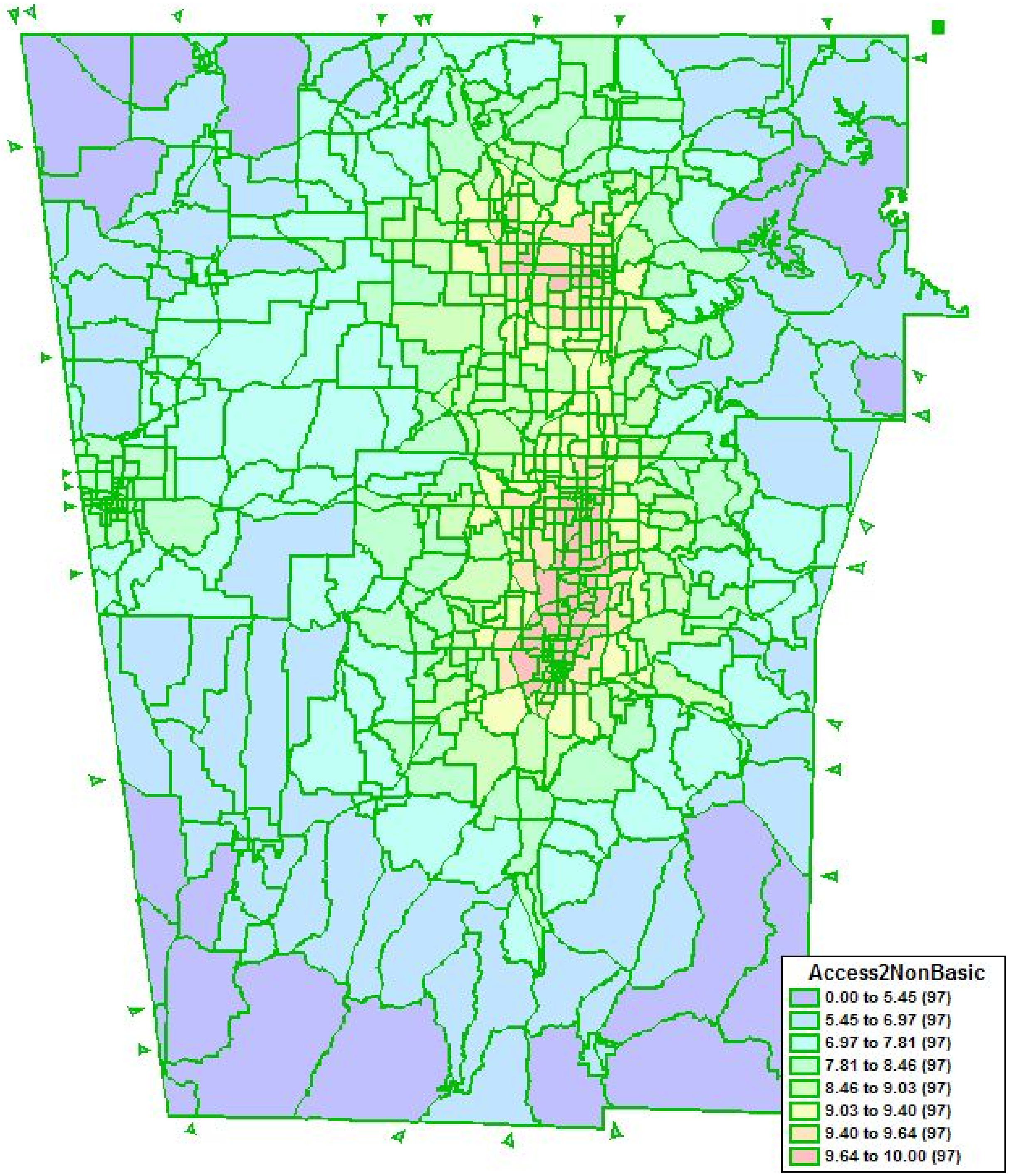


Figure 18. Accessibility to Non-Basic Employment Locations

C. TRIP GENERATION MODEL

The trip generation component of the Northwest Arkansas model consists of trip production models for several trip purposes. The models were estimated using multiple regression techniques based on the *Northwest Arkansas Regional Transportation Survey* conducted by MORPACE International in the fall of 2004.

1. Trip Production Model

From the standpoint of trip generation, the vast majority of trips are generated by households within the study area. The Northwest Arkansas Regional Transportation Survey was used to develop regression models of daily number of household trips (broken down by trip purpose) based on various characteristics of the household and its accessibility to employment of various types. This study provided both place information and activity-type information at all origins and destinations, as survey respondents had reported in their travel diaries and telephone retrievals. For the purposes of the travel model, the following seven trip purposes were identified from the survey data:

- Home-Based Work (HBW)
- Home-Based School (HBSC)
- Home-Based University (HBU)
- Home-Based Shop/Personal Business (HBSB)
- Home-Based Other (HBO)
- Non-Home-Based Work (NHBW)
- Non-Home-Based Other (NHBO)

The average trip rates for each purpose observed in the survey are reported in the table below.

Table 6. Average Survey Trip Rates

Trip Purpose	Abbreviation	Survey Average
Home-Based Work	HBW	1.47
Home-Based University	HBU	***
Home-Based School	HBSC	0.50
Home-Based Shop/Pers. Business	HBSB	1.39
Home-Based Other	HBO	2.07
Non-Home-Based Other	NHBO	3.24
Non-Home-Based Work	NHBW	1.21
Total Household Trips		9.88

*** HBU trips modeled not modeled based on NART Survey

Regression Models

It is common to use cross-classified trip rates to model trip productions rather than regression models. The advantages of cross-classified trip rates is that they allow non-linearity in trip-making relative to the explanatory variables and decrease aggregation bias. However, since trip generation in the Northwest

Arkansas model is based on a synthetic population, all aggregation bias has already been eliminated. Using log transformations and interactions of the predictor variables also allows regression models to allow for the most common sorts of non-linearity in trip making related to satiation effects/decreasing returns to scale and interaction effects while preventing illogical non-linearity. Moreover, the cross-classification approach is generally limited to two, or at the extreme, three explanatory variables per trip purpose, while regression models, on the other hand, can accommodate any number of variables. Both cross-classification and regression models were estimated based on the *Northwest Arkansas Regional Transportation Survey*, but in almost every case, the regression models offered at least some increased statistical goodness-of-fit due the incorporation of additional variables. In some cases, the cross-classified models could not even statistically reject simplified regression models with no additional variables despite their much greater degrees of freedom. The regression models were therefore adopted for the Northwest Arkansas model, except perhaps in the case of the home-based school purpose, which could be considered a hybrid cross-classification/regression model.

Table 7. HBW Trip Equation

R-squared = 0.68*	parameters and variables	sig.
Number of HBW trips =	1.5013*Ln(Workers+1)	.00
+	0.3497*Ln(Vehicles+1)	.01
-	0.6216*(Vehicles-Workers)	.01
+	0.3580*Ln(Workers+1)*Ln(Income+1)	.08
-	0.2779*Ln(Children+1)	.01
-	0.2279*SeniorHousehold	.06

*R-squared values of models without constants cannot be compared to R-squared values of models with constants.

Table 8. HBSC Trip Equation

R-squared = 0.51*	parameters and variables	sig.
Number of HBSC trips =	0.5750*(Children = 1)	.00
+	0.9721*(Children = 2)	.00
+	1.8644*(Children = 3)	.00
+	2.4172*(Children = 4)	.00
+	0.0723*Persons*Ln(Vehicles+1) *(Children<>0)	.05

Table 9. HBSB Trip Equation

R-squared = 0.08	parameters and variables	sig.
Number of HBSB trips =	0.8123*Ln(Persons+1)	.00
+	0.3366*Ln(Vehicles+1)	.09
+	0.2797*NonWorkerNonChildren	.01
+	0.4578*SeniorHousehold	.02
+	0.1709*AccessibilitytoRetail	.00
-	1.4179	.00

Table 10. HBO Trip Equation

R-squared = 0.29	parameters and variables	sig.
Number of HBO trips =	0.2869*NonWorkerNonChildren	.01
+	1.0120*Ln(Children+1)	.00
+	0.0740*Persons*Income	.01
+	0.1973*Persons*Ln(Vehicles+1)	.02
+	0.1845*AccessibilitytoNonBasicEmp	.00
-	1.2477	.03

Table 11. NHBO and NHBW Trip Equations

R-squared = 0.24	parameters and variables	sig.
Number of NHBO trips =	0.1607*Persons*Income	.00
+	0.4586*NonWorkerNonChildren	.03
+	2.8960*Ln(Children+1)	.00
+	0.5947	.05

R-squared = 0.45*	parameters and variables	sig.
Number of NHBW trips =	0.9030*Ln(Workers+1)	.00
+	0.1636*Workers*Income	.00

Some variables have been included, despite marginal statistical significance, based on the plausibility of their influence on the dependent variable and the reasonableness of their parameter.

Home-Based University Trips

Although the *Northwest Arkansas Regional Transportation Survey* captures some information on home-based university trips, the sample of student households is poor and group quarters (on-campus, fraternity/sorority, etc.) students are not included in the sample. The commuter survey conducted by the University of Arkansas provides valuable data used in the mode choice component of the model, but did not collect data on the number of trips students make to and from campus each day. The generation of home-based university trips is therefore based on the *1999 Indiana University Travel Demand Survey*.

Number of HBU trips = 2.06*UofAStudents

Other Student Trips

Trips made by students living in households (renting apartments, living with parents, etc.) are captured in the normal trip generation models. However, trips made by group quarters students (living in dorms, fraternities/sororities, etc.) must be generated differently. Again, the generation of these trips was based on the *1999 Indiana University Travel Demand Survey*.

Number of HBSB trips =0.5295*GQUstudents

Number of HBO trips = 0.7259*GQUstudents

Number of NHBO trips = 0.9288*GQUstudents

2. <u>Trip Attraction Model</u>

In terms of a travel demand model, the demand for trips is partly determined by the attractiveness of each zone. Attractions can be places of work, shopping locations, service locations, recreation areas, etc. Strictly speaking, attractions do not produce any trips – they attract trips (households are where trips are produced).

Productions and attractions are often confused with origins and destinations. Certainly when a person is leaving home to go to work, that trip is traveling from an origin which is a production to a destination which is an attraction. However, when that person makes the return trip home, that trip leaves from an origin (the workplace) which is an attraction to go to a destination (the household) which is a production.

A location that is an attraction is labeled as an attraction irrespective of the direction of travel. The trip attraction model is not based merely on the number of attractions, or the size of the attractions, in a given area, such as a TAZ. The important element is the number of trip ends associated with the attractions in a TAZ, whatever the number of possible attractions. The trip attraction model defines the attractiveness of each area.

The attractions for each trip purpose in the Northwest Arkansas Regional Travel Demand Model are calculated using a linear regression model that was calibrated using household travel survey data. The data were derived from the Northwest Arkansas Regional Transportation Survey conducted by MORPACE International in the fall of 2004. Respondents for the survey were limited to household residents of Benton and Washington Counties. Results of the survey included the origin and destination of trips during the survey period, type of trip, trip purpose, household size, and other data.

The following independent variables were checked against the existing attractions to develop the trip attraction model equations:

- Total Households
- Public School Enrollment
- Private School Enrollment
- Basic Employment
- Retail Employment
- High Income Service Employment
- Low Income Service Employment
- Total Employment (Basic + Retail + High Income Service + Low Income Service Employment)
- Non-Basic Employment (Retail + High Income Service + Low Income Service Employment)

The following logical steps were taken in order to develop the attraction equations:

1) Correlation between surveyed attractions and available socioeconomic variables was investigated. The investigation involved the examination of Pearson Correlation and the 2-Tailed Level of Significance. From this analysis, variables that were significantly correlated with attractions were selected as a pool of candidates for to be independent variables in the attractions equations.

2) A stepwise regression technique was employed in order to efficiently analyze the numerous combinations of several socioeconomic variables. The stepwise technique is appropriate manage multiple explanatory variables and is superior to the one-step multiple regression, forward and backward selection technique. In implementing the stepwise technique, no constants were forced during the analysis since the model without a constant produced better results in most cases. An attraction equation with a constant also implies a minimum number of attractions, without regard to the value of the independent variable(s), which is not always the case.

3) Regression results were analyzed for the following main statistics:

    a) Adjusted R Square
    b) Overall model F-statistic and its significance level
    c) Model coefficients (magnitude and signs)
    d) T-statistics for each of the variables used in the equation, and the significance level
    e) Multicollinearity among the variables used in the equation

4) The model selection process was not solely dependent on one statistic, such as Adjusted R Square. Rather, the process was based on the combination effects of the above statistics. An equation's R Square can increase as more independent variables are added, but that does not

necessarily mean that the equation is better for the model. The performance of each of the entered variables needs to be checked.

5) Besides the above statistics, logical judgments were made for appropriateness of each variable. For example, an independent variable like Basic Employment shows that it is statistically significant, thus it is natural to include Basic Employment in the equation since it improves the fit of the equation. However, if the trip purpose attraction this is being investigated is school trips, there is not a logical connection between Basic Employment numbers in an area and the number of school trips in that area.

The statistics software program SPSS was used to calculate the correlation between the attractions for each trip purpose to the socioeconomic variables in each district. The results of the correlation analysis are shown below in Table 12. The pool of potential independent variables to be used in the stepwise regression analysis was based on the correlation results.

Table 12. Trip Attraction Variable Correlation Analysis

Trip Purpose		Total HH	Public School Enrollment	Private School Enrollment	Total Employment	Basic Employment	Retail Employment	High Income Service	Low Income Service	NonBasic Employment
HBW_A	Pearson Correlation	0.886			0.978	0.916	0.878	0.892	0.944	0.965
	Sig. (2-tailed)	0.000			0.000	0.000	0.000	0.000	0.000	0.000
HBO_A	Pearson Correlation	0.901			0.956	0.866	0.869	0.884	0.940	0.958
	Sig. (2-tailed)	0.000			0.000	0.000	0.000	0.000	0.000	0.000
HBSH_A	Pearson Correlation	0.745			0.834	0.745	0.892	0.787	0.745	0.842
	Sig. (2-tailed)	0.000			0.000	0.000	0.000	0.000	0.000	0.000
HBSC_A	Pearson Correlation	0.806			0.776	0.740	0.570	0.642	0.852	0.760
	Sig. (2-tailed)	0.000			0.000	0.000	0.000	0.000	0.000	0.000
NHBO	Pearson Correlation	0.888			0.935	0.829	0.915	0.879	0.893	0.947
	Sig. (2-tailed)	0.000			0.000	0.000	0.000	0.000	0.000	0.000
NHBW_W	Pearson Correlation	0.836			0.968	0.895	0.893	0.911	0.916	0.962
	Sig. (2-tailed)	0.000			0.000	0.000	0.000	0.000	0.000	0.000
NHBW_O	Pearson Correlation	0.838			0.958	0.853	0.869	0.898	0.952	0.969
	Sig. (2-tailed)	0.000			0.000	0.000	0.000	0.000	0.000	0.000

** Correlation is significant at the 0.01 level (2-tailed).

Once the variables for use in the regression analysis were selected in the correlation analysis, a stepwise regression was used to establish the best model attraction equations for each trip purpose. In a stepwise regression analysis, different combinations of independent variables are tested to determine which combination is the best to use to best describe the attractions. Table 13, below, presents the results of the stepwise regression analysis, including the variables chosen for each trip purpose, their coefficients, and the R Square for the equation.

Table 13. Trip Attraction Stepwise Regression Results

Attraction Models By Trip Purpose	Independent Variables	R Square
HBW Attra.=0.783*(Total Emp)	Total Employment	0.97
HBO Attrra.=1.764*(Non-Basic Emp)+0.726*(Total HH)	Total Households & Non Basic Employment	0.957
HBSC Attra.= 1.700*(K12 Enrol)	K-12 Enrollment	n/a
HBSB Attra.=2.581*(Retail Emp)	Retail Employment	0.838
NHBW Attra.=0.761*(Total Emp)+1.007*(Non-Basic Emp)	Non-Basic & Total Employment	0.954
NHBO Attra=5.039*(Retail Emp)+1.821*(Non-Basic Emp)+0.899*Total HH	Total Households, Retail & Non Basic Employment	0.95

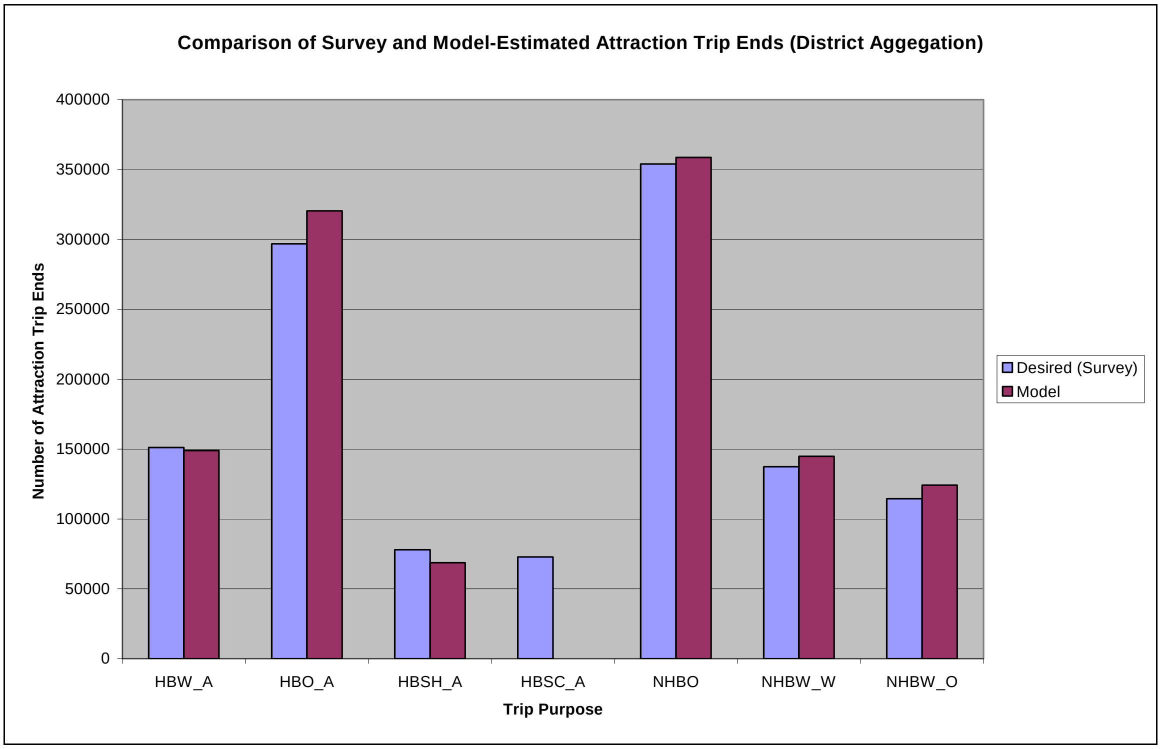


Figure 19. Comparison of Survey and Model Attraction Trip Ends

3. Special Trip Generator

Productions and Attractions of the trips from/to community colleges:

HBO Productions = 0.044*(Total Households), for all TAZs
NHBO Productions = 0.010*Employment, for all TAZs
NHBW Productions = 0.007*Employment, for all TAZs
HBO Attractions = 0.923*(College Enrollment)
NHBO Attractions = 0.287*(College Enrollment)
NHBW Attractions = 0.190*(College Enrollment)

Trip Productions and Attractions of the Airport:

NHBO Productions = 800
NHBW Productions = 450
HBO Attractions = 800
NHBO Attractions = 800
NHBW Attractions = 400

D. MODE CHOICE MODEL

The trip generation models produce numbers of person trips for each trip purpose. These trips must be divided into trips by various modes and converted to vehicle trips for the purpose of predicting vehicle flows on the roadway network. The Northwest Arkansas model divides the person trips from trip generation into trips of five modes: car driver, car passenger, public bus, school bus and non-motorized (walk/bike). The observed share of each mode for each trip purpose from the *Northwest Arkansas Regional Transportation Survey* is shown below.

Table 14. Survey Mode Share by Trip Purpose

	HBW	HBSC	HBSB	HBO	NHBO	NHBW
Car Driver	93.33%	9.63%	83.07%	66.93%	45.83%	86.90%
Car Passenger	4.71%	45.69%	13.89%	24.76%	49.90%	8.86%
Public Bus	0.99%	0.47%	2.26%	3.93%	1.90%	0.09%
School Bus	-	43.62%	-	-	-	-
Non-Motorized	0.97%	0.59%	0.78%	4.38%	2.37%	4.15%

The share of person trips by each mode for each trip purpose for a particular household is determined in the model by a disaggregate multinomial logit discrete choice model. Logit models are the most common technique for modeling mode choice in travel demand models. However, the Northwest Arkansas mode choice models are generally noteworthy in two respects. First, they are disaggregate models taking individual household attributes as variables rather than zonal averages as is more common in traditional models. This eliminates aggregation biases and results in a more accurate model. Second, these models are applied prior to destination choice and are independent of transit level-of-service variables. Most mode choice models are applied after destination choice in order to use level-of-service variables. This is of great importance where there is significant market for choice transit riders. However, where the transit market is essentially limited to captive riders, mode choice is basically a function of demographic variables, and applying the mode choice model prior destination choice allows the best use of these variables and obviates the need for a transit network model, which is costly to develop and maintain.

The multinomial logit model predicts the probability (or share) of an alternative (modes, in this case) as a function of the utility of that alternative and the utilities of all the other alternatives. The form of the logit model can be derived from the assumption that people (choice-makers) maximize their utility, and that the random component of utility (the error not explained by the deterministic portion of the utility function) is independently and identically distributed Gumbel. This theoretical basis for the model in the basic economic theory of random utility maximization combined with the simplicity of its functional form account for its widespread use. The general formula for the model is given below.

$$\text{Probability}\left(a' \mid i\right) = \frac{e^{V_{a'i}}}{\sum_{a} e^{V_{ai}}}$$

where Probability(a'|i) is the probability that the choice-maker (i) chooses the alternative (a') and V_{ai} is the deterministic portion of the utility of alternative a for choice-maker i. The deterministic utilities can be any function of independent variables which is linear in parameters (the function need not be linear in the variables).

The utility functions for the various modes for each trip purpose are presented below. The form of the logit model is such that units of utility are arbitrary, so that the utility of one alternative can be set to zero (or any number) and the other utilities defined in reference to it. The alternative held constant is called the reference alternative. Car Driver was chosen as the reference alternative for the Northwest Arkansas mode choice models. Its utility was initially set to zero for model estimation. For purposes of calibration, however, this utility was shifted to produce agreement with the survey. The final calibrated parameters of the utility functions of the mode choice model are presented in the table below.

Table 15. Mode Choice Probability Equation

Trip Purpose	Mode	constant		Ln((Vehicles/ Adults)+1)		Ln((Vehicles/ Person)+1)		Ln(Income+1)		Ln(Children+1)		Senior Household	
		parameter	t	parameter	t	parameter	t-stat	parameter	t	parameter	t	parameter	t
HBW	CD	0.3799	-										
	CP	-0.4191	(1.1)	-3.8170	(6.9)			-1.2450	(2.7)				
	PB	2.9080	(3.3)	-10.3400	(5.5)			-2.1200	(4.5)			-30.0000	
	NM	0.5229	(0.9)	-3.9470	(5.3)			-1.3700	(5.5)	-1.9590	(9.5)	-2.5140	(7.0)
HBSC	CD	0.3079	-										
	CP	2.4680	(2.1)			-6.0770	(3.9)	-1.2450	(2.7)	2.5440	(3.8)		
	PB	4.3500	(1.7)			-8.6030	(1.5)	-2.1200	(4.5)			-30.0000	
	SB	6.6710	(5.0)			-9.0150	(5.2)			2.4940	(3.5)		
	NM	-0.6615	(0.8)					-1.3700	(5.5)			-2.5140	(7.0)
HBSB	CD	0.1399	-										
	CP	-0.9634	(5.4)			-2.1120	(8.9)	-1.2450	(2.7)	0.5653	(7.1)		
	PB	4.3370	(4.9)			-31.5000	(9.1)	-2.1200	(4.5)			-30.0000	
	NM	1.2420	(2.5)			-5.4710	(10.4)	-1.3700	(5.5)	-1.9590	(9.5)	-2.5140	(7.0)
HBO	CD	0.0905	-										
	CP	-0.3263	(1.9)			-2.1120	(8.9)	-1.2450	(2.7)	0.5653	(7.1)		
	PB	4.9280	(7.7)			-31.5000	(9.1)	-2.1200	(4.5)			-30.0000	
	NM	3.3090	(8.7)			-5.4710	(10.4)	-1.3700	(5.5)	-1.9590	(9.5)	-2.5140	(7.0)
NHBO	CD	0.0110	-										
	CP	0.7429	(4.5)			-2.1120	(8.9)	-1.2450	(2.7)	0.5653	(7.1)		
	PB	3.8920	(7.4)			-31.5000	(9.1)	-2.1200	(4.5)			-30.0000	
	NM	2.6950	(7.6)			-5.4710	(10.4)	-1.3700	(5.5)	-1.9590	(9.5)	-2.5140	(7.0)
NHBW	CD	0.4636	-										
	CP	0.2997	(0.8)	-3.8170	(6.9)			-1.2450	(2.7)				
	PB	-0.6878	(0.6)	-10.3400	(5.5)			-2.1200	(4.5)			-30.0000	
	NM	1.9350	(4.1)	-3.9470	(5.3)			-1.3700	(5.5)	-1.9590	(9.5)	-2.5140	(7.0)

Student Trips

The mode shares for home-based university trips are based on the results of a commuter survey of University of Arkansas students, faculty, and staff was performed by the firm of Martin Alexiou Bryson in the fall of 2004. The mode shares are simply dependent on the distance from campus.

Table 16. Survey Result of University Student Trips

Distance to Campus	Personal Vehicles	Transit	Walk/Bike
< 0.5 mi	20%	15%	65%
0.5 - 1 mi	50%	30%	20%
1 - 2 mi	70%	25%	5%
2 - 5 mi	90%	8%	2%
5 - 10 mi	95%	5%	0%
10 - 25 mi	96%	4%	0%
> 25 mi	97%	3%	0%

E. TIME-OF-DAY CHOICE MODEL

Trip generation also produces the total number of daily trips for each purpose. However, ultimately, the model is designed to predict flows on the network during three periods. The three time periods in the Northwest Arkansas model are

- AM Peak: 6:00am – 9:00am
- PM Peak: 3:00pm – 6:00pm
- Off Peak: 12:00am – 6:00am, 9:00am – 3:00pm, 6:00pm-12:00am

The model must therefore divide the total daily trips into trips during each of the three times of day. The *Northwest Arkansas Regional Transportation Survey* observed shares of daily trips of each purpose departing in each hour are depicted in the graph below, and recorded in the preceding table.

Table 17. Time of Day Factors

Trip Purpose	Time of Day	Observed
HBW	AM	36.2%
	PM	27.0%
	OP	36.8%
HBU	AM	29.8%
	PM	19.6%
	OP	50.5%

HBSC	AM	65.7%
	PM	28.4%
	OP	5.9%
HBSB	AM	10.6%
	PM	28.8%
	OP	60.6%
HBO	AM	25.9%
	PM	24.1%
	OP	50.0%
NHBO	AM	10.1%
	PM	34.8%
	OP	55.0%
NHBW	AM	18.2%
	PM	25.1%
	OP	56.7%

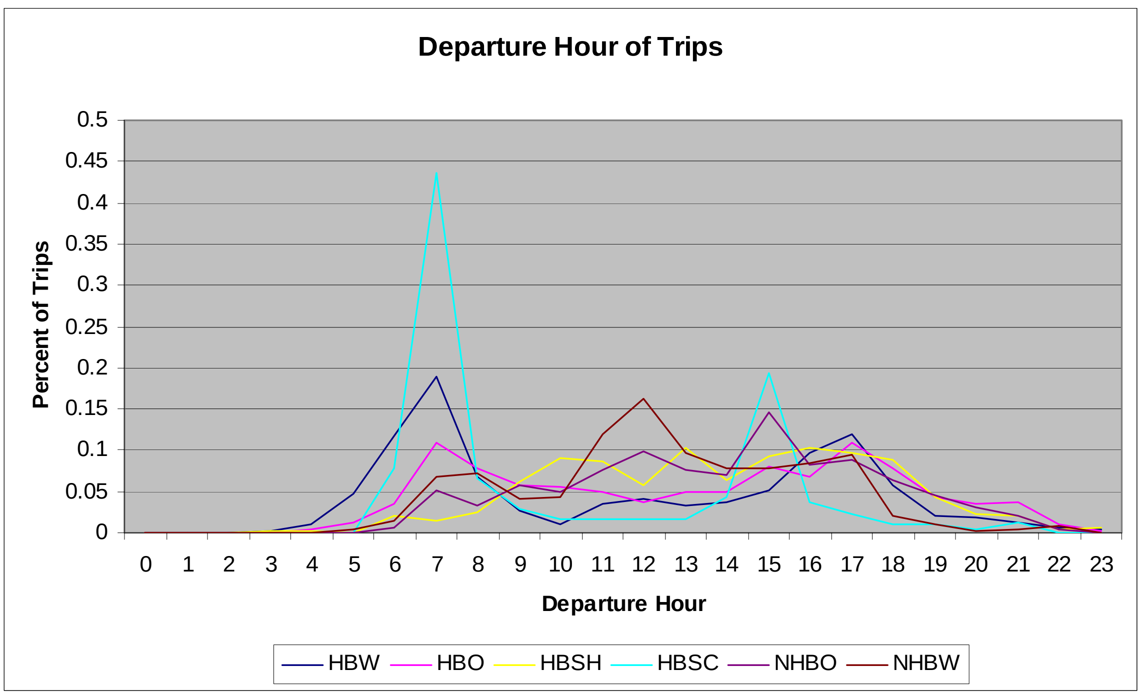


Figure 20. Trip Departure Hour

The share of daily trips by each time of day for each trip purpose for a particular household is determined in the model by a disaggregate multinomial logit discrete choice model, similarly to mode choice. [For a general introduction to logit models refer to the section on mode choice.] The parameters of the utility functions of the time of day choice model are presented below.

Table 18. Equation of Time of Day Choice

Trip Purpose	Time of Day	constant		Persons		Workers		Children		Senior Household		Income	
		Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat	Parameter	t-stat
HBW	AM	1.1840	(8.9)	-0.5860	(8.5)	0.0658	(1.1)	0.7584	(9.7)	-0.3974	(3.4)	-0.0679	(2.2)
	PM	0.0000											
	OP	0.8082	(6.4)	-0.5754	(9.5)	0.1878	(3.6)	0.7176	(10.6)	-0.3679	(3.7)	-0.1014	(3.9)
HBSC	AM	3.4710	(13.1)	-0.5860	(8.5)	0.0658	(1.1)	0.7584	(9.7)	-0.3974	(3.4)	-0.0679	(2.2)
	PM	0.0000											
	OP	2.5840	(9.6)	-0.5754	(9.5)	0.1878	(3.6)	0.7176	(10.6)	-0.3679	(3.7)	-0.1014	(3.9)
HBSB	AM	-0.4659	(3.1)	-0.5860	(8.5)	0.0658	(1.1)	0.7584	(9.7)	-0.3974	(3.4)	-0.0679	(2.2)
	PM	0.0000											
	OP	0.4861	(4.0)	-0.5754	(9.5)	0.1878	(3.6)	0.7176	(10.6)	-0.3679	(3.7)	-0.1014	(3.9)
HBO	AM	0.5324	(4.2)	-0.5860	(8.5)	0.0658	(1.1)	0.7584	(9.7)	-0.3974	(3.4)	-0.0679	(2.2)
	PM	0.0000											
	OP	0.4231	(3.6)	-0.5754	(9.5)	0.1878	(3.6)	0.7176	(10.6)	-0.3679	(3.7)	-0.1014	(3.9)
NHBO	AM	-0.5406	(4.1)	-0.5860	(8.5)	0.0658	(1.1)	0.7584	(9.7)	-0.3974	(3.4)	-0.0679	(2.2)
	PM	0.0000											
	OP	0.6564	(6.1)	-0.5754	(9.5)	0.1878	(3.6)	0.7176	(10.6)	-0.3679	(3.7)	-0.1014	(3.9)
NHBW	AM	-0.0201	(0.1)	-0.5860	(8.5)	0.0658	(1.1)	0.7584	(9.7)	-0.3974	(3.4)	-0.0679	(2.2)
	PM	0.0000											
	OP	0.2214	(1.7)	-0.5754	(9.5)	0.1878	(3.6)	0.7176	(10.6)	-0.3679	(3.7)	-0.1014	(3.9)

In addition to determining the share of daily trips of each purpose in each time of day, in order to produce period flows, the direction of trips must be taken into account. Trips must be divided between those from the production (generally, home) to the attraction (work, school, etc.) and vice versa. The directional splits for the times of day from the *Northwest Arkansas Regional Transportation Survey* are presented below.

Table 19. PA-to-OD Conversion Factors

	HBW		HBSC		HBSB		HBO		NHBO	NHBW	
	A to P	P to A	A to P	P to A	A to P	P to A	A to P	P to A		A to P	P to A
AM	4.65%	95.35%	0.00%	100.00%	20.49%	79.51%	20.44%	79.56%	10.14%	77.15%	22.85%
PM	94.01%	5.99%	98.96%	1.04%	62.93%	37.07%	57.73%	42.27%	34.82%	20.35%	79.65%
OP	55.98%	44.02%	94.78%	5.22%	49.28%	50.72%	59.89%	40.11%	55.05%	50.81%	49.19%

F. TRIP DISTRIBUTION MODEL

The gravity model was used to distribute zonal trip productions and attractions or trip origins and destinations. The gravity model is most widely used model for trip distribution. The methodology is based on Newton's law of gravitation, it assumes that the trips from a TAZ (i.e., trip productions) are distributed to other TAZs (i.e., trip attractions) in direct proportion to the size of the attraction TAZ and in inverse proportion to the spatial separation between adjacent TAZs. In general, the number of trips attracted to a TAZ reflects the size of the attraction TAZ and the interzonal travel time of the spatial separation between the TAZs.

The gravity model is sensitive to changes in transportation network such as capacity expansion, improvements on geometric and/or functional features of the roadway, and incorporation of a new facility, etc. In accordance with these changes, the gravity model re-estimates the trip interchange of person trips based on changes in the network link impedance.

The form of the gravity model is expressed as:

$$T_{ij} = P_i \left(\frac{A_j F_{ij} K_{ij}}{\sum_{k=1}^{zones} A_k F_{ik} K_{ik}} \right)$$

where,

T_{ij} = trips between TAZ i and TAZ j,
P_i = total productions of TAZ i,
A_j = total attractions of TAZ j,
F_{ij} = friction factor between TAZ i and TAZ j, and
K_{ij} = socioeconomic factor between TAZ i and TAZ j.

The trip distribution modeling process incorporated the following data inputs and modeling elements:

- Production and attraction trip ends by trip purpose from the trip generation model,
- Interzonal and intrazonal travel times computed using the TransCAD function of averaging the travel time to 4 neighbor TAZs,
- Friction factors calibrated for each trip purpose using gravity model procedures, and
- Gravity model applications by trip purpose using TransCAD procedures.

1. Trip Balance

When trip productions and attractions are calculated by purpose, it is necessary for their total sum of each trip purpose to be balanced as inputs to the trip distribution (gravity) model. The balancing procedure for trip productions and attractions of the NW Arkansas model uses two different methods in TransCAD for home-based and non-based trips respectively, i.e. holding productions constant for all home based trips and holding attractions constant for all non-homed trips. Since all trips of external stations are actual traffic count numbers, these trips were withheld with no changes in balance processes.

2. Gravity Model Calibration and Evaluation

In the trip distribution process, base year trip length frequency distribution (TLFD) and average trip length were estimated from the 2004 NW Arkansas Household Travel Behavior Survey. Model friction factors were then calibrated to replicate these base year trip distribution patterns. The estimated friction factors were input, along with trip productions and attractions and travel times, into Gravity model for each trip purpose. This step resulted in the development of production and attraction trip matrices which were later used for input to trip assignment processes.

3. Friction Factor

The friction factor in the Gravity model is a key component that represents the magnitude of frictions (or impedances) in traffic flows between pairs of TAZs. Friction factors are derived by trip purpose through trip-length frequency distributions and average trip lengths from a base year origin-destination travel survey.

The NW Arkansas Travel Survey data was analyzed to investigate base year TLFD's and average trip lengths by trip purpose. To derive these travel patterns, a skim table of free-flow time was constructed from the Benton and Washington county highway network. This skim table was then tagged with the survey's origin-destination trips to estimate the percentage of total trips by free-flow travel time. Table 20 summarizes average trip lengths by trip purpose from the survey. As indicated in these survey results, home-based work trips are the longest trips, and non-home-based work trips are the shortest.

Table 20. Base Year Average Trip Lengths by Trip Purpose

	HBW		HBO		HBSB		NHBO		NHBW	
	Average Travel Time	Vehicle Trips	Average Travel Time	Vehicle Trips	Average Travel Time	Vehicle Trips	Average Travel Time	Vehicle Trips	Average Travel Time	Vehicle Trips
OP	14.09	72297	10.79	120364	11.7	115166	10.36	135284	9.68	122162
AM	14.03	70464	10.48	59739	11.4	20197	10.14	22890	9.51	36577
PM	14.06	53597	10.78	59004	11.8	58053	10.14	99020	9.54	80325
Daily	**14.06**	196358	**10.71**	239107	**11.70**	193416	**10.26**	257194	**9.61**	239064
Survey	**13.3**		**10.9**		**11.1**		**9.3**		**8.6**	

Friction factors were calibrated for each trip purpose so that they replicate the observed TLFD's and average trip lengths shown in Table 20. The calibration of friction factors involves iterative procedures. These procedures can be outlined as follows:

1. Gravity model is evaluated with initial set of friction factors.
2. TLFD's and average trip lengths from the Gravity model run are estimated.
3. The trip length estimates are compared with the observed trip lengths patterns.
4. Revise the initial set of friction factors based on the comparison in Step 3.
5. Run Gravity model with the revised friction factors and return to Step 2.
6. Repeat Steps 2 to 5 until (a) the observed TLFD's and model TLFD's are relatively close to one another, (b) average trip lengths become stable and (c) the difference in average trip lengths between the observed and the estimated trips is around ±12% or less.

Finally friction factors were smoothed for all trip purposes. It should be noted, however, that the Northwest Arkansas Travel Survey does not provide enough samples for Home-Based-University trips. So the Gamma function with a= 100, b=0.3 and c=0.07 were used for this trip purposes.

Table 21. Calibrated Friction Factors [1]

Time	Trip Purpose[2]					
	HBW	HBO	HBSB	HBSC	NHBW	NHBO
1	0.001	0.001	0.001	0.001	0.010	0.010
2	24.096	34.750	2.348	10.083	30.095	33.530
3	37.213	18.000	26.312	16.351	18.059	20.230
4	249.875	15.000	21.956	17.897	14.736	14.575
5	120.263	11.275	15.127	14.954	9.717	9.950
6	92.790	8.178	9.047	9.165	7.511	6.801
7	70.525	4.966	5.541	7.543	4.915	4.093
8	53.468	4.070	4.258	5.401	3.634	3.347
9	41.620	2.943	3.444	4.246	2.592	2.508
10	34.980	2.396	2.753	2.809	2.053	2.074
11	29.000	2.072	2.317	2.265	1.546	1.652
12	23.293	1.866	1.950	1.910	1.144	1.377
13	19.000	1.537	1.800	1.426	0.924	1.085
14	17.245	1.105	1.327	1.226	0.619	0.786
15	14.600	0.961	1.215	1.034	0.595	0.677
16	11.936	0.803	0.999	0.766	0.511	0.601
17	10.078	0.658	0.832	0.776	0.445	0.490
18	9.143	0.550	0.669	0.619	0.372	0.437
19	8.515	0.561	0.625	0.571	0.307	0.400
20	8.496	0.478	0.499	0.435	0.282	0.340
21	8.450	0.429	0.431	0.378	0.258	0.292
22	8.400	0.388	0.362	0.235	0.251	0.259
23	8.350	0.299	0.256	0.167	0.218	0.189
24	8.341	0.257	0.230	0.183	0.176	0.156
25	8.245	0.203	0.231	0.139	0.147	0.139
26	8.134	0.188	0.192	0.142	0.111	0.115
27	7.400	0.149	0.182	0.144	0.080	0.088
28	6.966	0.168	0.134	0.134	0.054	0.084
29	6.175	0.136	0.154	0.114	0.073	0.069
30	5.392	0.138	0.124	0.099	0.045	0.075

Note: [1] This table only shows friction factors for travel time less than 30 minutes.
[2] HBW: Home-based work; HBS: Home-based school; HBSB: Home-based Shopping; HBO: Home-based others; NHBW: Non-home-based work; NHBO: Non-home-based others.

G. UNDER-REPORTING AND AREA ADJUSTMENT FACTORS

Before being distributed, the trip production tables are factored up to account for low trip generation rates due to under-reporting of trips in the household travel survey. Studies have shown that this is a significant and pervasive problem in developing trip rates from surveys based on the recall or journaling of survey respondents alone apart from some validation such as by GPS device.

In the model calibration and validation process, it was observed that the trips were overestimated in rural areas while the trips were underestimated in the urban area. So area factors were introduced to adjust the trips in different areas.

These adjustments can be thought of as the part of trip generation. The model source code has a provision for use of these under-reporting factors. Future users, possibly in a sub-area analysis may need to make use of this capability.

Table 21. Trip Rate Adjustment Factors

Trip Purpose	Under Reporting Adjustment Factor	Area Adjustment Factor	
		Urban	Rural
HBW	1.0136	1.0	0.9
HBSC	1.0495	1.1	0.9
HBSB	1.0078	1.1	0.9
HBO	1.0735	1.1	0.9
NHBO	1.0491	1.1	0.9
NHBW	0.9976	1.1	0.9

H. EXTERNAL MODELS

Trips with at least one trip-end outside the study area are considered external trips. External trips are further classified as External-Internal/Internal-External (EI-IE) trips if one trip-end falls outside the study area and as External-External (EE or through) trips if both trip-ends fall outside the study area. These external trips require special treatment from a trip generation standpoint in the travel demand modeling process.

The NW Arkansas regional model has 31 external stations where traffic can enter or exit the model's roadway network to and from the surrounding areas (Figure 21). Alliance Transportation Group Inc. conducted an external origin-destination survey with 24-hour vehicle classification counts at 6 external stations in the two-county study area in September of 2004. The external-external trip samples from this survey were expanded to the full size and used in validating the assignment of the external-external trip table.

External-internal/Intern-External trips are equal to the difference between the ADT at the station and the number of External-External trips (if any); and were, therefore, derived from the final estimates of the External-External trips.

The thirty-one external station locations, along with the number of external-external and external-internal auto and truck trips at each station, are displayed in Table 23. Three of the thirty-one stations carry over 15,000 daily trips, and ten of the thirty-one external stations serve with daily external-external trips, including two with over 1,500. All of the remaining twenty-one stations carry no external-external trips.

The auto trip exchanges between the ten stations with external-external trips are displayed in Table 24, and the truck trip exchanges for these stations are presented in Table 25.

Figure 22: External Station Location Map

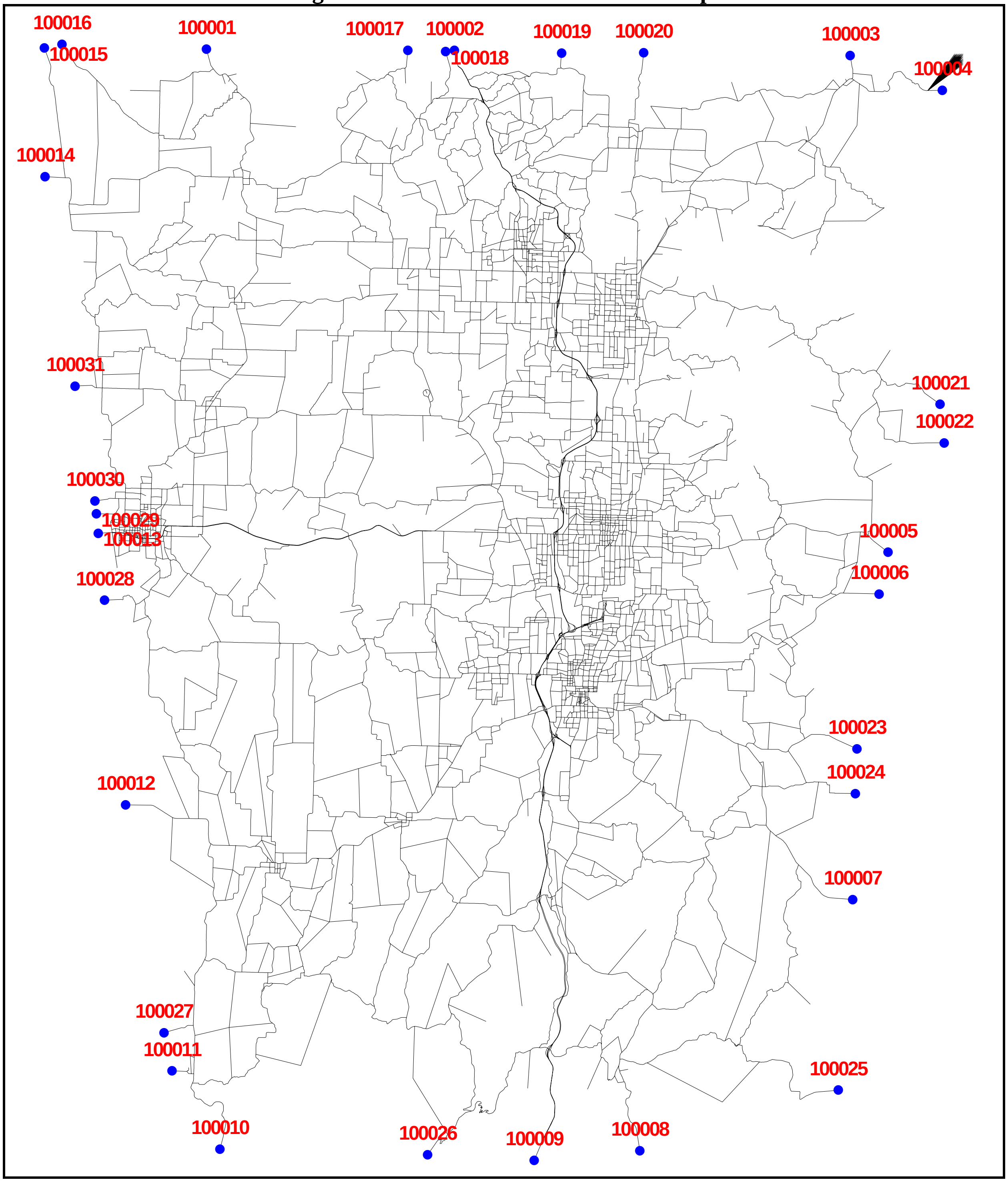


Table 23. Vehicle Trips at External Stations

External Station	Roadway	Survey Site	2-way ADT	External-External		External-Internal/ Internal-External		
				Auto	Truck	Auto	Truck	4-tire Commercial
100001	US 59		3300	0	0	2806	330	164
100002	**US 71 - Bella Vista**	**1**	**23100**	**689**	**1033**	**17797**	**2427**	**1154**
100003	AR 37		6600	0	0	5610	660	330
100004	US 62	2	2000	462	121	1218	99	100
100005	E HWY 412	3	6800	382	86	5232	760	340
100006	E HWY 45		3300	0	32	2806	298	164
100007	S HWY 16		1500	32	6	1244	144	74
100008	N HWY 71	4	980	95	21	792	24	48
100009	**I-540**		**17500**	**1164**	**1114**	**11088**	**3260**	**874**
100010	S HWY 59		1300	68	104	1038	26	64
100011	BALLARD WC 3255		870	0	0	742	86	42
100012	W HWY 62	5	2400	120	12	1910	238	120
100013	**US 412**	**6**	**20000**	**366**	**147**	**16836**	**2095**	**556**
100014	AR 43		970	26	0	780	116	48
100015	AR 43		3022	0	0	2570	302	150
100016	Honey Creek		460	0	0	392	46	22
100017	Ardwell		1506	0	0	1282	150	74
100018	Forest Hills		4000	0	0	3400	400	200
100019	AR 94		5760	0	0	4896	576	288
100020	Hayden		1600	0	0	944	576	80
100021	AR 127		790	0	0	674	78	38
100022	AR 12		410	0	0	350	40	20
100023	E HWY 74		2300	0	0	1956	230	114
100024	RAVEN WC 1097		1506	0	0	1282	150	74
100025	SUNSET WC 38		140	0	0	120	14	6
100026	HWY 220		680	0	0	358	302	20
100027	S HWY 244		850	0	0	724	84	42
100028	Twin Falls		3022	0	0	2570	302	150
100029	University		220	0	0	188	22	10
100030	Villa View		1300	0	0	1106	130	64
100031	AR 12		2800	0	0	2254	406	140
Total			**120986**	**3404**	**2676**	**94965**	**14371**	**5570**

Table 24. External-External Auto Trip Interchanges

	100002	100004	100005	100007	100008	100009	100010	100012	100013	100014	Sum
100002	--	79.00	--	--	9.00	244.00	13.00	5.00	17.00	13.00	380.00
100004	--	--	--	--	4.00	146.00	--	3.00	17.00	--	170.00
100005	26.00	--	--	16.00	6.00	79.00	--	11.00	86.00	--	224.00
100007	--	--	16.00	--	--	--	--	--	--	--	16.00
100008	13.00	11.00	--	--	6.00	20.00	--	--	--	--	50.00
100009	244.00	146.00	79.00	--	20.00	--	--	24.00	69.00	--	582.00
100010	13.00	--	--	--	--	--	--	21.00	--	--	34.00
100012	--	11.00	--	--	--	24.00	21.00	--	--	--	56.00
100013	--	45.00	63.00	--	--	69.00	--	--	--	--	177.00
100014	13.00	--	--	--	--	--	--	--	--	--	13.00
Sum	309.00	292.00	158.00	16.00	45.00	582.00	34.00	64.00	189.00	13.00	1702.00

Table 25. External-External Truck Trip Interchanges

	100002	100004	100005	100006	100007	100008	100009	100010	100012	100013	Sum
100002	--	--	--	16.00	--	--	426.00	52.00	--	16.00	510.00
100004	--	--	--	--	--	--	51.00	--	--	--	51.00
100005	16.00	--	--	--	--	2.00	26.00	--	--	16.00	60.00
100006	16.00	--	--	--	--	--	--	--	--	--	16.00
100007	--	--	--	--	--	--	--	--	3.00	--	3.00
100008	13.00	2.00	--	--	--	--	2.00	--	--	--	17.00
100009	426.00	51.00	26.00	--	--	2.00	--	--	3.00	49.00	557.00
100010	52.00	--	--	--	--	--	--	--	--	--	52.00
100012	--	--	--	--	3.00	--	3.00	--	--	--	6.00
100013	--	17.00	--	--	--	--	49.00	--	--	--	66.00
Sum	523.00	70.00	26.00	16.00	3.00	4.00	557.00	52.00	6.00	81.00	1338.00

I. TRUCK MODEL

Based on the method recommended in *Quick Response Freight Manual* (1996), a commercial vehicle model was developed for predicting trips for four-tire commercial vehicles, and trucks. Trucks include single unit trucks with six or more tires, and combination trucks consisting of a power unit (truck or tractor) and one or more trailing units. The model uses a four-step process. Theses steps are trip generation, distribution, choice of time of day and trip assignment.

The inputs to trip generation are the number of employees and the number of households by Traffic Analysis Zone (TAZ). The daily trip generation rates shown in Table 26 are for trip Origins (O) and Destinations (D). These rates were obtained by adjusting the original generation rates in *Quick Response Freight Manual* to replicate the current truck traffic condition in the Northwest Arkansas study area.

Table 26: Daily Trip Generation Rates

Generator (Employment)	Commercial Vehicle Trip Destinations (or Origins) per Unit per Day	
	Four -Tire Vehicles	Trucks (6+ Tires)
Agriculture, Mining and Construction	1.11	0.255
Manufacturing, Transportation, Communications, Utilities & Wholesale Trade	0.938	0.190
Retail Trade	0.888	0.175
Office and Services	0.437	0.042
Households	0.251	0.075

The model network includes external stations through which vehicle trips with one or both ends outside the NW Arkansas area can be loaded onto the network. Trips through external stations include:

- Internal-to-External (EI) trips which begin in a TAZ and end outside the study area;
- External-to-Internal (IE) trips which begin outside the study area and end in a TAZ;
- External-to-External (EE, through) trips which begin and end outside the study area.

The EE commercial trip table was obtained from the result of the external station survey, and the majorities of it are EE truck trips. This EE trip table was then assumed as the EE truck trip table. EI-IE O and D trips of external stations were obtained by subtracting the EE trips from the total traffic counts.

Before the trip distribution, the Trip O and D were balanced for all TAZs and external stations for the following types of trips:

- EI-IE truck trips of all TAZs and external stations;
- Internal-to-Internal (II) truck trips of all TAZs;
- EI-IE and II 4-tire commercial vehicle trips of all TAZs and external stations.

The EI-IE truck trips were classified as an individual type of trips because there was the trip information available from the major truck generator survey. The gravity model was employed to distribute zonal trip origins to destinations. The form of the gravity model is expressed as:

$$T_{ij} = O_i \frac{D_j F(t_{ij})}{\sum_j D_j F(t_{ij})}$$

Where T_{ij}= trips between TAZ *i* and TAZ *j*;
O_i = total trip originating at TAZ *i*;
D_j= total trip destined at TAZ *j*;
$F(t_{ij})$ = friction factor between TAZ *i* and TAZ *j;*
t_{ij} = travel time between TAZ *i* and TAZ *j*.

For EI-IE truck trips, friction factors were produced from the results of the major truck generator survey. For internal trips, friction factors recommended in *Quick Response Freight Manual* were used as a starting point and then adjusted to replicate the local traffic condition. The recommendation has the following form:

Four-tire commercial vehicles:

$$F_{ij}=e^{-0.13*t_{ij}}$$

Trucks:

$$F_{ij}=e^{-0.08*t_{ij}}$$

The time-of-day assignments were implemented in order to obtain the better model results. To facilitate it, the O-D trip tables from trip distribution must be factored to reflect morning peak, evening peak and off-peak periods prior to trip assignment. The time-of-day factors recommended in *Quick Response Freight Manual* were applied for the NW Arkansas Regional Travel Demand Model. Before peak and off-peak truck trip tables can be generated, truck E-E, EI-IE and internal trips need to be merged into one trip table.

Table 27: Time of Day Factors

Period	Percent
AM Peak – (7-9am)	20.10%
PM Peak – (3-6pm)	23.70%
Off-Peak	56.20%

As explained in the previous section, trip assignment for the Northwest Arkansas model follows time-of-day procedures instead of running a single 24-hour assignment. For each of three time periods, both a truck trip table and a 4-tire commercial vehicle trip table were developed, and then were assigned onto the network simultaneously with auto trips by using the multi-model multi-class equilibrium assignment method. Total 24-hour link volumes were then obtained by aggregating the truck and auto loadings by time period.

J. TRIP ASSIGNMENT MODELS

The assignment of trips to the network is the last step of the traditional sequential modeling processes. It provides the foundation for validating the model's performance in replicating base-year travel patterns. Once the base-year assignment is validated, it is further used to forecast future traffic conditions on the network and to evaluate any transportation improvements in the future.

The Northwest Arkansas model utilizes a time-of-day modeling procedure. For each time period, a separate user equilibrium assignment is run using the trip table estimated for the respective time period.

As crucial inputs to the trip assignment, the Northwest Arkansas model uses improved directional free-flow speed estimates and capacities by time-of-day. Also, it uses different volume-delay functions by roadway functional classification.

One of unique assignment features of the Northwest Arkansas model is that it comprises a feedback loop model procedure. The first assignment, which is referred to as "initial assignment", is done by running all 4-step processes with adjusted free-flow travel speed. The assignment using the free-flow speed is a common procedure adopted by most regional and urban travel demand models. The Northwest Arkansas model, however, takes the initial assignment as an intermediate step toward the subsequent feedback assignments. After the initial assignment, 24-hour link congested speeds are estimated based on loadings and congested speeds resulted from each time of day assignment. The 24-hour congested speeds are then fed back into the Gravity model to redistribute person trips. The redistributed trips are used to run the next time of day assignments.

This section describes the assignment procedures and validation results of the Northwest Arkansas model. Individual model components of the Northwest Arkansas model were put together to run trip assignment. A batch program to implement the individual models was written to automate the whole assignment process. The overall features of the batch program are described in detail in the *Model Users Guide*.

1. <u>Trip Assignment Procedures</u>

As explained in the previous section, trip assignment for the Northwest Arkansas model follows time-of-day procedures instead of running a single 24-hour assignment. For each of three time periods, a truck trip table developed for the respective time period is assigned along with an auto trip table using TransCAD's multimodal multiclass assignment (MMA) routine. This process was repeated for all time periods. Total 24-hour link volumes are then obtained by aggregating the truck and auto loadings by time period. Each of these assignments utilizes a user equilibrium method.

2. Trip Assignment Data Inputs

The data inputs used in trip assignment and validation process included:

- **Origin-Destination Truck and Auto Trip Tables.** Outputs from the trip distribution and subsequent matrix manipulation processes. These tables are vehicle trip matrices by time-of-day.
- **Highway Network.** The Northwest Arkansas regional highway network with key link attributes such as directional link free-flow travel speeds, link peak and off-peak capacities, and link-specific BPR parameters.

K. CALIBRATION/VALIDATION

Total link daily assignment from the base year time of day assignments was validated by comparing the percentage difference between observed traffic count and estimated model volume on the link. The systemwide calibration/validation was performed by roadway functional classification, volume-group range, screenline, major corridors, and area type.

The calibration and validation tasks began with the development of a special calibration report program, which is referred to as "CAL_REP". CAL_REP was originally developed by Bernardin, Lochmueller & Associates, Inc. as part of the Indiana Reference Modeling System (IRMS) for the purpose of quantifying model errors and assisting in the diagnosis of assignment problems. For the Northwest Arkansas model, a new version of CAL_REP which was customized to best fit to the model was developed using the Geographic Information System Developer's Kit (GIS-DK) script language. This program was then embedded as a post-processing module in the user model interface for easy access and implementation. The features of the model interface and the post-processing module are given in the "Model User's Guide".

The new version of CAL_REP was designed to report modeling errors for the:

- network as a whole,
- functional classes,
- volume group ranges,
- designated screenlines,
- designated corridors, and
- area types.

Error statistics reported and used for diagnosing the possible sources of model error are:

- percent root mean square errors,
- systemwide average error,
- mean loading errors and percentage errors, and
- total VMT errors and percentage errors.

The calibration and validation tasks were based on following a decision-tree that begins with finding "global" problems in the model. This beginning approach to correct global problems then moved on the "sub-area" errors, and was completed by focusing on specific link problems. In these approaches, all roadways in the Northwest Arkansas model network with daily counts higher than 1,000 vehicles were targeted.

The global problems were first identified by a systemwide average error and a systemwide vehicle miles traveled (VMT). All model components affecting these problems were revisited and corrected where necessary. These efforts included:

- Modification to trip production rates,
- Adjustment of friction factors,
- Adjustment of volume-delay functions,
- Modification to external trips.

Criteria for acceptable errors between observed and estimated traffic volumes vary by facility type, according to the magnitude of traffic volume usage. For example, higher volume roadways have stricter calibration guidelines than those with lower volumes. Acceptable error standards used for the calibration/validation efforts in this model are shown in Table 28. These thresholds were adopted by the Michigan Department of Transportation (MDOT) and they were used for other travel models including the Indiana Statewide Travel Demand Model, the Evansville Regional Travel Demand Model, and the Lexington Area Travel Demand Model. These error standards meet or exceed the standards set by FHWA and other parties for model validation.

Table 28. Validation Criteria

Category	Acceptable Error
Total VMT % Error	± 10%
Screenline % Error	± 5%
Freeways	± 6%
Major Arterials	± 7%
Minor Arterials	± 10%
Collectors	± 20%
All Area Types	± 10%
Volume Group 1,000 ~ 2,500 vpd	± 100%
Volume Group 2,500 ~ 5,000 vpd	± 50%
Volume Group 5,000 ~ 10,000 vpd	± 25%
Volume Group 10,000 ~ 25,000 vpd	± 20%
Volume Group 25,000 ~ 50,000 vpd	± 15%
Volume Group > 50,000 vpd	± 10%

Source: MDOT, 1993

4. Trip Assignment Validation Outputs

For the links where counts are higher than 1,000 vehicles per day, comparisons were made by volume-group between modeled and observed traffic counts. Table 27 summarizes the errors by volume-group in comparison to calibration criteria identified in Table 20. In Table 27, "% Error" represents the percentage difference between ground counts ("Average Counts") and model estimates ("Average Loading"). The Percent Root Mean Square Error (% RMSE) is the traditional and single best overall error statistic used for comparing loadings to counts. It has the following mathematical formulation:

$$\%RMSE = \frac{\sqrt{\sum(\text{Count} - \text{Loading})^2 / n}}{\text{Mean Count}} \times 100$$

A model is in a high degree of accuracy when the systemwide % RMSE of the network gets down in the range of 30%. When evaluating % RMSE for groups of links disaggregated by volume ranges, relatively large errors are acceptable for low volume groups. But, the errors should become smaller as volume increases.

Table 29. Model Performance by Volume Group

Volume Range	Average Counts	Average Loading	% RMSE	% Error	% Threshold	VMT % Error
1,001 ~ 2,000	825	1419	134.22	72.02	± 100	48.03
2,001 ~ 3,000	1515	2302	101.80	51.97	± 100	40.91
3,001 ~ 4,000	2572	2359	68.15	-8.27	± 50	-0.95
4,001 ~ 5,000	3538	3566	39.90	0.79	± 50	-4.88
5,001 ~ 6,000	4459	5187	63.44	16.34	± 25	9.40
6,001 ~ 8,000	5513	4263	49.75	-22.68	± 25	-5.14
8,001 ~ 10,000	7107	5699	44.32	-19.81	± 25	-17.30
10,001 ~ 15,000	8967	7452	39.12	-16.89	± 20	-10.13
15,001 ~ 20,000	12170	11005	32.96	-9.57	± 20	-5.81
20,001 ~ 25,000	17476	17674	17.13	1.14	± 20	2.60
25,001 ~ 30,000	22743	22014	22.40	-3.20	± 15	0.11
30,001 ~ 40,000	27348	27970	15.74	2.27	± 15	5.06
40,001 ~ 50,000	32533	32129	16.83	-1.24	± 15	-1.89
50,001 ~ 60,000	0	0	0.00	0.00	± 10	0.00
> 60,000	0	0	0.00	0.00	± 10	0.00
ALL	**10314**	**9864**	**31.83**	**31.83**		**-0.88**

Tables 30 and 31 provide assignment statistics by FHWA functional classification and for major highway corridors in the study area, respectively. Table 30 indicates low loading errors for higher urban and rural facilities. If the local roads are excluded, the model will be shown in an even higher accuracy. Error statistics summarized in Table 31 also shows the accuracy of the model for 11 major highway corridors.

Table 30. Model Performance by Functional Classification

Functional Classification	Average Counts	Average Loading	% RMSE	% Error	VMT % Error
Rural Interstate	9750	9545	13.06	-2.10	-7.63
Rural Prin. Arterial	11685	11549	11.93	-1.16	-0.91
Rural Minor Arterial	5299	5921	28.92	11.73	9.51
Rural Major Collector	4209	4692	51.32	11.47	14.08
Rural Minor Collector	2442	2026	44.90	-17.04	-6.73
Rural Local Roads	910	1388	52.62	52.62	52.62
Urban Interstate	25144	25797	10.27	2.59	2.09
Urban Prin. Arterial	16703	16274	24.50	-2.57	-1.66
Urban Minor Arterial	7918	6965	34.17	-12.04	-7.60
Urban Collectors	5044	3514	76.80	-30.33	-36.21
Urban Local Roads	5660	6003	53.29	6.08	19.49
All	**10314**	**9864**	**31.83**	**-4.36**	**-0.88**

Table 31. Model Performance for Major Corridors

Corridor	Average Counts	Average Loading	% RMSE	% Error	VMT % Error
Hammerschmidt Hwy	21362	21317	13.20	-0.21	-1.33
I-540 South	9750	9545	13.06	-2.10	-7.63
I-540 North	27895	29054	8.58	4.16	2.79
US 71 - Bella Vista	15100	14097	6.80	-6.64	-6.44
US 412	14918	13954	24.88	-6.47	-0.04
Walton	20040	21567	21.74	7.62	8.29
SR 59 N	8292	8996	21.37	8.50	10.82
US 71 Rogers	23833	25221	13.21	5.83	7.82
Old US 71 - Fayettev	18727	19146	28.88	2.24	-4.83
(old) US 71 - Spring	29623	30292	21.41	2.26	4.90
SR 102 / Hudson	17591	16503	17.82	-6.19	-0.82

Table 32 summarizes assignment statistics for screenlines, area types, counties and truck trips. Performance by area type is summarized for major employment district, urban, suburban, and rural areas.

Table 32. Model Performance by Screenline, Area Type, County and Truck Trips

Category		Avg Counts	Avg Loading	% RMSE	% Error
Screen-line	County Border Line	11345	11163	19.41	-1.61%
	East of I-540 (Benton)	11298	11546	31.35	2.19%
	Cutline between Fayetteville & Springdale	21433	20763	11.59	-3.13%
	Railroad in Fayetteville	10793	9918	39.98	-8.11%
Area Type	CDB	13130	11827	28.90	-9.93%
	Urban	11028	10055	35.17	-8.82%
	Suburban	7321	7624	32.15	4.13%
	Rural	4757	5178	33.31	8.84%
County	Benton	9203	8800	29.41	-4.37%
	Washington	11484	10985	33.14	-4.34%
Truck	Truck Daily Trips	1375	1418	34.49	3.19%

VIII. NORTHWEST ARKANSAS MODEL POST-PROCESSORS

A. POST_ALT

The outputs of the travel model are the loaded volumes of autos and trucks by direction and time-of-day on the various facilities in the model's roadway network. However, for planning and air quality purposes it is often important and helpful to further process the model outputs to produce estimates of speeds and level-of-service and to aggregate both these and the loadings (in terms of vehicle miles of travel) in various ways. All of this is done for the Northwest Arkansas Regional Travel Demand Model by a post-processor to the travel model called POST_ALT. The POST_ALT program can be run after any model run, and produces estimates of level-of-service and average speeds by time-of-day for each link in the roadway network as well as a report which computes statistics for groupings of roadway segments in the network such as by functional class, area type, county, or corridor.

1. Estimation of Hourly Average Speeds and Volumes

The hourly average speed for each link is calculated by using the Bureau of Public Roads (BPR) form of the volume delay function with link specific parameters. The volume delay function is used to adjust the link's free-flow speed on the basis of its hourly volume to capacity ratio to account for congestion related delay. The alpha and beta parameters for the BPR equation which are used in both the travel model's assignment procedure as well as the post-processing are coded on the network links. Several sets of volume-delay parameters were applied in the Northwest Arkansas regional model to different classes of roadway. Due the method of capacity estimation adopted for the model which specifies an absolute capacity rather than a practical capacity, the Northwest Arkansas model uses different volume delay parameters than many models which use practical capacities. The default sets of volume-delay parameters for the Northwest Arkansas regional model are presented in Table 33. Initial parameters were developed from analysis of the data on average speeds from the congestion management study and modified through the process of validation of the assignment.

Table 33. Default Volume Delay Function Parameters by Roadway Class

Roadway Class	Volume Delay Parameters			
	Alpha		Beta	
Rural Interstate	0.98		6.0	
Urban Interstate	0.94		6.0	
Other Freeways	0.94		6.0	
	Signalized		Unsignalized	
	Alpha	Beta	Alpha	Beta
Highway/Arterials with Posted Speed>=55mph	0.27	2.7	0.81	2.7
Highway/Arterials with Posted Speed 45-54mph	0.22	2.6	0.65	2.6
Other Arterial/Collector	0.05	4.0	0.15	4.0
Other	0.15	4.0	0.15	4.0

The estimation of link free-flow speeds is based on posted speed and facility type and is treated in Chapter IV in this document. The capacities used in the estimation of average speeds are also the same capacities used in the travel model proper developed using techniques from the HCM 2000 and are described in detail in Chapter V in this document. The last input to the volume delay function, the volume, is estimated by apportioning the model's assigned volumes in each period and direction using an hourly distribution developed together with the peak-hour traffic percentages from observed data. The hourly distribution of trips is displayed in Figure 24 and Table 34.

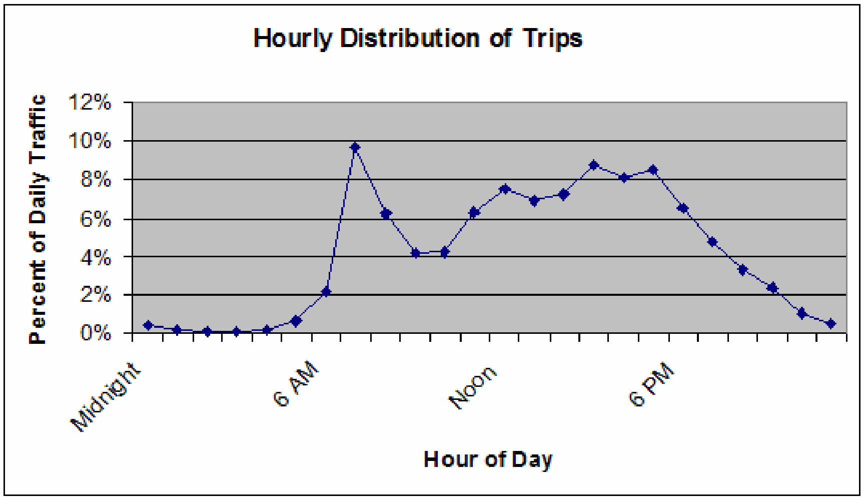


Figure 24. Northwest Arkansas Hourly Distribution of Total Traffic

Table 34. Distribution of Total Traffic by Hour

Period	Hour of Day	Percent of Daily Traffic	Percent of Period Assignment
Off Peak	1 AM	0.18%	0.31%
	2 AM	0.13%	0.22%
	3 AM	0.14%	0.24%
	4 AM	0.19%	0.32%
	5 AM	0.66%	1.12%
	6 AM	2.16%	3.68%
AM Peak	7 AM	9.67%	60.90%
	8 AM	6.21%	39.10%
Off Peak	9 AM	4.19%	7.13%
Off Peak	10 AM	4.25%	7.24%
	11 AM	6.27%	10.67%
	Noon	7.48%	12.73%
	1 PM	6.93%	11.78%
	2 PM	7.22%	12.28%
PM Peak	3 PM	8.75%	34.53%
	4 PM	8.09%	31.90%
	5 PM	8.51%	33.57%
Off Peak	6 PM	6.50%	11.06%
	7 PM	4.74%	8.07%
	8 PM	3.32%	5.65%
	9 PM	2.38%	4.05%
	10 PM	1.05%	1.79%
	11 PM	0.53%	0.90%
	Midnight	0.45%	0.76%

POST_ALT's speed estimation was calibrated to observed average speeds by time of day on major corridors from several congestion management studies. The calibration effort resulted in applying correction factors for signal delay and by area type. Signal delay was intentionally underrepresented in the travel model proper since using true delays would result in underloading of signalized facilities. This is due to a common psychological underestimation of the impact of signal delays on travel time. Similarly there is a psychological bias for certain trip attractors in urban areas and central business districts, and using true speeds in the model would cause under-assignment in the more densely developed areas.

2. Estimation of Level of Service

The estimates of level of service produced by POST_ALT are provided for general system level planning purposes and are not intended to replace manual level of service analyses for corridor planning and design purposes. Due to a variety of factors including the general assumptions regarding the percent of traffic in peak hour and peak fifteen minute periods and inherent limitations of the travel model to reproduce peak period directional splits, POST_ALT's estimates of level of service will not be as accurate as manual estimates for particular corridors which make use of corridor specific assumptions. It is therefore important that specific level of service analyses still be done for detailed planning when examining specific corridors and improvements.

POST_ALT estimates level of service using the criteria set forth in the HCM 2000. For the purposes of level of service analysis, the facilities in the model's roadway network are grouped into three facility types: freeways, expressways and rural multilane highways; rural two-lane roads and highways; and urban streets. Each of these facility types are dealt with separately in the Highway Capacity Manual and use differing criteria for determining level of service. Level of service for freeways, expressways and rural multilane highways is determined by peak period flow density in terms of passenger cars per lane per mile. For, rural two-lane roads and highways, level of service is determined by percent time following and average speed. For urban streets, level of service is determined on the basis of average speed alone.

For all facility types, a peak hour factor of 0.92 is assumed in urban areas and 0.88 is assumed in rural areas. The peak hour volume is assumed to be the greater of 60.9% of the AM period loading or 34.53% of the PM period loading. The directional split from the model for the peak period is used.