Travel Demand Forecasting Model
Methodology and Validation Report

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Ohio-Kentucky-Indiana Regional Council of Governments

ABSTRACT

TITLE: Travel Demand Forecasting Model Methdology and Validation Report

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AGENCY: The Ohio-Kentucky-Indiana Regional Council of Governments (OKI), is the regional planning organization for the eight-county, tri-state area of Greater Cincinnati. OKI works on an array of regional issues related to transportation planning, commuter services, and air and water quality.

Executive Director: Mark Policinski

ABSTRACT: This document describes the methodology used in the OKI/MVRPC Travel Demand Forecasting Model and the development of model input data (zonal socieconomic data, highway network data and transit network data). The document also provides the results of the application of the model to year 2000 conditions.

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Chapter 1 Introduction

1.1 Study Area

The travel demand model is a regional model. The metropolitan areas currently simulated in the model are: Cincinnati Metropolitan Region (OKI) and Dayton Metropolitan Region (MVRPC).

1.1.1 The OKI Region

The region, for which the Ohio-Kentucky-Indiana Regional Council of Governments is responsible for transportation planning, includes eight counties in three states in the Greater Cincinnati Metropolitan Area. As shown in Figure 1.1.1, the region consists of Butler, Clermont, Hamilton and Warren Counties in Ohio, Boone, Campbell and Kenton Counties in Kentucky and Dearborn County in Indiana.

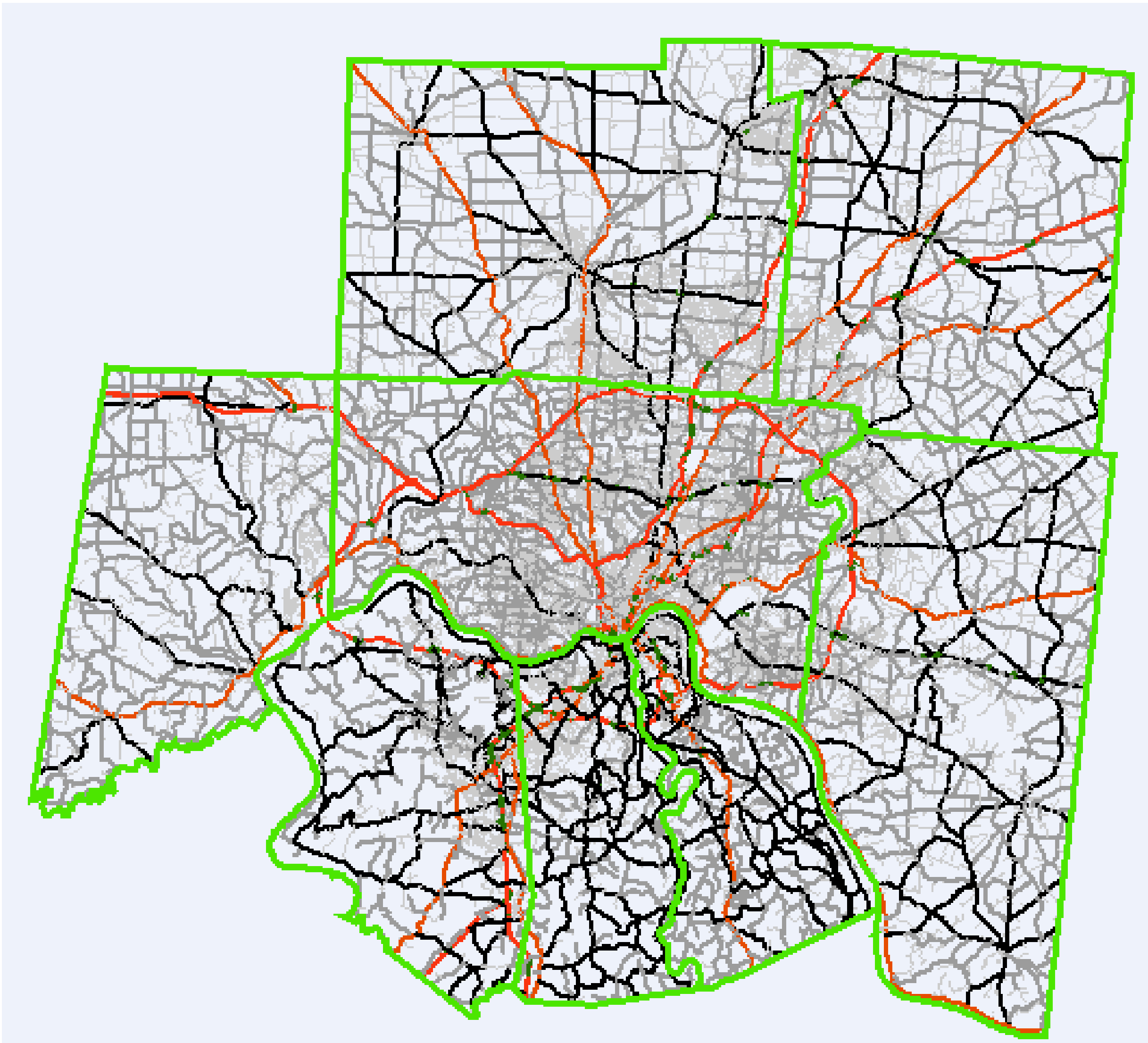
The region has about 1.9 million people and 2,300 square miles. Within this area are 191 units of county, city, village, and township governments. As the largest city within the study area, Cincinnati is located near the regional center. About one third of the region's population lives in Cincinnati (population 345,800) or the four other largest cities (Hamilton, Middletown, Covington and Fairfield with populations ranging from about 60,000 to 40,000, respectively).

Geographic features have influenced the region's transportation patterns and its early development as a transportation hub. These features include the region's waterways, of which the Ohio River is the most significant, and the region's terrain, which varies from gently rolling in the northern and eastern areas to steeply sloping in the southern and western areas. From the time of the earliest settlements to the present, valleys and ridge tops have helped determine the locations of the region's major transportation routes.

Transportation facilities have always been important to this region's growth and prosperity. In the late 1700s, the Ohio River supported Cincinnati's emergence as the gateway to the West, a point of convergence for people and goods. In the 1800s, the Miami-Erie Canal and the railroad system established the OKI Region as a commercial and transportation center.

Today, the region's transportation network includes five interstate highways, an international airport, and a web of arterial highways. As one of the most heavily multi-modal networks in the country, the region's transportation system is invaluable both to the health of the region's economy and the mobility of its population.

Figure 1.1.1 – The OKI Region



1.1.2 The MVRPC Region

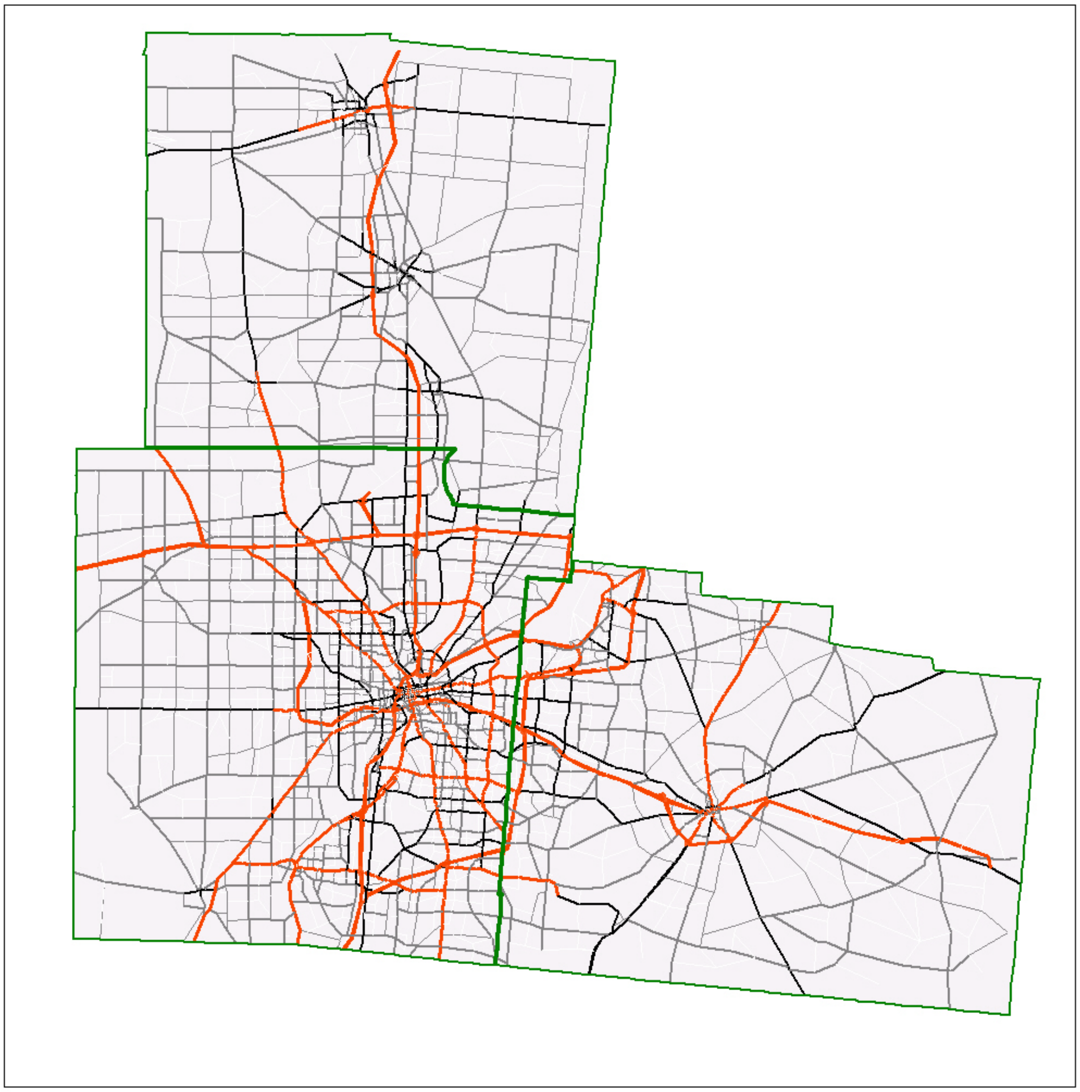
The Miami Valley Regional Planning Commission (MVRPC) is the regional planning commission for Darke, Greene, Miami, Montgomery, and Preble Counties in West Central Ohio. MVRPC is also the Metropolitan Planning Organization (MPO) for Greene, Miami, and Montgomery Counties and two jurisdictions in Warren County: Franklin and Carlisle. The MPO is part of the Dayton-Springfield Metropolitan Statistical Area that also includes Clark County.

The MPO is home to approximately 805,000 people in 1300 square miles in Greene, Miami, and Montgomery Counties. Within this area are 76 units of county, city, village, and township governments as well as Wright Patterson Air Force Base. According to the 2000 Census, about 70 percent of the population lives in Montgomery County with 166,000 living in Dayton, the largest city in the area.

Early settlements in the area date to the late 1700s. In 1829, the Miami-Erie canal reached Dayton from Cincinnati, contributing to growth and development of the region. Transportation and transportation technology have played an important role in the history of the area. Dayton is known as the birthplace of aviation, after the historic first flight of Dayton residents Orville and Wilbur Wright and in 1910 the first automobile self starter system was invented by Edward Deeds and Charles F. Kettering who formed the Dayton Engineering Laboratories.

Today, the region's transportation network includes three interstates, freeways, and principal arterials, including the intersection of I-70 and I-75, a major focal point for intermodal traffic.

Figure 1.1.2 – The MVRPC Region



1.2 History and Issues in Travel Demand Model Development

The travel demand model translates land use patterns and socio-economic characteristics of the population into estimates of travel magnitude, travel flow patterns and patronage on the various modes comprising the transportation system. The model provides a systematic way to analyze the immensely complex structure of urban development and travel. The Travel Demand Model was developed for such purposes. The model was so designed that the accuracy of the results are suitable for system planning at a regional level.

The Travel Demand Model was first designed in mid-1960s. The origin-destination survey data collected in 1965 was used to calibrate the model. In 1978 the study area was expanded to include the entire area of each of the nine counties (Butler, Clermont, Hamilton and Warren in Ohio, Boone, Campbell and Kenton in Kentucky and Dearborn and Ohio in Indiana). The model was also redesigned and modal choice models were added for the first time. In the modeling process, the entire study area was divided into traffic analysis subareas (i.e. zones or districts). There are 248 districts comprised of 909 zones in the study area plus 64 external stations.

In 1979, the model was first calibrated and validated at the district level using data obtained from the 1965 home interview survey, a 1978 small sample home interview survey, the 1975 Census Annual Housing Survey, and a 1978 bus on-board survey. Then, in 1983, the model was validated again at the zonal level against traffic counts taken in the years around 1978, 1978 transit line ridership and 1978 peak load point transit passenger counts in addition to the survey and census data. In both cases, the socio-economic data and the highway network and transit network representing 1978 conditions were used. The modules from the two most popular computer batteries for demand forecasting application (i.e. FHWA's PLANPAC and UMTA's UTPS) were used to perform the model.

In 1993, the model was converted to the PC-based TRANPLAN platform. Shortly after this conversion, the traffic zone system was expanded from 909 zones to 1003 zones. Many of the suburban zones have been subdivided to better simulate the loading pattern of traffic on to streets. The model was validated against 1990 traffic and transit ridership patterns.

In year 1995-1996 several trip surveys wee conducted. A household activity and travel survey was performed. The sample size was 3,000 OKI households proportioned by the number of households in each county. A transit on board trip survey was performed for Queen City Metro and Transit Authority of Northern Kentucky service areas. An external station trip survey was conducted along the cordon line of OKI study area and MVRPC study area. Additional trip surveys were conducted at King’s Island and the Northern Kentucky/Greater Cincinnati International Airport. In addition, travel time/speed studies were performed and results were incorporated into highway network link coding.

The model was recalibrated using the survey data mentioned above. Enhancements were made to the model methodology as well. The enhancements include (1) incorporating a nested logit model for modal choice phase to handle the transit access modes and ride-share of various occupancies, (2) incorporating a feedback loop from assignment phase to trip distribution phase to better simulate the peak period highway operation conditions, (3) incorporating an integrated highway/transit network to better simulate transit operating conditions, (4) using an equilibrium highway assignment procedure and (5) incorporating a time of the day analysis element.

In 2002, the model was expanded to include MVRPC (Dayton Metropolitan Area) region. In addition, enhancements were made to the model. The enhancements include (1) increasing the zones from 1,003 zones to 1,608 zone in OKI area, (2) restructuring the nested modal choice models for modal choice phase (3) using utility logsum for Gravity models in trip distribution phase and (4) modifying truck trip model. OKI's 1995-1996 survey data, MVRPC's 1990 household trip survey data and MVRPC's 1995 external station trip survey data were used for this work. The trip production and attraction scale factors are used to match observed VMT better.

In 2003, the model was applied to socioeconomic data and highway/transit data representing year 2000 conditions. In the process, adjustments were made to the model. The primary adjustments were made to trip generation model. Trip production and attraction rate scale factors are removed and the production/attraction balance is performed separately for OKI region and MVRPC region. Minor adjustments were made to the transit network/path building programs. EPA's MOBILE62 program (2/25/2004) version was incorporated in the model. The results of the model were compared to observed year 2000 traffic flow and transit ridership patterns. ~~The result of the validation is documented in Chapter 4.~~

2005 Model work using MVRPC 1001 household trip survey data (separate trip rates/friction factor, truck trip factoring, capacity feedback)
2006 Model work converting to VOYAGER scripts (except Step6, 22, 63 and post model programs)
2007 Model validation work using 2005 data (May 2007)

Other improvements will continue to be developed and will be included in future versions of the model. This will be an evolution from the original OKI Travel Demand Model which was designed and developed in the era in which providing more roadway capacity was considered the solution to transportation related problems. The requirements for the transportation planning process have become more demanding with the passage of the ISTEA legislation of 1991 and the companion Clean Air Act Amendments of 1990. A broader perspective of transportation in terms of mobility vs. travel is now required. This implies the need to model an intermodal system of transportation as well as testing non-structural policy alternatives for congestion management. The model also needs to incorporate the movement of goods in addition to exclusively people. The output of the model will need to address the impacts of tested alternatives on congestion, land use, and relief of the existing air quality problems facing the region. Along with the increasing demands for sophistication of the model, ~~the ISTEA also imposes a three-year plan review and update cycle~~. OKI will continue to refine and enhance the model to meet the data needs.

Chapter 2 Description of Travel Demand Model

2.1 Model Overview

In transportation planning, the knowledge of traffic volumes on the roadway segments and riderships on transit lines are very important. The information is needed to assess the intensity of problems of a transportation system and determine the needed transportation improvements. The information is also needed to assess the effectiveness of the proposed transportation improvements. Travel demand model is a tool used to estimate the traffic volumes on roadway segments and riderships on transit routes. It estimates traffic volumes and transit riderships based on the distribution of population and employment, and operation conditions of the transportation system serves them. The model is basically a set of mathematical equations simulating human's choice of trip making. The population/employment represents the travel demand and the transportation system represents the supply to serve the travel demand. The trip makers choose the way the supply is used to meet their demand. The model simulates how travelers make their travel choice on the use of the transportation system to best meet their needs. Traditionally, for simplicity, it is assumed that travelers making trip decisions independently and sequentially: to make a trip or not, where to, which transportation model and which highway route or transit line to take. The structure of a travel demand model usually includes four elements according to these decisions: trip generation, trip distribution, modal choice and assignment.

The OKI/MVRPC travel demand model is a traditional trip based sequential four-phase model. The model estimates daily trips by trip purpose. The trip purposes include: home-based work, home-based university, home-based other, home-based school transit, non-home-based auto, non-home-based transit, taxi, truck, external-internal, and external-external. The model is based on division of the region under study into hundreds of geographic areas called traffic analysis zones. In trip generation phase, the number of trip ends in each zone is estimated. First the households in each zone are classified according the demographic characteristics of the households (i.e. household size, number of workers in the household and automobiles owned by the household) and employment in each zone are classified according to the employment type (i.e. retail, office, and industrial), and then the trip rates of the corresponding classes are applied to estimate the trips produced and attracted. In the trip distribution phase, where the trips will go is estimated. The number of trips starting in each zone and ending in every other zone is calculated based on the travel composite impedances. In the modal choice phase, the number of the trips using different transportation modes (i.e. drive-alone, share-ride2, share-ride3, local bus by walk, local bus by driving, express bus by walk, express bus by driving, light rail by walk, light rail by driving, commuter rail by walk and commuter rail by driving) are estimated based on the relative differences in their travel times and costs. Finally in the assignment phase, the highway routes and transit routes the trips will take are determined, and the traffic volumes on roadway segments and riderships on transit lines are estimated. The traffic volumes and transit riderships are also used for cost/benefit analysis, estimating air pollution, energy consumption and safety. The structure of the model is described in Figure 2.1.2. An additional program is added to OKI/MVRPC travel demand model to perform these calculations.

The model is structured to estimate trips by traffic analysis zone. The region simulated in the model covers OKI (Cincinnati Metropolitan Area) and MVRPC (Dayton Metropolitan Area). The entire region is divided into 2,425 traffic analysis zones (1,608 in OKI area and 817 in

MVRPC area). There are 106 external stations (63 in OKI area and 43 in MVRPC area). The model estimates person trips for home-based and non-home based trip purposes and vehicle trips for truck, taxi, external-internal and external-external trip purposes. The person trips are converted to vehicle trips and all vehicle trips of various trip purposes are combined before being assigned to the highway network.

The model was calibrated using the socioeconomic data and transportation system data (See Chapter 3 for details) representing 1995 conditions. The trip data used are from OKI household trip survey (1995), MVRPC household trip survey (1990), OKI transit on-board trip survey (1995), MVRPC transit on-board trip survey (1996), and OKI/MVRPC external station trip surveys (1995-1996). The model was validated using year 2000 data in year 2003.

2004 model validation work
2005 model calibration work
2006 model convertion work
2006 model validation work

Figure 2.1.1 – Traffic Analysis Zones and External Stations

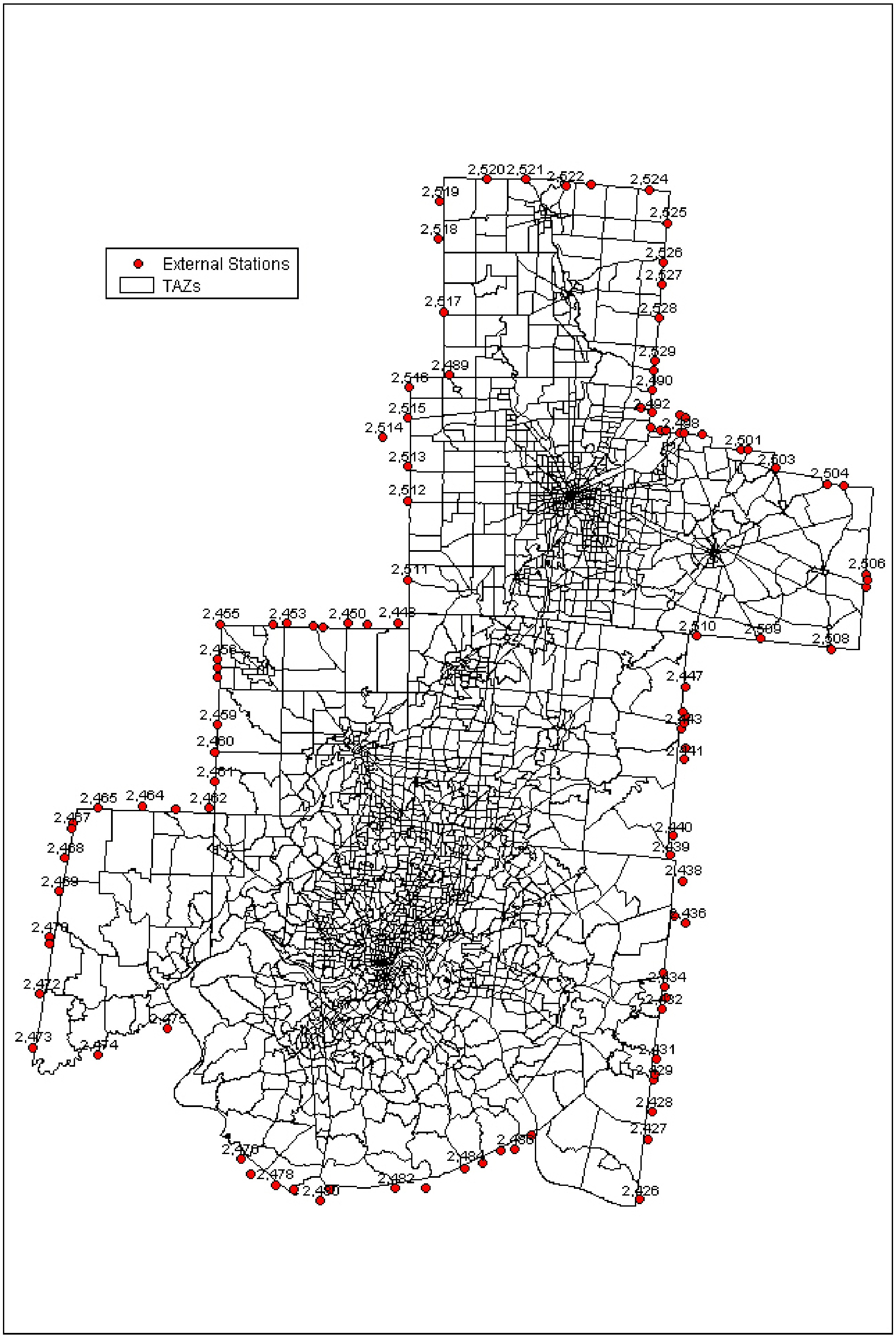
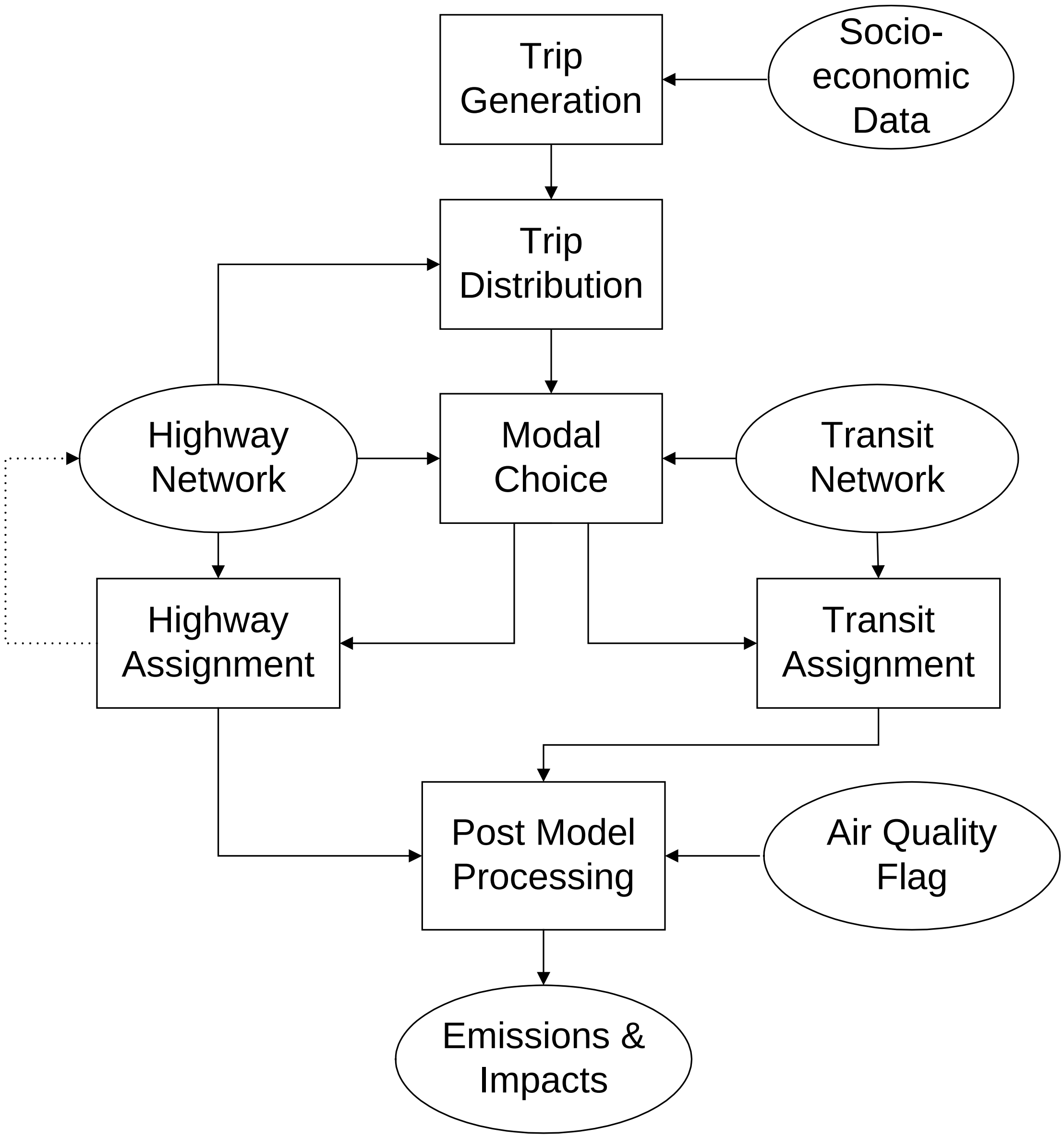


Figure 2.1.2 – Structure of OKI/MVRPC Travel Demand Model



2.2 Trip Generation

The trip generation models involve forecasting the number of trips generated from and attracted to a traffic analysis zone (i.e. trip productions and attractions) in the study area. The forecasting of person and vehicle trips produced from or attracted to a traffic zone is based on the premise that people travel for a specific purpose and that the trips that are made are related to quantifiable land use and socio-economic conditions of the zone. The trip generation models represent the relationships between person/vehicle trips to and from a traffic zone and its socio-economic conditions. In the OKI/MVRPC Travel Demand Model, four techniques are employed to define the relationships for various trip purposes: cross-classification analysis, regression analysis, trip rate analysis and growth factoring analysis.

2.2.1 Person Trip Production Equations for HBW, HBU, HBO and HBSC Trips

Disaggregate household cross-classification models are developed to forecast person trip productions for trip purposes: HBW, HBU, HBO and HBSC. The independent variables used in these models include workers per household, persons per household, automobiles per household and area type for the zone in which the household is located. The number of independent variables used varies for different trip purposes. The following equations are used to estimate person trip productions for HBW, HBU, HBO and HBSC:

$$P_i^{hbw} = \Sigma_{w=1}^{5} \Sigma_{a=1}^{4} (P_{i,w,a}^{hbw}) = \Sigma_{w=1}^{5} \Sigma_{a=1}^{4} (HH_{i,w,a} * PRATE_{at(i),w,a}^{hbw} * PFACT^{hbw})$$

$$P_i^{hbu} = \Sigma_{a=1}^{4} (P_{i,a}^{hbu}) = \Sigma_{a=1}^{4} (HH_{i,a} * PRATE_{at(i),a}^{hbu} * PFACT^{hbu})$$

$$P_i^{hbo} = \Sigma_{p=1}^{6} \Sigma_{a=1}^{4} (P_{i,p,a}^{hbo}) = \Sigma_{p=1}^{6} \Sigma_{a=1}^{4} (HH_{i,p,a} * PRATE_{at(i),p,a}^{hbo} * PFACT^{hbo})$$

$$P_i^{hbsc} = \Sigma_{p=1}^{6} \Sigma_{a=1}^{4} (P_{i,p,a}^{hbsc}) = \Sigma_{p=1}^{6} \Sigma_{a=1}^{4} (HH_{i,p,a} * PRATE_{at(i),p,a}^{hbsc} * TRATE_i * PFACT^{hbsc})$$

Where:

P_i^x is the daily person trip productions in zone i for trip purpose x (i.e. HBW, HBU, HBO or HBSC). P_i^{hbsc} =0, if zone i is not served by transit.

$P_{i,w,p,a}^x$ is the daily person trip productions in zone i made by the household group (w,p,a) for trip purpose x.

$P_{i,w,a}^x = \Sigma_p P_{i,w,p,a}^x$ $\quad$ $P_{i,p,a}^x = \Sigma_w P_{i,w,p,a}^x$ $\quad$ $P_{i,a}^x = \Sigma_p \Sigma_w P_{i,w,p,a}^x$

"w" is the index for the first dimension of the household type, 1 for 0 worker per household, 2 for 1 workers per household, 3 for 2 workers per household, 4 for 3 workers per household and 5 for 4 and above workers per household with an average of 4.254. "p" is the index for the second dimension of the household type, 1 for 1 person per household, 2 for 2 persons per household, 3 for 3 persons per household, 4 for 4 persons per household, 5 for 5 persons per household and 6 for 6 and above persons per household with an average of 6.627.

"a" is the index of the third dimension of the household type, 1 for 0 auto per household, 2 for 1 autos per household, 3 for 2 autos per household, and 4 for 3 and above autos per household with an average of 3.379.

"at" is the area type of the area in which the traffic zone is located, 1 for CBD, 2 for urban, 3 for suburban and 4 for rural.

$HH_{i,w,p,a}$ is the number of households belonging to household group (w,p,a) in zone i. The households in each zone are grouped in this phase also. The methodology of household grouping will be described later.

$HH_{i,w,a} = \Sigma_p HH_{i,w,p,a}$ $\qquad HH_{i,p,a} = \Sigma_w HH_{i,w,p,a}$ $\qquad HH_{i,a} = \Sigma_p \Sigma_w HH_{i,w,p,a}$

$PRATE_{at(i),w,a}^{hbw}$ is the daily HBW person trip productions per household for household group (w,a) in the area type (at) in which zone i is located. Two different sets of trip rates for HBW are developed for OKI Region and MVRPC Region. Tables 2.2.1-2.2.2 show the rates for HBW.

$PRATE_{at(i),a}^{hbu}$ is the daily HBU person trip productions per household for household group (a) in an area of area type (at) in which zone i is located. The rates for HBU are the same for both regions. Table 2.2.3 shows the rates for HBU.

$PRATE_{at(i),p,a}^{hbo}$ is the daily HBO person trip productions per household for household group (p,a) in an area of area type (at) in which zone i is located. Two different sets of trip rates for HBO are developed for OKI Region and MVRPC Region. Tables 2.2.4-2.2.5 show the rates for HBO.

$PRATE_{at(i),p,a}^{hbsc}$ is the daily HBSC person trip productions per household for household group (p,a) in an area of area type (at) in which zone i is located. The rates are the same for both regions. Table 2.2.6 shows the rates for HBSC.

$TRATE_i$ is the public transit usage rate. (See Table 2.2.7 for details.)

0.0000	for zones outside Hamilton County
0.1275	for zones within Cincinnati School District
0.0506	for zones outside of Cincinnati School District within OKI region
0.0506	for zones Kentucky State in OKI region
0.1275	for zones in Oakwood in MVRPC region
0.0506	for zone in Dayton in MVRPC region
0.0000	for zones in Montgomery County outside of Oakwood and Dayton and Greene County and Miami County in MVRPC region

$PFACT^x$ is the regional production rate scale factor for trip purpose x. These factors are calibrated in the validation phase to adjust the trip production rates so the model estimated VMT within each region match the observed VMT. The scale factors for OKI Region are 1.0 for HBW, HBU, HBO and HBSC. The scale factors for MVRPC Region are 0.9979 for HBW, 1.7090 for HBU and 1.2595 for HBO. (See Table 2.2.8.)

The households in each zone are classified among household groups. The household groups are defined using three variables: worker, person and auto. "w", "p" and "a" are the index for value ranges for these variables. The dimensions for each variable are follows:

Workers : 0, 1, 2, 3, 4^+
Persons : 1, 2, 3, 4, 5, 6^+
Automobiles : 0, 1, 2, 3^+

The following equation is used to classify the households into household groups:

$$HH_{i,w,p,a} = HH_i * (HH_{at(i),\, w,\, p.a}{}^b * ADJ_{at(i),\, w,p,a}) / \Sigma_w \Sigma_p \Sigma_a\ (HH_{at(i),\, w,\, p.a}{}^b * ADJ_{at(i),\, w,p,a})$$

Where:

$HH_{i,w,p,a}$ is the number of households in the analysis year in zone i belonging to household group (w,p,a).

HH_i is the total numbers of households in the analysis year in zone i.

$HH_{at(i),w,p,a}{}^b$ is the household classification factor for household group (w,p,a) in area type "at" in which zone i is located. Two sets of factors are developed, one for OKI Region and the other for MVRPC Region. For OKI Region the factors are developed using the household data obtained from 1990 census data and 1995 OKI household trip survey data. (See Tables 2.2.9-2.2.12.) For MVRPC Region the factors are developed using 1990 census data. These factors are labeled base household classification table. (See Tables 2.2.13-2.2.16)

$ADJ_{at(i),w,p,a}$ is the adjustment factor for household group (w,p,a) to assure that the overall average values on workers per household, persons per household and autos per household for all households in the zone matches the estimated analysis year zonal average workers per household ($WorkerPerHH_i$), persons per household ($PersonPerHH_i$) and autos per household ($AutoPerHH_i$) in zone i. The combination of $HH_{at(i),w,p,a}{}^b$ and $ADJ_{at(i),w,p,a}$ is a revised household classification table. The adjustment factors were calculated using the classical optimization technique which seeks to minimize the sum of cell-by-cell differences (χ square) between the base and revised household distributions, with the constraints of matching specified average values for each dimension of the tables, and maintaining a specified number of total households in the zone.

Table 2.2.1 – HBW Daily Person Trip Production per Household Rates, OKI Region ($PRATE_{at(i),w,a}^{hbw}$)

Area Type (at)	Autos Owned Per Household (a)	Workers Per Household (w)				
		0	1	2	3	4+
CBD & Urban	0	n/a	0.8797	2.3579	3.2211	4.2048
	1	n/a	1.2348	2.2947	3.2211	4.4887
	2	n/a	1.3465	2.4629	3.2211	4.4887
	3+	n/a	1.5354	2.4629	4.1244	4.4887
Suburban	0	n/a	1.3768	2.3455	2.5024	4.2048
	1	n/a	1.3768	2.3455	2.5024	4.4887
	2	n/a	1.4109	2.4647	2.5024	4.4887
	3+	n/a	1.4109	2.5887	3.8954	4.4887
Rural	0	n/a	1.3139	2.3702	2.5024	4.2048
	1	n/a	1.3139	2.3702	3.6792	4.4887
	2	n/a	1.4198	2.3702	3.6792	4.4887
	3+	n/a	1.4198	2.6629	4.2048	4.4887

Table 2.2.2 – HBW Daily Person Trip Production per Household Rates, MVRPC Region ($PRATE_{at(i),w,a}^{hbw}$)

Area Type (at)	Autos Owned per Household (a)	Workers per Household (w)				
		0	1	2	3	4+
CBD & Urban	0	n/a	1.5423	2.8939	4.2103	4.2103
	1	n/a	1.7108	2.9969	4.4182	6.6775
	2	n/a	1.8483	3.0917	4.4182	6.8732
	3+	n/a	2.4614	3.0961	4.8855	7.4900
Suburban	0	n/a	1.4464	2.8939	4.2103	4.2103
	1	n/a	1.6100	2.9969	4.4182	6.6775
	2	n/a	1.7239	3.0917	4.4182	6.8732
	3+	n/a	1.7239	3.0961	4.8855	7.4900
Rural	0	n/a	1.4767	2.8939	4.2103	4.2103
	1	n/a	1.5366	2.9969	4.4182	6.6775
	2	n/a	1.6465	3.0917	4.4182	6.8732
	3+	n/a	2.0911	3.0961	4.8855	7.4900

Table 2.2.3 – HBU Daily Person Trip Production per Household Rates, OKI Region & MVRPC Region ($PRATE_{at(i),a}^{hbu}$)

Autos Owned Per Household (a)	Area Type (at)		
	CBD & Urban	Suburban	Rural
0	0.0278	0.0200	0.0160
1	0.0762	0.0420	0.0818
2	0.0872	0.0576	0.1200
3+	0.1428	0.1294	0.1950

Table 2.2.4 – HBO Daily Person Trip Production per Household Rates, OKI Region ($PRATE_{at(i),p,a}^{hbo}$)

Area Type (at)	Autos Owned Per Household (a)	Persons Per Household (p)					
		1	2	3	4	5	6+
CBD & Urban	**0**	0.8972	1.6581	2.3884	2.3884	2.5448	2.7005
	1	1.6603	3.5892	4.0137	6.4326	6.4326	6.4326
	2	2.0213	3.5892	5.2097	7.7801	10.5647	10.5647
	3+	2.5384	3.5892	7.2816	9.7026	10.5647	13.0152
Suburban	**0**	0.9455	1.6581	2.3884	2.3884	2.5450	3.2612
	1	1.7396	4.1105	5.5828	8.3771	9.9859	10.5012
	2	1.3552	4.1105	5.5828	8.3771	9.9859	13.6907
	3+	1.1170	4.1105	5.5848	8.3771	9.9859	13.6907
Rural	**0**	0.9455	1.6581	2.3884	2.3884	2.5450	3.2612
	1	1.7113	2.1742	5.6078	6.5226	10.0055	10.0055
	2	1.9099	3.9482	5.6124	7.2951	10.0055	14.5124
	3+	1.9099	3.4157	5.6124	7.2951	10.8559	14.5124

Table 2.2.5 – HBO Daily Person Trip Production per Household Rates, MVRPC Region ($PRATE_{at(i),w,a}^{hbo}$)

Area Type (at)	Autos Owned per Household (a)	Persons per Household (p)					
		1	2	3	4	5	6+
CBD & Urban	0	0.8454	0.9251	0.3111	1.3111	1.3111	1.3111
	1	0.9703	1.9290	2.2515	2.2515	2.2515	2.2515
	2	1.9144	2.4494	2.7659	5.1366	5.1366	5.1366
	3+	1.9144	2.4494	2.7659	5.1366	5.1366	5.1366
Suburban	0	0.7227	0.8792	1.6211	1.6494	1.6494	1.6494
	1	1.5082	2.4384	3.4913	4.1952	4.6840	5.2011
	2	2.8954	2.8954	4.5366	6.0474	7.3303	8.3510
	3+	3.2738	4.1036	5.4212	6.7871	8.0589	8.9992
Rural	0	0.3106	0.6055	0.8824	0.8824	0.8824	0.8824
	1	1.5405	1.4633	3.3601	4.0258	4.6460	5.1953
	2	1.5405	2.4326	3.8679	5.5629	6.0212	6.2527
	3+	1.5405	2.4326	3.8679	5.9776	7.0927	7.8606

Table 2.2.6 – HBSC Daily Transit Person Trip Production Rates per Household, OKI Region & MVRPC Region ($PRATE_{at(i),p,a}^{hbsc}$)

Area Type (at)	Auto Owned Per Household (a)	Person Per HH (p)					
		1	2	3	4	5	6+
CBD/Urban	0	0.0122	0.1997	0.9514	1.7030	2.3813	3.0589
	1	0.0122	0.1527	0.4615	1.1413	2.0873	2.7064
	2	0.0122	0.0226	0.1880	0.7244	2.0873	2.7064
	3+	0.0122	0.0226	0.1880	0.7244	2.0873	2.1191
Suburban	0	0.0011	0.1984	0.9514	1.7030	2.3813	3.0589
	1	0.0011	0.1984	0.5679	1.1413	1.8561	2.7064
	2	0.0011	0.0127	0.4225	1.1413	1.8561	2.7064
	3+	0.0011	0.0127	0.1585	0.8736	1.3228	2.1191
Rural	0	0.0049	0.1984	0.9514	1.7030	2.3813	3.0589
	1	0.0049	0.0539	0.8913	1.5360	2.2934	3.1372
	2	0.0049	0.0539	0.5970	1.5360	2.2934	3.1372
	3+	0.0049	0.0539	0.3493	0.8742	1.9476	2.3032

Table 2.2.7 – Home-Based School Trip Public Transit Usage Codes ($TRATE_i$)

Traffic Analysis Zones	Yellow Bus Service	HBSCTUSE Code	Discount Factor
Zones in OKI region:			
Outside Hamilton Co.	Pervasive	0	0
Within Cincinnati Public School District	Negligible	1	0.1275
Outside Cincinnati Public School District, but inside Hamilton Co.	Moderate	2	0.0506
In Kentucky	Moderate	3	0.0506
Zones in MVRPC region:			
Oakwood (1829,1887,1972, 1974,1978)	Negligible	1	0.1275
Dayton	Moderate	2	0.0506
Rest of Montgomery Co.	Pervasive	0	0
Greene Co., Miami Co.	Pervasive	0	0

Table 2.2.8 – Trip Production and Attraction Scale Factors ($PFACT^{hbw}$, $PFACT^{hbu}$, $PFACT^{hbo}$, $PFACT^{hbsc}$, $AFACT^{hbw}$, $AFACT^{hbu}$, $AFACT^{hbo}$, $AFACT^{hbsc}$)

		HBW	HBU	HBO	HBSC
OKI Region	Productions	1.0000	1.0000	1.0000	1.0000
	Attractions	1.0000	1.0000	1.0000	1.0000
MVRPC Region	Productions	0.9979	1.7090	1.2595	1.0000
	Attractions	1.0000	1.0000	1.0000	1.0000

Table 2.2.9 – OKI Base Household Classification Table for Area Type: CBD ($HH_{CBD,w,p,a}^{b}$)

Autos/HH	Person/HH	Workers/HH				
		0	**1**	**2**	**3**	**4+**
0	**1**	394	293	0	0	0
	2	31	12	40	0	0
	3	9	1	0	1	0
	4	0	1	0	0	0
	5	0	0	0	0	0
	6+	0	0	0	0	0
1	**1**	67	379	0	0	0
	2	12	45	57	0	0
	3	1	1	1	0	0
	4	0	11	2	1	0
	5	0	7	1	0	0
	6+	0	1	0	0	0
2	**1**	15	26	0	0	0
	2	7	7	52	0	0
	3	2	2	1	6	0
	4	0	1	1	2	0
	5	0	1	1	2	0
	6+	0	0	0	0	0
3+	**1**	2	0	0	0	0
	2	0	0	6	0	0
	3	0	0	0	4	0
	4	0	0	0	9	0
	5	0	0	0	2	0
	6+	0	0	0	1	0

Table 2.2.10 – OKI Base Household Classification Table for Area Type: Urban ($HH_{Urban,w,p,a}{}^{b}$)

Autos/HH	Person/HH	Workers/HH				
		0	**1**	**2**	**3**	**4+**
0	**1**	9607	9542	0	0	0
	2	4812	3016	2353	0	0
	3	1292	1915	1883	149	0
	4	1719	1019	410	300	150
	5	0	420	280	300	0
	6+	0	469	287	150	0
1	**1**	17946	40376	0	0	0
	2	8059	6222	2808	0	0
	3	474	1457	1883	389	0
	4	856	1488	2249	399	389
	5	475	1748	452	100	100
	6+	0	714	180	100	242
2	**1**	1522	4011	0	0	0
	2	4779	6572	17648	0	0
	3	698	1697	5337	980	0
	4	840	1062	6304	750	170
	5	0	1484	1073	628	170
	6+	0	259	685	250	212
3+	**1**	527	925	0	0	0
	2	310	1619	3673	0	0
	3	150	902	1595	1762	0
	4	150	897	1417	1754	391
	5	0	650	260	298	339
	6+	0	0	260	199	100

Table 2.2.11 – OKI Base Household Classification Table for Area Type: Suburban ($HH_{Suburban,w,p,a}^{b}$)

Autos/HH	Person/HH	Workers/HH				
		0	1	2	3	4+
0	1	3000	1000	0	0	0
	2	470	380	290	0	0
	3	340	340	340	204	0
	4	200	242	300	200	100
	5	0	0	0	100	100
	6+	0	0	0	0	242
1	1	15707	49699	0	0	0
	2	8029	8189	3142	0	0
	3	562	5200	2622	680	0
	4	86	3000	1500	800	0
	5	0	795	230	200	0
	6+	0	200	100	144	0
2	1	1481	9872	0	0	0
	2	19818	25067	46622	0	0
	3	1026	10062	20652	1816	0
	4	0	15214	30584	1609	0
	5	0	7005	7142	270	0
	6+	0	1806	3387	184	558
3+	1	0	1267	0	0	0
	2	2077	5531	15537	0	0
	3	565	6828	10725	10102	0
	4	0	2799	10927	7800	2000
	5	0	1555	2943	3480	1516
	6+	0	500	1709	1455	379

Table 2.2.12 – OKI Base Household Classification Table for Area Type: Rural ($HH_{Rural,w,p,a}{}^{b}$)

Autos/HH	Person/HH	Workers/HH				
		0	**1**	**2**	**3**	**4+**
0	**1**	1000	300	0	0	0
	2	380	90	90	0	0
	3	110	110	110	0	0
	4	0	184	100	0	0
	5	0	0	0	0	0
	6+	0	0	0	0	0
1	**1**	2960	6224	0	0	0
	2	1082	1280	239	0	0
	3	330	1967	679	0	0
	4	300	1000	400	0	0
	5	0	0	0	0	0
	6+	0	253	0	0	0
2	**1**	783	2665	0	0	0
	2	4094	6503	11879	0	0
	3	279	1855	7097	325	0
	4	274	3875	4720	295	0
	5	0	1532	2654	0	0
	6+	0	1068	1073	0	0
3+	**1**	0	194	0	0	0
	2	2159	2930	3903	0	0
	3	585	1565	3565	1546	0
	4	331	2070	4400	2060	608
	5	331	590	1876	1256	253
	6+	0	0	200	310	485

Table 2.2.13 – MVRPC Base Household Classification Table for Area Type: CBD ($HH_{CBD,w,p,a}^{b}$)

Auto / HH	Person / HH	Workers per Household				
		0	1	2	3	4+
0	1	75	20	0	0	0
	2	9	11	0	0	0
	3	3	0	0	0	0
	4	0	0	4	0	0
	5	0	0	0	0	0
	6+	0	0	0	0	0
1	1	69	83	0	0	0
	2	30	61	21	0	0
	3	5	19	15	0	0
	4	0	7	10	4	0
	5	4	7	0	7	0
	6+	0	11	0	0	0
2	1	2	10	0	0	0
	2	20	30	48	0	0
	3	3	20	42	3	0
	4	0	9	36	2	2
	5	0	5	5	0	0
	6+	0	14	5	0	0
3+	1	0	3	0	0	0
	2	3	10	16	0	0
	3	0	10	10	12	0
	4	0	3	14	9	2
	5	0	0	4	3	15
	6+	0	10	0	0	0

Table 2.2.14 – MVRPC Base Household Classification Table for Area Type: Urban ($HH_{Urban,w,p,a}{}^{b}$)

Auto / HH	Person / HH	Workers per Household				
		0	**1**	**2**	**3**	**4+**
0	**1**	8621	2288	0	0	0
	2	1094	1252	0	0	0
	3	320	0	0	0	0
	4	0	0	438	0	0
	5	0	0	0	0	0
	6+	0	0	0	0	0
1	**1**	7897	9582	0	0	0
	2	3434	6993	2407	0	0
	3	537	2138	1736	0	0
	4	0	865	1101	450	0
	5	457	836	0	800	0
	6+	0	1263	0	0	0
2	**1**	283	1199	0	0	0
	2	2290	3499	5591	0	0
	3	335	2341	4885	396	0
	4	0	1081	4130	282	284
	5	0	522	621	0	0
	6+	0	1579	624	0	0
3+	**1**	0	344	0	0	0
	2	308	1097	1852	0	0
	3	0	1200	1168	1419	0
	4	0	388	1647	1009	204
	5	0	0	445	360	1704
	6+	0	1133	0	0	0

Table 2.2.15 – MVRPC Base Household Classification Table for Area Type: Suburban ($HH_{Suburban,w,p,a}^{b}$)

Auto / HH	Person / HH	Workers per Household				
		0	1	2	3	4+
0	1	4134	196	0	0	0
	2	329	0	223	0	0
	3	0	0	0	0	0
	4	0	0	0	0	0
	5	0	0	0	0	0
	6+	0	0	0	0	0
1	1	8768	15762	0	0	0
	2	5159	5756	1523	0	0
	3	325	3707	846	463	0
	4	195	1279	521	0	0
	5	228	301	305	0	0
	6+	0	0	0	0	0
2	1	388	1374	0	0	0
	2	4916	8820	19375	0	0
	3	445	5278	7349	1482	0
	4	0	5619	11440	799	831
	5	0	3854	2793	153	494
	6+	0	1992	794	431	0
3+	1	0	643	0	0	0
	2	676	2512	3846	0	0
	3	695	3174	4886	3763	0
	4	167	1095	4461	3239	778
	5	195	773	2091	143	1849
	6+	0	1119	371	403	1332

Table 2.2.16 – MVRPC Base Household Classification Table for Area Type: Rural Area ($HH_{Rural,w,p,a}{}^{b}$)

Auto /HH	Person / HH	Workers per Household				
		0	1	2	3	4+
0	1	338	0	0	0	0
	2	0	0	0	0	0
	3	0	0	0	0	0
	4	0	0	0	0	0
	5	0	0	0	0	14
	6+	2	8	9	1	1
1	1	1148	638	0	0	0
	2	0	729	348	0	0
	3	0	325	0	0	0
	4	138	0	0	0	0
	5	0	0	0	1	125
	6+	20	69	75	11	7
2	1	0	0	0	0	0
	2	330	1405	1342	0	0
	3	82	156	1119	0	0
	4	0	416	763	0	0
	5	86	260	0	0	200
	6+	31	111	120	18	10
3+	1	0	0	0	0	0
	2	65	237	494	0	0
	3	80	0	659	525	0
	4	0	817	375	448	0
	5	0	255	238	0	132
	6+	21	72	80	12	7

2.2.2 Person Attraction Equations for HBW, HBU, HBO and HBSC Trips

The trip rate technique is applied to develop the person trip attraction equations for HBW, HBU, HBO, and HBSC trips.

$A_i^{hbw} = 1.506 \times EMP_i \times AFACT^{hbw} \times FBAL^{hbw}$

$A_i^{hbu} = UENR_i \times URATE_i \times AFACT^{hbu} \times FBAL^{hbu}$

$A_i^{hbo} = [(0.230 \times LEMP_i + 0.200 \times MEMP_i + 12.744 \times HEMP_i + 1.062 \times HH_i) \times FCBD_{at(i)} + ADD_i^{hbo}] \times AFACT^{hbo} \times FBAL^{hbw}$

$A_i^{hbsc} = SENR_i \times SRATE_i \times AFACT^{hbsc} \times FBAL^{hbsc}$ for zones with a high school(s)

Where:

A_i^x is the daily person trip attractions in zone i for trip purpose x (i.e. HBW, HBU, HBO and HBSC).

EMP_i is the total employment in zone i. The total employment is grouped in to three categories : High HBO trip rate employment, medium HBO trip rate employment and low HBO trip rate employment.

$LEMP_i$ is the low HBO trip rate employment in zone i. $LEMP_i = EMP_i * LEMP\%_i$. Where $LEMP\%_i$ is the percentage of employment belonging to the group with a low trip generation rate. See Table 2.2.17 for grouping definition.

$MEMP_i$ is the medium HBO trip rate employment in zone i. $MEMP_i = EMP_i * MEMP\%_i$. Where $MEMP\%_i$ is the percentage of employment belonging to the group with a medium trip generation rate.

$HEMP_i$ is the high HBO trip rate employment in zone i. $HEMP_i = EMP_i * HEMP\%_i$. Where $HEMP\%_i$ is the percentage of employment belonging to the group with a high trip generation rate.

HH_i is the number of households in zone i.

$UENR_i$ is the daily university enrollment in zone i.

$SENR_i$ is the secondary school enrollment in zone i.

$SENR_i = (SENR_i^{1990}) \times SPOP_{county(i)} / SPOP_{county(i)}^{1990}$

Where:

$SENR_i^{1990}$ is the 1990 secondary school enrollment.

$SPOP_{county(i)}^{1990}$ is 1990 high school age (age 12-17) population of the county in which zone i is located. See Table 2.2.22 for 1990 high school age populations by county.

$SPOP_{county(i)}$ is analysis year high school age (age 12-17) population of the state in which zone i is located. See Table 2.2.22 for 1995, 2010, 2020 and 2030 high school age populations by county.

$URATE_i$ is the daily person trips per enrollment made by university students in zone i. See Tables 2.2.18 and 2.2.19 for the zones with universities and their rates.

$SRATE_i$ is the daily person trips per enrollment made by secondary school students in zone i. See Tables 2.2.20 and 2.2.21 for the zones with high schools and their rates.

$FCBD_{at(i)}$ is a factor to adjust the HBO trip attraction rates for zones in Central Business Area (CBD). Since many of the trips in CBD are made by walking, the person trip rates should be discounted. $FCBD_{at(i)} = 0.3$ for zone i located in an area which area type "at" = 1. $FCBD_{at(i)} = 1$ for non-CBD zones.

ADD_i^{hbo} is daily person trip attraction add-on in zone i for trip purpose HBO. For the zones with special generator(s), the HBO person trip attractions are often underestimated with the HBO trip attraction rates for HEMP and MEMP in the equation. ADD_i^{hbo} is added to make up the difference. The add-on trip attractions are estimated for the zones with major recreational centers, shopping centers/strips, the Greater Cincinnati Airport and other special zones:

(1) For zones with recreational centers

$$ADD_i^{hbo} = PATRONAGE_i * ADDRATE_i^{rec}$$

(2) For zones with shopping centers/strips

$$ADD_i^{hbo} = REMP_i * ADDRATE_i^{shop}$$

(3) For the zone with Cincinnati North Kentucky International Airport

$$ADD_i^{hbo} = 0.0169 * EMP^{oki} – 7,579$$

(4) For the zone with Covington IRS Office

$$ADD_i^{hbo} = 4,000$$

(5) For the zone with Drawbridge Inn

$$ADD_i^{hbo} = 5{,}000$$

Where

$PATRONAGE_i$ is the daily patronage of the recreational centers in zone i.

$ADDRATE_i^{rec}$ is the HBO daily add-on trip attractions per recreational patronage in zone i and it is set to 1.23 for all zones with recreational centers. See Tables 2.2.23 and 2.2.24 for the zones with recreational centers and their rates.

$REMP_i$ is the retail employment in zone i. $REMP_i$ = $HEMP_i$, the employment with high HBO trip rate.

$ADDRATE_i^{shop}$ is the daily HBO add-on attractions per retail employment in zone i. See Tables 2.2.25 and 2.2.26 for the zones with shopping centers or strips and their rates.

EMP^{oki} is the total employment in the OKI region.

$AFACT^x$ is the regional attraction scale factor for trip purpose x. These factors are calibrated in the validation phase to adjust the trip attractions so the model better estimate the traffic at the boarder between OKI and MVRPC region. The scale factors for OKI Region are 1.00 for HBW and 1.00 for HBO. The scale factors for MVRPC Region are 1.00 for HBW and 1.00 for HBO. (See Table 2.2.8.)

$FBAL^{hbw}$, $FBAL^{hbu}$, $FBAL^{hbo}$ and $FBAL^{hbsc}$ are the production and attraction balancing factors for trip purposes HBW, HBU, HBO and HBSC respectively. The zonal person attractions are adjusted by these factors so that the total person trip attractions for the region matches the total person trip productions for the region.

$$FBAL^{hbw} = \sum_{i=1}^{all} P_i^{hbw} / \sum_i^{all} A_i^{hbw}$$
$$FBAL^{hbu} = \sum_{i=1}^{all} P_i^{hbu} / \sum_i^{all} A_i^{hbu}$$
$$FBAL^{hbo} = \sum_{i=1}^{all} P_i^{hbo} / \sum_i^{all} A_i^{hbo}$$
$$FBAL^{hbsc} = \sum_{i=1}^{all} P_i^{hbsc} / \sum_i^{all} A_i^{hbsc}$$

Table 2.2.17 – Employment Classification Table
(be replaced by below)

Employment Category	Description
Low HBO Trip Rate Employment (LEMP)	Agriculture, Forestry, Fisheries, Mining, Construction, Manufacturing, Armed Forces
Medium HBO Trip Rate Employment (MEMP)	Transportation, Communication, Other Public Utilities, Wholesale Trade, Finance, Insurance, Real Estate, Health Services, Educational Services, Public Administration, Other Professional Services
High HBO Trip Rate Employment (HEMP)	Retail Trade, Business and Repair Services, Personal Services, Entertainment and Recreation Services

The employment data by 10 industrial categories are grouped for used in trip attraction (3 groups : Low, Medium and High) calculation and for truck trip (4 groups : Agriculture, mining and construction; Office & Servcies; Manufacturing, Transportation, Communications, Utilities & Wholesale Trade; and Retail) calculation as follows:

Employment Class	Trip Generation Grouping	Truck Model Grouping
Agriculture	Low	Agriculture, Mining and Construction
Construction	Low	Agriculture, Mining and Construction
Finance, insurance, real estate	Medium	Office & Services
Manufacturing	Low	Manufacturing, Transportation, Communications, Utilities & Wholesale trade
Mining	Low	Agriculture, Mining and Construction
Public	Medium	Office & Services
Retail	High	Retail
Service	Medium	Office & Services
Transportation, communications, utility	Low	Manufacturing, Transportation, Communications, Utilities & Wholesale trade
Wholesale trade	Medium	Manufacturing, Transportation, Communications, Utilities & Wholesale trade

The base year 2000 OKI socioeconomic database contains employment for each TAZ for ten industry categories based on two-digit SIC codes. The two digit codes and their corresponding industry categories are as follows:

Category	Two-digit SIC Code
Agriculture	01-09
Mining	10-14

Construction	15-17
Manufacturing	20-39
Transportation, Communications, Utilities	40-49
Wholesale Trade	50-51
Retail Trade	52-59
Finance, Insurance, Real Estate (FIRE)	60-67
Services	70-89
Public Administration	91-97

Table 2.2.18 – Daily Home-Based University Person Trip Attraction Rate per Enrollment ($URATE_i$) in OKI Region

UNIVERSITY NAME	$ZONE_i$	$URATE_i$
Xavier University	208	0.492
Miami University – Oxford	698	0.236
Northern Kentucky University	1303	0.800
Antonelli Institute of Art and Photography	261	0.910
Art Academy of Cincinnati	249	0.910
OMI College of Applied Science	238	0.910
Hebrew Union College	330	0.320
Cincinnati Technical College	349	0.800
University of Cincinnati	332	0.320
Medical Center / College of Medicine - UC	337	0.320
College of Nursing - UC	336	0.320
College of Pharmacy - UC	336	0.320
Institute of Technical Careers	338	0.910
God's Bible College	318	0.492
Raymond Walter College	103	0.800
Scarlet Oaks Vocational School	410	0.910
Cincinnati College of Mortuary Science	480	0.910
Southern Ohio College MTA	398	0.910
Mt. Saint Joseph College	537	0.516
Diamond Oaks Vocational School	583	0.910
D. Russell Lee Vocational School	841	0.910
Miami University - Hamilton	802	0.800
Miami University - Middletown	888	0.800
Warren County Career Center	1101	0.910
Live Oak Vocational School	1159	0.910
Thomas More College	1423	0.910
Clermont College	1211	0.910

Table 2.2.19 – Daily Home-Based University Person Trip Attraction Rate per Enrollment ($URATE_i$) for MVRPC Region

UNIVERSITY NAME	$ZONE_i$	$URATE_i$
Wilberforce University	2273	0.40
Wright State University	2143	0.40
Cedarville College	2298	0.35
Central State University Campus	2272	0.35
Sinclair Community College	1643	0.70
Central Michigan University	2017	0.70
Kettering College of Medical Arts	2045	0.70
Park College	2017	0.70
Miami-Jacobs College	1633	0.70
RETS Tech Center	2033	0.70
United Theological Seminary	1798	0.70
Capitol University - Adult Degree Program	1623	0.70
University of Dayton	1892	0.25
Antioch College	2277	0.25
Edison Community College	2357	0.70
Air Force Institute of Technology	2017	0.70

Table 2.2.20 – Daily Home-Based School Transit Person Trip Attraction Rate per Enrollment ($SRATE_i$) for Zones with High Schools Served by Public Transit (Not Including Yellow Bus Service) in OKI Region

School	$ZONE_i$	$SRATE_i$
McNicholas High School	20	0.084
Moeller High School	145	0.018
Shroder Junior High School	161	1.4
Walnut Hills High School	210	1.76
Purcell-Marian High School	211	1.781
Withrow High School	216	1.87
Summit Country Day High School	219	0.105
Clark Montessori High School	236	1.242
St Ursula Academy High School	238	0.511
Creative & Performing Arts High	251	0.901
Taft High School	303	0.693
Bloom Junior High School	311	1.141
Gods Bible High School	318	0.2
Hughes Alternative Center High	322	1.48
St. Bernard/Roger Bacon High School	356	0.427
Harmony Community School	367	1.261
Woodward High School	371	1.124
Aiken High School	471	1.123
McAuley High School	472	0.039
St Xavier High School	480	0.132
Seton/Elder High School	514	0.58
Western Hills High School	517	1.445
Mother Of Mercy High School	565	0.615
Dater Junior High School	567	1.166
Lasalle High School	593	0.276
Newport Middle School	1260	0.072
Newport High School	1263	0.045
Newport Central/Holy Spirit	1284	0.088
Campbell Co.High School	1322	0.029
Reiley Middle School	1324	0.05
Covington Latin	1345	0.235
Holmes High School/Chapman Vocational	1356	0.344
Notre Dame Academy	1361	0.462
Covington Catholic	1362	0.8
Ludlow High School.	1367	0.07
Villa Madonna Academy	1376	0.067
Beechwood High School.	1397	0.084
Covington Adult High School	1406	0.333
Holy Cross	1407	0.532
S.Dearborn High/Middle	1580	0.006
High Scott School	1604	0.031

Table 2.2.21 – Daily Home-Based School Transit Person Trip Attraction Rate per Enrollment ($SRATE_i$) for Zones with High Schools Served by Public Transit (Not Including Yellow Bus Service) in MVRPC Region

High School	$ZONE_i$	$SRATE_i$
Patterson Co-op High School	1628	0.50
Dunbar High School	1681	0.50
Wayne High School	1752	0.50
Belmont High School	1752	0.50
Chaminade-Julienne High School	1774	0.50
Colonel White High School	1833	0.50
Meadowdale High School	1842	0.50
Oakwood High School	1973	0.20
Carroll High School	2015	0.50

Table 2.2.22 – School-Age Population by County

County	Population Between 11 and 17 Years Old				
	1990	1995	2010	2020	2030
Butler	62,090	66,762	76,938	87,302	89,480
Clermont	33,960	36,529	35,140	34,786	33,400
Hamilton	171,160	177,770	186,140	189,696	197,758
Warren	23,326	26,801	31,776	36,890	45,110
Boone	12,995	14,640	20,922	22,824	26,526
Campbell	17,243	17,151	16,734	15,554	15,146
Kenton	29,654	29,380	28,552	27,024	26,116
Dearborn	8,748	9,945	10,238	11,044	10,974
Montgomery	44,093	44,220	45,251	45,830	46,409
Greene	11,620	12,166	13,145	13,908	14,670
Miami	8,388	8,698	9,334	9,807	10,280

Table 2.2.23 – Daily Home-Based Other Add-on Person Trip Attraction Rate per Patronage for Recreational Centers ($ADDRATE_i^{rec}$) in OKI Region

DESCRIPTION	$ZONE_i$	$ADDRATE_i^{rec}$
Cincinnati Museum of Natural History	110	1.23
Krohn Conservatory	110	1.23
Cincinnati Art Museum	110	1.23
Coney Island Amusement Park	145	1.23
Riverdowns Race Track	145	1.23
Music Hall	203	1.23
Union Terminal Museums	203	1.23
Cincinnati Zoo	233	1.23
Surf Cincinnati Waterpark	363	1.23
Americana Amusement Park	591	1.23
Kings Island Amusement Park	682	1.23
College Football Hall of Fame	682	1.23
Jack Nicklaus Sports Center	683	1.23
Cincinnati Nature Center	709	1.23
Turfway Race Track	814	1.23

Table 2.2.24 – Daily Home-Based Other Add-on Person Trip Attraction Rate per Patronage for Recreational Centers ($ADDRATE_i^{rec}$) in MVRPC Region

DESCRIPTION	$ZONE_i$	$ADDRATE_i^{rec}$
Boonshoft Museum of Discovery	1924	1.23
Dayton Art Institute	1761	1.23
Hara Arena	1844	1.23
Courthouse Square	1638	1.23
Nutter Center	2143	1.23
Victoria Theatre	1627	1.23
Memorial Hall	1617	1.23
Fraze Pavilion	1922	1.23
USAF Museum	2017	1.23

Table 2.2.25 – Daily Home-Based Other Add-on Person Trip Attraction Rate Per Retail Employment for Shopping Centers/Strips ($ADDRATE_i^{shop}$) in OKI Region

GENERATOR	$ZONE_i$	$ADDRATE_i$
SR-28 Commercial	695	6.96
	696	6.98
	971	6.98
	972	6.96
SR-32 Commercial	51	6.00
	977	6.00
Beechmont Avenue Commercial	25	6.10
	52	6.41
	148	5.75
Kenwood Commercial	173	6.13
	174	6.39
	907	4.25
Montgomery Commercial	284	6.76
Fields-Ertel Road Commercial	951	6.00
	966	6.00
	967	6.00
Forestfair Commercial	364	6.00
	365	6.00
	958	6.00
	959	6.00
Pleasant Avenue Commercial	501	5.37
	502	5.76
	573	6.24
	915	6.24
Tricounty Commercial	41	4.50
	42	4.48
	371	5.00
	372	4.42
	376	6.38
	377	4.37
	379	4.76
S.R.4 Commercial	367	5.00
	494	5.00
	567	4.99
	568	5.18
	574	5.36
	918	5.36
	920	5.36
	921	5.36
	922	5.36
Colerain Avenue Commercial	45	5.07
	46	4.92
	449	5.37
	454	4.83
	455	4.39
	456	5.00
	465	3.77
	497	4.82
	905	5.00

GENERATOR	$ZONE_i$	$ADDRATE_i$
Western Hills Commercial	416	5.86
	417	5.88
Covington Commercial	764	6.36
Fort Wright Commercial	791	5.57
Buttermilk Pike Commercial	899	6.77
Edgewood Commercial	57	6.37
	797	4.94
	798	6.13
	799	6.13
	800	4.90
	902	6.00
Florence Commercial	60	5.96
	815	6.34
	816	6.10
	817	5.29
	818	5.24
	819	5.76
	820	6.00
	821	4.64
	995	6.36
	996	5.76
	997	5.76
	998	5.29

Table 2.2.26 – Daily Home-Based Other Add-on Person Trip Attraction Rate Per Retail Employment for Shopping Centers/Strips ($ADDRATE_i^{shop}$) in MVRPC Region

GENERATOR	$ZONE_i$	$ADDRATE_i$
Town and Country	1860	5.90
Salem Mall	1869	5.90
Northmont Plaza	1879	4.50
Waynetowne Plaza	1998	5.75
Northpark Shopping Center	2005	5.90
Township Square	2012	4.50
Cross Pointe Centre	2030	4.50
Centerville Place	2037	5.75
Carrollton Plaza	2055	5.90
Corners at the Mall	2064	5.90
Dayton Mall	2065	6.10
Lyons Crossing	2113	5.75
Beavercreek Towne	2179	5.75
Mall at Fairfield Commons	2188	6.10
Fairfield Crossing	2189	5.75
Sugarcreek Plaza I & II	2211	5.90
Miami Valley Centre Mall	2337	5.75
Piqua Mall	2357	5.75

2.2.3 Person Trip Origin and Destination Equations for NHB Trips

For a non-home-based (NHB) trip, by definition, neither end of the trip occurs at home. The trip is made after a home-based trip or another non-home-based trip is made. Therefore, the number of NHB trips in a zone is proportional to the number of home-based trip attractions in the zone. A cross-classification model is used to forecast the auto/transit person trip origins and destinations. Since neither end of the trip is at home, the trip origins are treated as productions and the destinations as attractions. For each of the mode/trip end combinations, the following equations are used to estimate the NHB person trip productions and attractions:

$$P_i^{nhb} = HBA_{i,AUTO}^{hbw} \times NHBPRATE_{at(i), AUTO}^{hbw} + HBA_{i,TR}^{hbw} \times NHBPRATE_{at(i),TR}^{hbw} + HBA_{i,AUTO}^{hbo} \times NHBPRATE_{at(i), AUTO}^{hbo} + HBA_{i,TR}^{hbo} \times NHBPRATE_{at(i),TR}^{hbo} + HBA_i^{hbu} \times NHBPRATE_{at(i)}^{hbu}$$

$$A_i^{nhb} = HBA_{i,AUTO}^{hbw} \times NHBARATE_{at(i), AUTO}^{hbw} + HBA_{i,,TR}^{hbw} \times NHBARATE_{at(i),TR}^{hbw} + HBA_{i,AUTO}^{hbo} \times NHBARATE_{at(i), AUTO}^{hbo} + HBA_{i,TR}^{hbo} \times NHBARATE_{at(i),TR}^{hbo} + HBA_i^{hbu} \times NHBARATE_{at(i)}^{hbu}$$

Where:

P_i^{nhb} is the daily person trip productions for trip purpose NHB in zone i.

$HBA_{i,m}^{x}$ is x (hbw and hbo) purpose daily person trip attractions by mode m (AUTO or TR) in zone i.

$$HBA_{i,AUTO}^{hbw} = \Sigma_j \left(T_{j,i,DA}^{hbw} + T_{j,i,SR}^{hbw}\right)$$
$$HBA_{i,AUTO}^{hbo} = \Sigma_j \left(T_{j,i,DA}^{hbo} + T_{j,i,SR}^{hbo}\right)$$
$$HBA_{i,TR}^{hbw} = \Sigma_j \left(T_{j,i,TR}^{hbw}\right)$$
$$HBA_{i,TR}^{hbo} = \Sigma_j \left(T_{j,i,TR}^{hbo}\right)$$

HBA_i^{x} is x (hbu) purpose daily person trip attractions

$$HBA_i^{hbu} = \Sigma_j \left(T_{j,i,DA}^{hbu} + T_{j,i,SR}^{hbu} + T_{j,i,TR}^{hbu}\right)$$

Where

$T_{j,i,k}^{x}$ is the person trip interchanges by mode k [i.e. Drive Alone (DA), Shared-Ride (SR) and Transit (TR)] in zone i for trip purpose x (i.e. HBW, HBU and HBO). The mode specific person trip attractions are estimated in the modal choice phase that will be described later.

$NHBPRATE_{at(i),m}^{x}$ is the daily NHB person trip origins by mode m (auto and transit) per x purpose home-based person trip attraction by area type (at) in which zone i is located. One set is developed for HBW/HBO trip attractions (see Table 2.2.27) and another set for HBU attractions (see Table 2.2.28).

$NHBARATE_{at(i),m}^{x}$ is the daily NHB person trip destinations (auto and transit combined) per x purpose home-based person trip attraction by area type (at) in which zone i is located. One set is developed for HBW/HBO trip attractions (see Table 2.2.27) and another set for HBU attractions (see Table 2.2.28).

Table 2.2.27 – NHB Daily Person Trip Origins per HBW/HBO Trip Attraction Rates ($NHBARATE_{at(i),m}^{x}$)

Mode	Trip End	Area Type			
		CBD	Urban	Suburban	Rural
Auto	Origin	0.4328	0.4476	0.4092	0.3163
	Destination	0.3719	0.4482	0.4230	0.3367
Transit	Origin	0.1458	0.4558	0.3889	0.3889
	Destination	0.2778	0.3469	0.4167	0.4167

Table 2.2.28 – NHB Daily Person Trip Destinations per HBU Trip Attraction Rates ($NHBARATE_{at(i),m}^{x}$)

Trip End	Area Type			
	CBD	Urban	Suburban	Rural
Origin	0.3801	0.4478	0.4092	0.3175
Destination	0.3546	0.4453	0.4230	0.3373

2.2.4 Vehicle Trip End Equations for EI Trips at Internal Zones

The number of vehicle trips from an internal zone to outside of the region or from outside of the region to an internal zone varies depending on the development within the zone as well as the relative position of the zone to the cordon line of the region. In addition, the regional shopping and recreational centers attract significant trips from areas outside of the region. Five regression equations were calibrated using 1995 survey data to estimate the EI trip ends in the internal zones:

(1) For zones in central Cincinnati Areas (CLOC =1)

$$EIINT_i = (0.043 * POP_i + 0.040 * EMP_i) * FBAL^{ei}$$

(2) For zones in intermediate areas (CLOC=2)

$$EIINT_i = (0.075 * POP_i + 0.080 * EMP_i) * FBAL^{ei}$$

(3) For zones close to the cordon line (CLOC=3)

$$EIINT_i = (0.193 * POP_i + 0.306 * EMP_i) * FBAL^{ei}$$

(4) For zones with regional commercial and recreational centers (CLOC=5)

$$EIINT_i = (0.241 * EMP_i) * FBAL^{ei}$$

(5) For zones in central Dayton/Xenia Area (CLOC=7)

$$EIINT_i = (0.057 * POP_i + 0.079 * EMP_i) * FBAL^{ei}$$

(6) For Wright Patterson Air Force Museum (Zones= 2,139 and 2,141) (CLOC=5)

$$EIINT_i = ((0.241 + 0.215) * EMP_i) * FBAL^{ei}$$

Where:

$EIINT_i$ is the daily EI auto trip ends in zone i. Since EI equation is calibrated with vehicle (auto and commercial truck) trip data from 1995 external station trip survey, the initial $EIINT_i$ represent daily vehicle trip ends. However after balancing $EIINT_i$ represents auto trip ends because the $EIEXT_j$ include auto trip only, see Section 2.2.5.

POP_i is the population in zone i. $POP_i = HH_i * PersonPerHH_i$. Where HH_i and $PersonPerHH_i$ are the households and average persons per household in zone i.

EMP_i is the total employment in zone i.

CLOC is the close to cordon line code.

$FBAL^{ei}$ is the EI trip end balancing factor. The EI trip end at external stations are adjusted by this factor so that the total EI trip ends at all external stations match the total EI trip end in all the internal zones.

$$FBAL^{ei} = (\Sigma_{j=1}^{all\ ext} EIEXT_{j}) / (\Sigma_{i=1}^{all\ ext} EIINT_{i})$$

$EIEXT_j$ is the daily EI autotrip ends at external station j, see Section 2.2.5.

The zonal person trip productions and attractions calculated using home based trip production rates and home based trip attraction equations include the EIINT. To avoid the double counting of EIINT, the amount of EIINT of each category should be deducted from the zonal productions and attractions calculated. It assumes the number of HBU trips for EIINT is negligible and the number of NHB trips is about 0.38 of home-based trip attractions for HBW and HBO. Further assume the average vehicle occupancies for HBW, HBO and NHB trips are 1.15, 1.77, and 1.55. Thus, the breakdowns of EIINT by production/attraction and trip purpose are approximated using the following equations:

$$EIINT_i^{hbwp} = EIINT_i * \{P_i^{hbw}/1.15\} * \{1/ TOTLV_i\}$$

$$EIINT_i^{hbwa} = EIINT_i * \{A_i^{hbw}/1.15\} * \{1/ TOTLV_i\}$$

$$EIINT_i^{hbop} = EIINT_i * \{P_i^{hbo}/1.77\} * \{1/ TOTLV_i\}$$

$$EIINT_i^{hbwa} = EIINT_i * \{A_i^{hbw}/1.77\} * \{1/ TOTLV_i\}$$

where:

$$TOTLV_i = (P_i^{hbw} + A_i^{hbw}) / 1.15 + (P_i^{hbo} + A_i^{hbo}) / 1.77 + 0.38 * (A_i^{hbw} + A_i^{hbo}) / 1.55$$

The HBW and HBO person trip productions in each zone attracted to all internal zones only, assuming that the average vehicle occupancies for HBW and HBO trips are 1.15 and 1.77 is:

$$P_{*i}^{hbw} = P_i^{hbw} - 1.15 * EIINT_i^{hbwp}$$

$$P_{*i}^{hbo} = P_i^{hbo} - 1.77 * EIINT_i^{hbop}$$

The HBW and HBO person trip attractions in each zone produced from all internal zones only are calculated as:

$$A_{*i}^{hbw} = A_i^{hbw} - 1.15 * EIINT_i^{hbwa}$$

$$A_{*i}^{hbo} = A_i^{hbo} - 1.77 * EIINT_i^{hboa}$$

Where:

$EIINT_i^{hbwp}$ and $EIINT_i^{hbop}$ are the daily vehicle trip productions for trip purpose HBW and HBO in zone i attracted to external stations.
$EIINT_i^{hbwa}$ and $EIINT_i^{hboa}$ are the daily vehicle trip attractions for trip purpose HBW and HBO in zone i produced from external stations.

P_i^{hbw} and P_i^{hbo} are the daily HBW and HBO person trip productions in zone i.

A_i^{hbw} and A_i^{hbo} are the daily HBW and HBO person trip attractions in zone i.

P_{*i}^{hbw} and P_{*i}^{hbo} are the daily HBW and HBO person trip productions in zone i attracted to all internal zones only.

A_{*i}^{hbw} and A_{*i}^{hbo} are the daily HBW and HBO person trip attractions in zone i produced from all internal zones only.

$TOTLV_i$ are the daily home based and non-home based vehicle trip ends for zone i.

2.2.5 Vehicle Trip End Equations for EE and EI Trips at External Stations

The vehicle trip ends at external stations are estimated based on observed traffic count information. The following equations are used:

$EE_i = 1995CNT_i * (1\text{-}1995TRUCK\%_i) * (1978EE\%_i\text{+}ADJEE_i)\text{*} GFEXT_i$

$EIEXT_i\text{=}1995CNT_i * (1\text{-}1995TRUCK\%_i) * (1\text{-}(1978EE\%_i\text{+}ADJEE_i))\text{*}GFEXT_i$

Where:

$EIEXT_i$ is the daily EI auto trip ends at external station i.

EE_i is the daily EE autotrip ends at external station i.

$1995CNT_i$ is the 1995 daily traffic counts at external station i, see Table 2.2.29.

1995TRUCK% is the truck traffic % at external station i in year 1995, see Table 2.2.29

$1978EE\%_i$ is the percentage of 1978 traffic counts belongs to EE trips at external station i, see Table 2.2.29.

$ADJEE_i$ is the adjustment factor applied to $1978EE\%_i$ to better represent 1995 conditions at external station i, see Table 2.2.29.

$GFEXT_i$ is the traffic growth factor from 1995 to the analysis year at external station i.

$$GFEXT_i = (1\text{+ GROWTH RATE}_i)^{(\text{analysis year-1995})}$$

GROWTH RATE_i is the growth in traffic per year for external station i,

$$\text{GROWTH RATE}_i = (GROWTH78\_00_i)^{1/22} - 1$$

See Table 2.2.29 for $GROWTH78\_00_i$, the growth factors from 1978 to 2000.

Table 2.2.29 – Trip Ends at External Stations (OKI/MVRPC)

External $Stations_i$	Station Name	$GROWTH78\_00_i$	1978EEi	$ADJEE_i$	$1995CNT_i$	1995TK%i
2426	US 52	1.370	0.090	0	2,174	0.084
2427	SR 756	1.370	0.004	0	963	0.053
2428	SR 774	1.370	0.063	0	783	0.083
2429	SR 125	1.370	0.011	0	5,924	0.065
2430	Spring Grove Rd	1.370	0.067	0	931	0.047
2431	Starling Rd	1.370	0.032	0	1,498	0.047
2432	Old SR 32	1.370	0.007	0	3,118	0.065
2433	SR 32	1.370	0.046	0	20,135	0.109
2434	Dela Palma Rd	1.370	0.026	0	3,314	0.022
2435	Jackson Pk	1.370	0.015	0	1,153	0.044
2436	US 50	1.370	0.024	0	3,682	0.106
2437	SR 131	1.370	0.007	0	2,585	0.062
2438	Lucas Rd	1.480	0.280	0	633	0.074
2439	SR 133	1.480	0.034	0	2,371	0.025
2440	SR 28	1.480	0.030	0	7,086	0.087
2441	SR 132	1.480	0.007	0	647	0.090
2442	SR 350	1.480	0.031	0	980	0.045
2443	US 22	1.480	0.041	0	1,931	0.093
2444	Harveysburg Rd	1.480	0.256	0	545	0.039
2445	Wilmington Rd	1.480	0.035	0	649	0.029
2446	IR 71	1.540	0.136	0	33,446	0.291
2447	SR 73	1.480	0.408	0	5,764	0.129
2448	SR 122	1.410	0.020	0	3,424	0.081
2449	SR 503	1.410	0.019	0	1,605	0.077
2450	Wayne Trace Rd	1.410	0.000	0	400	0.058
2451	SR 744	1.410	0.030	0	1,422	0.046
2452	US 127	1.410	0.024	0	3,911	0.240
2453	SR 177	1.410	0.018	0	1,197	0.043
2454	SR 732	1.410	0.022	0	2,289	0.025
2455	US 27	1.410	0.022	0	5,336	0.085
2456	Contreras Rd	1.410	0.006	0	550	0.098
2457	Fairfield Rd	1.410	0.010	0	1,364	0.053
2458	Brookville Rd	1.410	0.000	0	749	0.039
2459	Peoria-Reily Rd	1.410	0.011	0	376	0.064
2460	SR 126	1.410	0.008	0	1,580	0.085
2461	Okeana Drewsburg Rd	1.410	0.007	0	565	0.051
2462	Carolina Trace Rd	1.440	0.057	0	667	0.102
2463	US 52	1.440	0.076	0	5,426	0.100
2464	SR 1	1.440	0.130	0	2,097	0.155
2465	Peters Rd	1.440	0.600	0	959	0.069
2466	IR 74	1.440	0.049	0	20,230	0.334

Table 2.2.29 – Trip Ends at External Stations (OKI/MVRPC) (continue)

External $Stations_i$	Station Name	$GROWTH78\_00_i$	$1978EE_i$	$ADJEE_i$	$1995CNT_i$	1995TK%i
2466	IR 74	1.440	0.049	0	20,230	0.334
2467	SR 46	1.440	0.204	0	2,895	0.108
2468	N Dearborn Rd	1.440	0.021	0	1,313	0.053
2469	SR 48	1.440	0.021	0	1,831	0.074
2470	SR 350	1.440	0.115	0	4,460	0.091
2471	Old SR 350	1.440	0.052	0	711	0.000
2472	US 50	1.440	0.169	0	6,116	0.211
2473	SR 62	1.440	0.258	0	568	0.141
2474	SR 262	1.440	0.377	0	1,067	0.019
2475	SR 56	1.440	0.134	0	12,815	0.043
2476	US 42	1.540	0.032	0	3,067	0.073
2477	IR 71	1.540	0.322	0	23,511	0.403
2478	SR 16	1.540	0.063	0	1,642	0.000
2479	SR 491	1.540	0.077	0	934	0.000
2480	IR 75	1.540	0.223	0	35,815	0.335
2481	US 25	1.540	0.028	0	3,342	0.111
2482	SR 17	1.540	0.049	0	1,616	0.114
2483	SR 177	1.540	0.000	0	621	0.082
2484	US 27	1.540	0.041	0	7,333	0.185
2485	SR 154	1.540	0.033	0	1,006	0.014
2486	SR 10	1.540	0.000	0	775	0.035
2487	AA Highway	1.540	0.040	0	6,540	0.163
2488	SR 8	1.540	0.000	0	496	0.046
2489	SR 49	1.596	0.104	0	7,747	0.088
2490	US 40 E	1.268	0.088	0	3,738	0.053
2491	Bellefontaine Rd	1.476	0.000	0	701	0.039
2492	SR 235	1.303	0.084	0	12,441	0.053
2493	I 675 N	1.302	0.139	0	7,092	0.034
2494	I 70 E	1.206	0.475	0	60,130	0.262
2495	Lower Valley Pk	1.229	0.025	0	4,900	0.141
2496	Medway Rd	1.491	0.005	0	1,833	0.023
2497	Haddia Rd	1.488	0.013	0	1,672	0.105
2498	Spangler Rd	1.779	0.083	0	398	0.088
2499	Dayton-Springfield Rd	1.096	0.024	0	11,474	0.025
2500	W Enon Rd	1.344	0.055	0	1,022	0.035

Table 2.2.29 – Trip Ends at External Stations (OKI/MVRPC) (continue)

External $Stations_i$	Station Name	$GROWTH78\_00_i$	1978EEi	$ADJEE_i$	$1995CNT_i$	1995TK%i
2501	Polecat Rd	1.164	0.033	0	1,054	0.006
2502	US 68 N	1.201	0.077	0	7,405	0.061
2503	SR 72 N	1.352	0.111	0	3,857	0.078
2504	US 42 N	1.675	0.110	0	1,114	0.106
2505	Selma-Jamestown Rd	1.000	0.313	0	452	0.044
2506	SR 734	1.546	0.055	0	800	0.065
2507	Old US 35 E	0.373	0.154	0	4,803	0.268
2508	SR 72 S	1.468	0.214	0	1,883	0.096
2509	US 68 S	1.595	0.136	0	5,887	0.114
2510	SR 380	1.428	0.064	0	2,145	0.064
2511	SR 725 W	1.188	0.235	0	3,784	0.047
2512	US 35 W	1.294	0.042	0	6,700	0.042
2513	Lexington-Salem Rd	1.111	0.022	0	1,128	0.049
2514	I 70 W	1.203	0.584	0	29,756	0.290
2515	US 40 W	1.290	0.108	0	2,583	0.051
2516	Baltimore-Phillispburg Pk	1.077	0.046	0	805	0.050
2517	SR 571 W	1.622	0.576	0	1,936	0.072
2518	US 36 W	1.447	0.172	0	4,966	0.080
2519	SR 185	1.422	0.242	0	2,048	0.064
2520	SR 48 N	1.379	0.342	0	1,810	0.197
2521	SR 66	1.455	0.113	0	3,800	0.057
2522	I 75 N	1.416	0.537	0	40,969	0.223
2523	County Rd 25 A	1.263	0.136	0	2,006	0.032
2524	SR 589	1.889	0.310	0	415	0.043
2525	US 36 E	1.496	0.207	0	4,866	0.095
2526	Old Troy Pike	1.703	0.085	0	311	0.019
2527	SR 55	1.459	0.134	0	1,701	0.036
2528	SR 41	1.569	0.103	0	2,132	0.050
2529	SR 571 E	1.088	0.412	0	3,899	0.037
2530	Scarff Rd	1.227	0.068	0	685	0.039
2531	New US 35 East	7.984	0.154	0	400	0.268

2.3 Trip Distribution

The trip distribution models estimate the number of trips going from one traffic zone to the other. Two types of models are utilized in this phase: Gravity Model and Fratar Growth Factoring Model.

2.3.1 Gravity Models

Gravity Models are developed for trip purposes HBW, HBU, HBO, NHB, and EI. A Gravity Model distributes trips produced from a traffic zone to all traffic zones in direct proportion to the relative attraction of the traffic zones and in inverse proportion to the travel impedance between them. Gravity models are development for peak and offpeak periods and for four trip purposes (HBW, HBU, HBO, NHB). The relationship utilized may be expressed mathematically as follows:

$$T_{i,j}^{p,x} * P_i^{p,x} * (A_j^{p,x} * K_{i,j}^{x} * F_{i,j}^{p,x}) / \Sigma_j^{all} (A_j^{p,x} * K_{i,j}^{x} * F_{i,}^{p,x})$$

for x = HBW, HBU, HBO, NHB

p = peak and offpeak

$$T_{i,j}^{ei} = P_i^{ei} * A_j^{ei} * F_{i,j}^{ei} / \Sigma_j^{all} (A_j^{ei} * F_{i,}^{ei})$$

Where:

$T_{i,j}^{p,x}$ is the person trip interchanges from zone i to zone j for trip purpose x (HBW, HBU, HBO, and NHB) and period p.

$T_{i,j}^{ei}$ is the daily EI vehicle trip interchanges from zone i to external station j

$P_i^{p,x}$ is the person trip productions in zone i for trip purpose x and period p. The trip purposes include HBW, HBU, HBO and NHB. $P_i^{peak,x} = P_i^{x} * PK^{x}$ and $P_i^{offpeak,x} = P_i^{x} * (1-PK^{x})$. P_i^{x} is the daily person trip productions in zone i for trip purpose x (HBW, HBU and HBO). $PK^{peak,x}$ is the peak factor for trip purpose x ($PK^{peak,hbw} = 0.608$, $PK^{peak,hbu} = 0.632$, $PK^{peak,hbo} = 0.421$, $PK^{peak,hbw} = 0.368$). For NHB, the trip productions are estimated by peak and offpeak periods separately in trip generation phase.

P_i^{ei} is the daily EI vehicle trip ends at external station i, $EIEXT_i$ are used as P_i^{ei}.

$A_j^{x,p}$ is the person trip attractions in zone j for trip purpose x and period p, the trip purposes include HBW, HBU, HBO and NHB. $A_j^{peak,x} = A_j^x * PK^x$ and $A_j^{offpeak,x} = A_j^x * (1-PK^x)$. A_j^x is the daily person trip attractions in zone j for trip purpose x (HBW, HBU and HBO). $PK^{peak,x}$ is the peak factor for trip purpose x ($PK^{peak,hbw} = 0.608$, $PK^{peak,hbu} = 0.632$, $PK^{peak,hbo} = 0.421$, $PK^{peak,hbw} = 0.368$). For NHB, the trip attractions are estimated by peak and offpeak periods separately in trip generation phase.

A_j^{ei} is the daily EI vehicle trip ends in zone j, $EIINT_i$ are used as A_{iei}.

$F_{i,j}^{x,p}$ is the friction factor representing the travel impedance for the trips from zone i to zone j for trip purpose x and time period p. The friction factor is a function of utility logsum (See Section 2.4). For each time period, a set of friction factor is developed for trip purposes HBW, HBU, HBO, and NHB individually. The friction factors are developed for logsum impedance unit from 1 to 450 with an increment of 1 unit, see Table 2.3.1.

$F_{i,}^{ei}$ is the friction factor representing the travel impedance for the trips from external station i to zone j for EI trips. The friction factor is a function of travel time only. The friction factors are developed for time impedance from 0-89 minutes with an increment of 1 minute. See Table 2.3.2.

$K_{i,j}^x$ is the K factor for trip interchange from zone i to zone j for trip purpose x, see Table 2.3.4

An iterative procedure is employed to refine trip interchange estimates until estimated zonal trip ends attracted to each zone closely match the desired zonal trip attractions calculated in the trip generation phase.

2.3.2 Friction Factors

The friction factors for HBW, HBU, HBO, and NHB trip purposes were calibrated using 1995 Household activity survey (HAS) trip length frequency distribution data. Friction factors for HBW are used for HBU. This is because due to the relatively few HBU trips that resulted in an unsuccessful calibration process for this trip purpose. The friction factors for EI trips were calibrated using 1995-1996 external station trip survey data.

2.3.3 Bridge Penalties

In addition, a set of bridge penalties ($_{pen}t_l$) in terms of time in minutes is added to the driving time to better simulate the travel impedance in estimating trip distribution across the rivers. The bridge penalties are link specific and are calibrated to match 1995 traffic volume crossing the bridges. See Table 2.3.3 for the bridge penalties.

2.3.4 K Factors

A small set of K-factors were calculated and applied to the model, primarily to correct the over-estimation of trips between Northern Kentucky and Ohio. This kind of overestimation is not unusual, given that the two regions are connected only by a small number of bridges. It was also found that a correction was necessary to better estimate Cincinnati CBD bound trips. In addition, a set of K-factors were calculated and applied to the model to better estimate the trip interchanges between OKI and MVRPC regions. The K-factors are shown in Table 2.3.4.

2.3.5 Growth Factoring Models

Gravity models were not developed for HBSC, EE and TAXI due to insufficient data. Instead, Fratar Models were developed for these trip purposes. A Fratar Model, using growth factoring techniques, takes a base trip table and a set of growth factors for each origin and destination zone as inputs. Mathematically, the model may be expressed as follows:

$$T_{i,j}^{x} = {}_{o}T_{i,j}^{x} * PG_{i}^{x} * AG_{j}^{x} * [\Sigma_{j}^{all} ({}_{o}T_{i,j}^{x}) / \Sigma_{j}^{all} ({}_{o}T_{i,j}^{x} * AG_{j}^{x})]$$

For x = HBSC transit, Taxi and EE

Where:

$T_{i,j}^{x}$ is the daily person trip interchanges or vehicle trip interchanges from zone i to zone j or external station i to external station j for trip purpose x. $T_{i,j}^{x}$ represents person transit trips for HBSC and vehicle trips for TAXI and EE.

${}_{o}T_{i,j}^{x}$ is the base year daily person trip interchanges or vehicle trip interchanges from zone i to zone j or external station i to external station j for trip purpose x. The 1965 HBSC transit, 1965 TAXI and 1978 EE trip tables are used as the base trip table in the Fratar Models.

PG_{i}^{x} and AG_{i}^{x} are the trip production and attraction growth factors for trip purpose x in zone i or external station i.

$$PG_{i}^{x} = P_{i}^{x} / \Sigma_{j}^{all} ({}_{o}T_{i,j})$$

$$AG_{i}^{x} = A_{i}^{x} / \Sigma_{j}^{all} ({}_{o}T_{i,j})$$

Where:

P_{i}^{x} and A_{i}^{x} are the daily person or vehicle trip productions and attractions for trip purpose x (i.e. HBSC, TAXI and EE) in zone i. For EE trips $P_{i}^{ee} = A_{j}^{ee} = 0.5 * EE_{i}$

Factoring is done iteratively to refine trip interchange estimates until the sum of the estimated interchanges produced and attracted to each zone closely match the zone's desired trip productions and attractions (i.e. $\Sigma_{i} [T_{i,j}^{x}] = \Sigma_{i} [{}_{o}T_{i,j}^{x} * AG_{j}]$).

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
1	1483	1483	9999999	9999999	0	0	9999999	9999999
2	10004	10004	9999999	9999999	0	0	9999999	9999999
3	29854	29854	9999999	9999999	0	0	9999999	9999999
4	63797	63797	9999999	9999999	0	0	9999999	9999999
5	113530	113530	9999999	9999999	0	0	9999999	9999999
6	179950	179950	9999999	9999999	0	0	9999999	9999999
7	263331	263331	9999999	9999999	0	0	9999999	9999999
8	363461	363461	9999999	9999999	0	0	9999999	9999999
9	479757	479757	9999999	9999999	0	0	9999999	9999999
10	611344	611344	9999999	9999999	0	0	9999999	9999999
11	757136	757136	9999999	9999999	0	0	9999999	9999999
12	915887	915887	9999999	9999999	0	0	9999999	9999999
13	1086247	1086247	9999999	9999999	0	0	9999999	9999999
14	1266795	1266795	9999999	9999999	0	0	9999999	9999999
15	1456080	1456080	9999999	9999999	0	0	9999999	9999999
16	1652641	1652641	9999999	9999999	0	0	9999999	9999999
17	1855034	1855034	9999999	9999999	0	0	9999999	9999999
18	2061849	2061849	9999999	9999999	0	0	9999999	9999999
19	2271721	2271721	9999999	9999999	0	0	9999999	9999999
20	2483345	2483345	9999999	9999999	0	0	9999999	9999999
21	2695483	2695483	9999999	9999999	0	0	9999999	9999999
22	2906969	2906969	9999999	9999999	0	0	9999999	9999999
23	3116716	3116716	9999999	9999999	0	0	9999999	9999999
24	3323717	3323717	9999999	9999999	0	0	9999999	9999999
25	3527044	3527044	9999999	9999999	0	0	9999999	9999999
26	3725854	3725854	9999999	9999999	0	0	9999999	9999999
27	3919383	3919383	9999999	9999999	0	0	9999999	9999999
28	4106947	4106947	9999999	9999999	0	0	9999999	9999999
29	4287940	4287940	9999999	9999999	0	0	9999999	9999999
30	4461832	4461832	9999999	9999999	0	0	9999999	9999999
31	4628163	4628163	9999999	9999999	0	0	9999999	9999999
32	4786542	4786542	9999999	9999999	0	0	9999999	9999999
33	4936646	4936646	9999999	9999999	0	0	9999999	9999999
34	5078210	5078210	9999999	9999999	0	0	9999999	9999999
35	5211031	5211031	9999999	9999999	0	0	9999999	9999999
36	5334957	5334957	9999999	9999999	0	0	9999999	9999999
37	5449888	5449888	9999999	9999999	0	0	9999999	9999999
38	5555772	5555772	9999999	9999999	0	0	9999999	9999999
39	5652597	5652597	9999999	9999999	0	0	9999999	9999999
40	5740395	5740395	9999999	9999999	1	1	9999999	9999999
41	5819232	5819232	9999999	9999999	1	1	9999999	9999999
42	5889205	5889205	9999999	9999999	2	2	9999999	9999999
43	5950445	5950445	9999999	9999999	3	3	9999999	9999999
44	6003105	6003105	9999999	9999999	5	5	9999999	9999999
45	6047365	6047365	9999999	9999999	7	7	9999999	9999999
46	6083425	6083425	9999999	9999999	11	11	9999999	9999999
47	6111503	6111503	9999999	9999999	17	17	9999999	9999999

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB (continue)

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
51	6148857	6148857	9999999	9999999	82	82	9999999	9999999
52	6140769	6140769	9999999	9999999	118	118	9999999	9999999
53	6126262	6126262	8658020	9999999	168	168	9999999	9999999
54	6105623	6105623	6952416	9999999	236	236	9999999	9999999
55	6079137	6079137	5607380	9999999	330	330	9999999	9999999
56	6047094	6047094	4541742	9999999	456	456	9999999	9999999
57	6009783	6009783	3693670	9999999	625	625	9999999	9999999
58	5967491	5967491	3015820	9999999	848	848	9999999	9999999
59	5920503	5920503	2471756	9999999	1141	1141	9999999	9999999
60	5869101	5869101	2033308	9999999	1522	1522	9999999	9999999
61	5813564	5813564	1678593	9999999	2014	2014	9999999	9999999
62	5754166	5754166	1390536	9999999	2643	2643	9999999	9999999
63	5691174	5691174	1155754	9999999	3443	3443	9999999	9999999
64	5624851	5624851	963717	9999999	4452	4452	9999999	9999999
65	5555453	5555453	806105	9999999	5716	5716	9999999	9999999
66	5483230	5483230	676316	9999999	7287	7287	9999999	9999999
67	5408423	5408423	569094	9999999	9228	9228	9999999	9999999
68	5331268	5331268	480238	9999999	11610	11610	9999999	9999999
69	5251991	5251991	406380	9999999	14513	14513	9999999	9999999
70	5170813	5170813	344807	9999999	18031	18031	9999999	9999999
71	5087944	5087944	293329	9999999	22268	22268	9999999	9999999
72	5003587	5003587	250170	9999999	27340	27340	9999999	9999999
73	4917938	4917938	213890	9999999	33377	33377	9999999	9999999
74	4831183	4831183	183311	9999999	40523	40523	9999999	9999999
75	4743501	4743501	157471	9999999	48935	48935	9999999	9999999
76	4655064	4655064	135582	9999999	58786	58786	9999999	9999999
77	4566033	4566033	116995	9999999	70261	70261	9999999	9999999
78	4476563	4476563	101174	9999999	83561	83561	9999999	9999999
79	4386801	4386801	87677	9999999	98899	98899	9999999	9999999
80	4296886	4296886	76136	9999999	116502	116502	9999999	9999999
81	4206949	4206949	66247	9999999	136609	136609	9999999	9999999
82	4117115	4117115	57755	9999999	159470	159470	9999999	9999999
83	4027500	4027500	50447	9999999	185343	185343	9999999	9999999
84	3938215	3938215	44146	9999999	214497	214497	9999999	9999999
85	3849361	3849361	38703	9999999	247205	247205	9999999	9999999
86	3761036	3761036	33990	9999999	283743	283743	9999999	9999999
87	3673328	3673328	29903	9999999	324388	324388	9999999	9999999
88	3586323	3586323	26353	9999999	369418	369418	9999999	9999999
89	3500095	3500095	23262	9999999	419103	419103	9999999	9999999
90	3414719	3414719	20567	9999999	473710	473710	9999999	9999999
91	3330259	3330259	18213	9999999	533490	533490	9999999	9999999
92	3246776	3246776	16153	9999999	598685	598685	8712718	9999999
93	3164325	3164325	14348	9999999	669517	669517	7375343	9999999
94	3082957	3082957	12763	9999999	746187	746187	6256766	9999999
95	3002718	3002718	11370	9999999	828874	828874	5319050	9999999
96	2923648	2923648	10144	9999999	917728	917728	4531193	9999999
97	2845785	2845785	9062	9999999	1012870	1012870	3867803	9999999

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB (continue)

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
101	2546989	2546989	5850	9999999	1457503	1457503	2093177	9999999
102	2475571	2475571	5260	9999999	1584635	1584635	1803563	9999999
103	2405499	2405499	4736	9999999	1717994	1717994	1556744	9999999
104	2336786	2336786	4269	9999999	1857420	1857420	1346007	9999999
105	2269441	2269441	3853	9999999	2002709	2002709	1165750	9999999
106	2203470	2203470	3481	9999999	2153609	2153609	1011291	9999999
107	2138877	2138877	3149	9999999	2309826	2309826	878706	9999999
108	2075664	2075664	2851	9999999	2471019	2471019	764706	9999999
109	2013828	2013828	2585	9999999	2636805	2636805	666521	9999999
110	1953369	1953369	2346	9999999	2806758	2806758	581818	9999999
111	1894281	1894281	2131	9999999	2980412	2980412	508631	9999999
112	1836557	1836557	1938	9999999	3157265	3157265	445294	9999999
113	1780190	1780190	1765	9999999	3336780	3336780	390398	9999999
114	1725170	1725170	1608	9999999	3518389	3518389	342746	9999999
115	1671485	1671485	1467	9999999	3701497	3701497	301321	9999999
116	1619124	1619124	1339	9999999	3885485	3885485	265257	9999999
117	1568073	1568073	1224	9999999	4069714	4069714	233815	9999999
118	1518317	1518317	1120	9999999	4253531	4253531	206366	9999999
119	1469840	1469840	1025	9999999	4436270	4436270	182370	9999999
120	1422626	1422626	940	9999999	4617261	4617261	161364	9999999
121	1376658	1376658	862	9999999	4795832	4795832	142951	9999999
122	1331916	1331916	791	9999999	4971314	4971314	126790	9999999
123	1288384	1288384	727	9999999	5143045	5143045	112589	9999999
124	1246041	1246041	669	9999999	5310375	5310375	100093	9999999
125	1204867	1204867	616	9999999	5472673	5472673	89085	9999999
126	1164842	1164842	567	9999999	5629325	5629325	79375	9999999
127	1125946	1125946	523	9999999	5779746	5779746	70801	9999999
128	1088157	1088157	482	9999999	5923376	5923376	63221	9999999
129	1051455	1051455	445	9999999	6059688	6059688	56513	9999999
130	1015817	1015817	412	9999999	6188192	6188192	50568	9999999
131	981222	981222	381	9999999	6308434	6308434	45295	9999999
132	947650	947650	352	9999999	6420001	6420001	40612	9999999
133	915076	915076	326	9999999	6522524	6522524	36450	9999999
134	883481	883481	302	9999999	6615675	6615675	32745	9999999
135	852842	852842	280	9999999	6699176	6699176	29446	9999999
136	823138	823138	260	9999999	6772794	6772794	26503	9999999
137	794346	794346	242	9999999	6836342	6836342	23877	9999999
138	766446	766446	225	9999999	6889683	6889683	21530	9999999
139	739415	739415	209	9999999	6932726	6932726	19432	9999999
140	713233	713233	194	9999999	6965428	6965428	17553	9999999
141	687879	687879	181	9999999	6987792	6987792	15870	9999999
142	663331	663331	169	9999999	6999866	6999866	14360	9999999
143	639570	639570	157	9999999	7001741	7001741	13005	9999999
144	616574	616574	147	9999999	6993553	6993553	11788	9999999
145	594323	594323	137	9999999	6975474	6975474	10693	9999999
146	572798	572798	128	9999999	6947717	6947717	9708	9999999
147	551980	551980	120	9999999	6910530	6910530	8820	9999999

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB (continue)

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
151	475386	475386	92	9999999	6673546	6673546	6057	9999999
152	457816	457816	86	9999999	6593997	6593997	5524	9999999
153	440840	440840	81	9999999	6507108	6507108	5041	9999999
154	424443	424443	76	9999999	6413302	6413302	4604	9999999
155	408607	408607	71	9999999	6313015	6313015	4208	9999999
156	393315	393315	67	9999999	6206695	6206695	3849	9999999
157	378551	378551	63	9999999	6094795	6094795	3523	9999999
158	364300	364300	59	9999999	5977777	5977777	3226	9999999
159	350545	350545	56	9999999	5856103	5856103	2957	9999999
160	337272	337272	52	9999999	5730236	5730236	2711	9999999
161	324465	324465	49	9999999	5600637	5600637	2488	9999999
162	312111	312111	47	9999999	5467762	5467762	2285	9999999
163	300194	300194	44	9999999	5332061	5332061	2099	9999999
164	288702	288702	41	9999999	5193976	5193976	1930	9999999
165	277621	277621	39	9999999	5053938	5053938	1775	9999999
166	266937	266937	37	9999999	4912367	4912367	1634	9999999
167	256637	256637	35	9999999	4769668	4769668	1505	9999999
168	246710	246710	33	9999999	4626234	4626234	1387	9999999
169	237143	237143	31	9999999	4482441	4482441	1279	9999999
170	227925	227925	29	9999999	4338647	4338647	1180	9999999
171	219043	219043	28	9999999	4195195	4195195	1090	9999999
172	210487	210487	26	8555967	4052408	4052408	1007	9999999
173	202246	202246	25	7052117	3910592	3910592	930	9999999
174	194309	194309	24	5823645	3770032	3770032	860	9999999
175	186666	186666	22	4818211	3630997	3630997	796	9999999
176	179308	179308	21	3993769	3493732	3493732	737	9999999
177	172223	172223	20	3316478	3358466	3358466	682	9999999
178	165403	165403	19	2759049	3225409	3225409	632	9999999
179	158840	158840	18	2299434	3094749	3094749	586	9999999
180	152523	152523	17	1919788	2966658	2966658	544	9999999
181	146444	146444	16	1605637	2841289	2841289	505	9999999
182	140596	140596	16	1345226	2718776	2718776	469	9999999
183	134970	134970	15	1128986	2599237	2599237	436	9999999
184	129558	129558	14	949115	2482772	2482772	405	9999999
185	124352	124352	13	799243	2369467	2369467	376	9999999
186	119346	119346	13	674155	2259391	2259391	350	9999999
187	114532	114532	12	569580	2152598	2152598	326	9999999
188	109903	109903	12	482010	2049129	2049129	304	9999999
189	105453	105453	11	408560	1949010	1949010	283	9999999
190	101175	101175	11	346854	1852258	1852258	264	9999999
191	97062	97062	10	294931	1758876	1758876	246	9999999
192	93110	93110	10	251173	1668855	1668855	229	9999999
193	89312	89312	9	214237	1582180	1582180	214	9999999
194	85662	85662	9	183011	1498822	1498822	200	9999999
195	82155	82155	8	156573	1418747	1418747	187	9999999
196	78786	78786	8	134155	1341911	1341911	174	9999999
197	75550	75550	8	115117	1268266	1268266	163	9999999

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB (continue)

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
201	63834	63834	6	63324	1004381	1004381	125	9999999
202	61189	61189	6	54729	945741	945741	117	9999999
203	58651	58651	6	47367	889883	889883	110	9999999
204	56213	56213	6	41051	836727	836727	103	9999999
205	53874	53874	5	35627	786190	786190	97	9999999
206	51628	51628	5	30961	738189	738189	91	9999999
207	49472	49472	5	26942	692639	692639	85	9999999
208	47404	47404	5	23476	649453	649453	80	9999999
209	45419	45419	5	20482	608546	608546	75	9999999
210	43514	43514	4	17894	569832	569832	71	9999999
211	41686	41686	4	15653	533225	533225	66	9999999
212	39933	39933	4	13710	498641	498641	62	7962139
213	38251	38251	4	12024	465994	465994	59	5537018
214	36638	36638	4	10558	435203	435203	55	3849109
215	35090	35090	4	9282	406185	406185	52	2674755
216	33606	33606	3	8171	378861	378861	49	1858011
217	32182	32182	3	7201	353153	353153	46	1290193
218	30817	30817	3	6354	328983	328983	43	895580
219	29508	29508	3	5614	306278	306278	41	621438
220	28253	28253	3	4965	284965	284965	39	431060
221	27050	27050	3	4397	264975	264975	36	298899
222	25897	25897	3	3898	246238	246238	34	207185
223	24791	24791	3	3460	228690	228690	32	143563
224	23731	23731	3	3075	212266	212266	31	99443
225	22716	22716	2	2735	196907	196907	29	59359
226	21742	21742	2	2436	182553	182553	27	31915
227	20809	20809	2	2172	169148	169148	26	21783
228	19915	19915	2	1939	156638	156638	24	13500
229	19058	19058	2	1900	144971	144971	23	9782
230	18238	18238	2	1900	134098	134098	22	8782
231	17451	17451	2	1900	123972	123972	21	7537
232	16698	16698	2	1900	114547	114547	20	5207
233	15976	15976	2	1116	105780	105780	18	3596
234	15285	15285	2	1003	97632	97632	18	3483
235	14623	14623	2	902	90063	90063	17	2763
236	13989	13989	2	812	83037	83037	16	1982
237	13381	13381	2	732	76518	76518	15	1932
238	12800	12800	2	660	70474	70474	14	1859
239	12243	12243	1	596	64874	64874	13	1729
240	11709	11709	1	539	59688	59688	13	1506
241	11700	11700	1	487	54889	54889	12	1038
242	11600	11600	1	441	50450	50450	11	975
243	11500	11500	1	400	46346	46346	11	867
244	11400	11400	1	363	42556	42556	10	763
245	11300	11300	1	330	39056	39056	10	713
246	11200	11200	1	300	35826	35826	9	567
247	11100	11100	1	273	32847	32847	9	524

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB (continue)

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
251	10700	10700	1	189	23101	23101	7	384
252	10600	10600	1	173	21130	21130	7	355
253	10500	10500	1	158	19319	19319	7	328
254	9500	9500	1	145	17654	17654	6	304
255	8500	8500	1	132	16126	16126	6	281
256	7500	7500	1	122	14723	14723	6	260
257	6500	6500	1	112	13437	13437	5	240
258	5210	5210	1	103	12257	12257	5	222
259	4979	4979	1	94	11176	11176	5	205
260	4758	4758	1	87	10186	10186	5	190
261	4546	4546	1	80	9279	9279	4	176
262	4344	4344	1	74	8450	8450	4	162
263	4150	4150	1	68	7691	7691	4	150
264	3965	3965	1	63	6997	6997	4	139
265	3788	3788	1	58	6364	6364	4	128
266	3619	3619	1	54	5785	5785	4	119
267	3457	3457	1	50	5257	5257	3	110
268	3303	3303	1	46	4775	4775	3	102
269	3155	3155	1	43	4335	4335	3	94
270	3013	3013	1	40	3935	3935	3	87
271	2878	2878	1	37	3569	3569	3	80
272	2749	2749	1	34	3237	3237	3	74
273	2625	2625	1	32	2934	2934	3	69
274	2507	2507	1	30	2659	2659	2	63
275	2394	2394	1	28	2408	2408	2	59
276	2287	2287	0	26	2180	2180	2	54
277	2184	2184	0	24	1973	1973	2	50
278	2085	2085	0	22	1785	1785	2	46
279	1991	1991	0	21	1615	1615	2	43
280	1901	1901	0	20	1460	1460	2	40
281	1815	1815	0	18	1319	1319	2	37
282	1733	1733	0	17	1192	1192	2	34
283	1654	1654	0	16	1076	1076	2	31
284	1579	1579	0	15	971	971	2	29
285	1508	1508	0	14	877	877	2	27
286	1439	1439	0	13	791	791	1	25
287	1374	1374	0	13	713	713	1	23
288	1312	1312	0	12	643	643	1	21
289	1252	1252	0	11	579	579	1	20
290	1195	1195	0	10	522	522	1	18
291	1141	1141	0	10	470	470	1	17
292	1089	1089	0	9	423	423	1	15
293	1039	1039	0	9	380	380	1	14
294	991	991	0	8	342	342	1	13
295	946	946	0	8	308	308	1	12
296	903	903	0	7	277	277	1	11
297	862	862	0	7	249	249	1	10

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB (continue)

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
301	714	714	0	6	162	162	1	8
302	681	681	0	5	145	145	1	7
303	650	650	0	5	130	130	1	7
304	620	620	0	5	117	117	1	6
305	592	592	0	5	104	104	1	6
306	565	565	0	4	94	94	1	5
307	539	539	0	4	84	84	1	5
308	514	514	0	4	75	75	1	4
309	490	490	0	4	67	67	1	4
310	468	468	0	4	60	60	1	4
311	446	446	0	3	54	54	1	3
312	425	425	0	3	48	48	1	3
313	406	406	0	3	43	43	0	3
314	387	387	0	3	38	38	0	3
315	369	369	0	3	34	34	0	3
316	352	352	0	3	31	31	0	2
317	336	336	0	3	27	27	0	2
318	320	320	0	3	24	24	0	2
319	305	305	0	2	22	22	0	2
320	291	291	0	2	19	19	0	2
321	278	278	0	2	17	17	0	2
322	265	265	0	2	15	15	0	1
323	252	252	0	2	14	14	0	1
324	241	241	0	2	12	12	0	1
325	229	229	0	2	11	11	0	1
326	219	219	0	2	10	10	0	1
327	209	209	0	2	9	9	0	1
328	199	199	0	2	8	8	0	1
329	190	190	0	2	7	7	0	1
330	181	181	0	2	6	6	0	1
331	172	172	0	2	5	5	0	1
332	164	164	0	1	5	5	0	1
333	157	157	0	1	4	4	0	1
334	149	149	0	1	4	4	0	1
335	142	142	0	1	3	3	0	1
336	136	136	0	1	3	3	0	0
337	129	129	0	1	3	3	0	0
338	123	123	0	1	2	2	0	0
339	117	117	0	1	2	2	0	0
340	112	112	0	1	2	2	0	0
341	107	107	0	1	2	2	0	0
342	102	102	0	1	1	1	0	0
343	97	97	0	1	1	1	0	0
344	92	92	0	1	1	1	0	0
345	88	88	0	1	1	1	0	0
346	84	84	0	1	1	1	0	0
347	80	80	0	1	1	1	0	0

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB (continue)

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
351	66	66	0	1	0	0	0	0
352	63	63	0	1	0	0	0	0
353	60	60	0	1	0	0	0	0
354	57	57	0	1	0	0	0	0
355	54	54	0	1	0	0	0	0
356	52	52	0	1	0	0	0	0
357	49	49	0	1	0	0	0	0
358	47	47	0	1	0	0	0	0
359	45	45	0	1	0	0	0	0
360	43	43	0	1	0	0	0	0
361	41	41	0	1	0	0	0	0
362	39	39	0	1	0	0	0	0
363	37	37	0	1	0	0	0	0
364	35	35	0	1	0	0	0	0
365	33	33	0	1	0	0	0	0
366	32	32	0	1	0	0	0	0
367	30	30	0	1	0	0	0	0
368	29	29	0	1	0	0	0	0
369	28	28	0	1	0	0	0	0
370	26	26	0	1	0	0	0	0
371	25	25	0	1	0	0	0	0
372	24	24	0	1	0	0	0	0
373	23	23	0	1	0	0	0	0
374	22	22	0	1	0	0	0	0
375	21	21	0	1	0	0	0	0
376	20	20	0	0	0	0	0	0
377	19	19	0	0	0	0	0	0
378	18	18	0	0	0	0	0	0
379	17	17	0	0	0	0	0	0
380	16	16	0	0	0	0	0	0
381	15	15	0	0	0	0	0	0
382	15	15	0	0	0	0	0	0
383	14	14	0	0	0	0	0	0
384	13	13	0	0	0	0	0	0
385	13	13	0	0	0	0	0	0
386	12	12	0	0	0	0	0	0
387	11	11	0	0	0	0	0	0
388	11	11	0	0	0	0	0	0
389	10	10	0	0	0	0	0	0
390	10	10	0	0	0	0	0	0
391	9	9	0	0	0	0	0	0
392	9	9	0	0	0	0	0	0
393	9	9	0	0	0	0	0	0
394	8	8	0	0	0	0	0	0
395	8	8	0	0	0	0	0	0
396	7	7	0	0	0	0	0	0
397	7	7	0	0	0	0	0	0

Table 2.3.1 – Friction Factors ($F_{ij}^{x,p}$) for HBW, HBU, HBO, NHB (continue)

	PEAK PERIOD				OFF PEAK PERIOD			
Logsum	HBW	HBU	HBO	NHB	HBW	HBU	HBO	NHB
401	6	6	0	0	0	0	0	0
402	5	5	0	0	0	0	0	0
403	5	5	0	0	0	0	0	0
404	5	5	0	0	0	0	0	0
405	5	5	0	0	0	0	0	0
406	4	4	0	0	0	0	0	0
407	4	4	0	0	0	0	0	0
408	4	4	0	0	0	0	0	0
409	4	4	0	0	0	0	0	0
410	4	4	0	0	0	0	0	0
411	4	4	0	0	0	0	0	0
412	3	3	0	0	0	0	0	0
413	3	3	0	0	0	0	0	0
414	3	3	0	0	0	0	0	0
415	3	3	0	0	0	0	0	0
416	3	3	0	0	0	0	0	0
417	3	3	0	0	0	0	0	0
418	2	2	0	0	0	0	0	0
419	2	2	0	0	0	0	0	0
420	2	2	0	0	0	0	0	0
421	2	2	0	0	0	0	0	0
422	2	2	0	0	0	0	0	0
423	2	2	0	0	0	0	0	0
424	2	2	0	0	0	0	0	0
425	2	2	0	0	0	0	0	0
426	2	2	0	0	0	0	0	0
427	2	2	0	0	0	0	0	0
428	2	2	0	0	0	0	0	0
429	1	1	0	0	0	0	0	0
430	1	1	0	0	0	0	0	0
431	1	1	0	0	0	0	0	0
432	1	1	0	0	0	0	0	0
433	1	1	0	0	0	0	0	0
434	1	1	0	0	0	0	0	0
435	1	1	0	0	0	0	0	0
436	1	1	0	0	0	0	0	0
437	1	1	0	0	0	0	0	0
438	1	1	0	0	0	0	0	0
439	1	1	0	0	0	0	0	0
440	1	1	0	0	0	0	0	0
441	1	1	0	0	0	0	0	0
442	1	1	0	0	0	0	0	0
443	1	1	0	0	0	0	0	0
444	1	1	0	0	0	0	0	0
445	1	1	0	0	0	0	0	0
446	1	1	0	0	0	0	0	0
447	1	1	0	0	0	0	0	0

Table 2.3.2 – Friction Factors (F^{ei}_{ij}) for EI

Time	Factor	Time	Factor
1	0	46	58
2	0	47	56
3	0	48	54
4	2010	49	52
5	1820	50	49
6	1650	51	46
7	1440	52	44
8	1310	53	41
9	1190	54	38
10	1085	55	36
11	1015	56	34
12	925	57	33
13	855	58	32
14	770	59	30
15	700	60	28
16	650	61	26
17	590	62	24
18	540	63	22
19	487	64	21
20	449	65	20
21	425	66	19
22	382	67	18
23	352	68	17
24	326	69	16
25	301	70	15
26	278	71	13
27	257	72	12
28	238	73	11
29	220	74	11
30	204	75	10
31	188	76	10
32	174	77	9
33	162	78	8
34	150	79	8
35	139	80	7
36	129	81	7
37	119	82	6
38	110	83	6
39	102	84	5
40	95	85	5
41	88	86	5
42	82	87	4
43	76	88	4
44	70	89	4
45	68		

Table 2.3.3 – Bridge Penalties ($_{pen}t_l$) for Gravity Models

Anode	Bnode	Pen	Description
8207	8300	0	Fourth Street Bridge, Licking River, Covington
8259	8356	0	Twelfth Street Bridge, Licking River, Covington
8201	8299	7	Suspension Bridge, Ohio River, Downtown Cincinnati
3257	3977	4	Clay Wade Bailey Bridge, Ohio River, Downtown Cincinnati
3258	8295	5	Central Bridge, Ohio River, Downtown Cincinnati
3260	8267	6	L & N Bridge, Ohio River, Downtown Cincinnati
3897	3898	0	Schneider Bridge, Licking River, Northern Kentucky
4774	4701	3	Western Hills Viaduct Westbound, Mill Creek, Cincinnati
4774	4703	3	Western Hills Viaduct Eastbound, Mill Creek, Cincinnati
5910	4826	3	Gest Street, Mill Creek, Cincinnati
5002	4828	3	Eighth Street Viaduct, Mill Creek, Cincinnati
10298	4830	3	Sixth Street, Mill Creek, Cincinnati
4972	5102	3	Hopple Street, Mill Creek, Cincinnati
6472	5177	1	Harrison Road, Great Miami River, Miamitown
8922	8920	12	Combs-Hehl Bridge (I-275 East Bridge) Eastbound, Ohio River
8921	8923	12	Combs-Hehl Bridge (I-275 East Bridge) Westbound, Ohio River
10824	9702	10	I-275 West Bridge Southeastbound, Ohio River
9701	11068	10	I-275 West Bridge Northwestbound, Ohio River
8928	10825	5	I-74/275 Eastbound, Great River, Miamitown
9335	8929	5	I-74/275 Westbound, Great River, Miamitown
9543	9760	3	I-471 Northbound, Ohio River, Downtown Cincinnati
9542	9761	7	I-471 Southbound, Ohio River, Downtown Cincinnati
9695	9787	0	I-275 Eastbound, Licking River, Northern Kentucky
9786	9694	0	I-275 Westbound, Licking River, Northern Kentucky
975	9799	7	Brent Spence Memorial Bridge Southbound, Ohio River, Downtown Cincinnati
9750	9798	7	Brent Spence Memorial Bridge Northbound, Ohio River, Downtown Cincinnati
6470	5179	1	Harrison Road, Great Miami River, Miamitown
2206	6457	1	Lost Bridge, Elizabethtown
7201	7200	1	US 27, Great Miami River, Venice
7639	7731	1	SR 128, Great Miami River, Hamilton!
3656	7674	1	SR 129, Great Miami River, Hamilton!
3487	6837	1	SR 4, Great Miami River, Middletown
7325	3611	1	SR 122, Great Miami River, Middletown
6886	6998	1	SR 73, Great Miami River, Trenton
3633	6973	1	US 127, Great Miami River, Hamilton!
3653	7628	1	Black Street, Great Miami River, Hamilton!
6847	6848	1	SR 123, Great Miami River, Carlisle/Franklin
6997	7039	1	Liberty Fairfield Road, Great Miami River, NE of Hamilton!

Table 2.3.4 – K factors ($K_{i,j}^{x}$)

Trip Purpose	Trip Interchange (Origin/Destination District)						
	Ham/CBD	Ham/NKY	NKY/Ham	OKI/MVRPC	MVRPC/OKI	MG/Mia	Mia/MG
HBW							
Peak	1.2	0.3	0.8	0.4	0.4	0.5	0.5
Off Peak		0.5	0.8	0.4	0.4	0.5	0.5
HBO							
Peak	0.8	0.2	0.3	0.4	0.4	0.25	0.25
Off Peak	0.7	0.2	0.3	0.4	0.4	0.25	0.25
NHB							
Peak		0.6	0.4	0.5	0.5	0.25	0.25
Off Peak		0.4	0.4	0.5	0.5	0.25	0.25

District	Counties	Traffic Analysis Zones
CBD, OKI	Cincinnati CBD	252-295
Ham, OKI	Hamilton	1-251,296-690,1588,1601,1602
OKI	Clermont	1128-1254,1600
OKI	Butler, Warren, Dearborn	691-1127,1551-1587,1589-1599,1608
NKU, OKI	Boone, Campbell, Kenton	1255-1550,1603-1607
MG, MVRPC	Montgomery	1609-2136
MVRPC	Greene	2137-2318
Mia, MVRPC	Miami	2319-2425
	External Stations	2426-2531

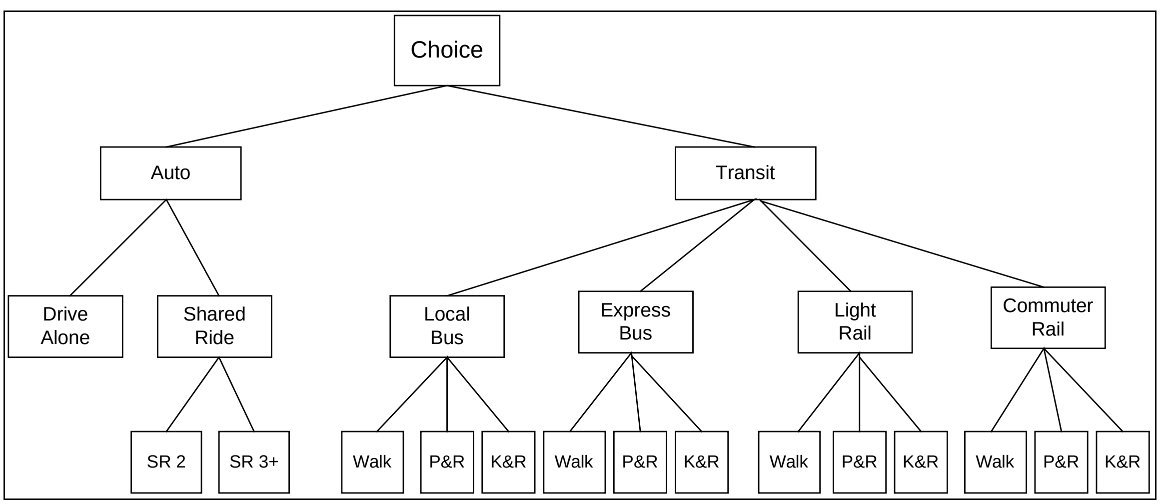
2.4 Mode Choice

The trip tables developed in the trip distribution phase for HBW, HBU, HBO and NHB include both person auto trips and person transit trips. In this phase modal choice models separate the person trips by travel modes. The modal choice models are used to separate these person trips into 15 travel mode groups as below:

- Auto drive-alone, Auto share-ride2, Auto share-ride3
- Local bus by walk, Local bus by park&ride, Local bus by kiss&ride
- Express bus by walk, Express bus by park&ride, Express bus by kiss&ride
- Light Rail by walk, Light Rail by park&ride, Light Rail by kiss&ride
- Commuter Rail by walk, Commuter Rail by park&ride, Commuter Rail by kiss&ride

Nested logit models are developed for the modal choice models. The structure for the OKI/MVRPC mode choice model is depicted in Figure 2.4.1. In this structure, a choice is first made between auto and transit. Under the transit side, the first level nest distinguishes between local bus, express bus, and light rail and commuter rail. The second level transit nest models the choice between walk access, park and ride access and kiss and ride access to each transit mode. The highway side is divided into drive alone and shared ride, with shared ride further subdivided into 2-person and 3+ person carpools.

Figure 2.4.1 – Mode Choice Model Structure



2.4.1 Mathematical Formulation

Modal choice models estimate modal share of the travel market given the time and cost characteristics of the various competing modes and the demographic and socioeconomic characteristic of the urban residents. The standard logit formulation can be expressed as:

$$P_i = \frac{e^{U_i}}{\sum_k e^{U_i}}$$

where:

- P_i is the probability of a traveler choosing mode i
- U_i is a linear function of the attributes of mode i that describe its attractiveness
- $\sum_k e^{U_i}$ is the summation of the linear functions of the attributes over all the alternatives (k) for which a choice is feasible

The utility expression for each available mode (i) is specified as a linear function that incorporates a range of variable types, including time, cost, location measures and socio-economic characteristics of the traveler. For example,

$$U_i = \beta_1 * Time_i + \beta_2 * Cost_i + \beta_3 * Location_{Var} + \beta_4 * SE + \beta_{0,i}$$

where:

- U_i is the utility for mode i
- $\beta_{0,i}$ is a constant specific to mode i that captures the overall effect of any significant variables that are missing or unexplained in the expression (e.g., comfort, convenience, safety)
- β_1 is a set of coefficients describing the level-of-service (in travel time) provided by mode i (e.g., in-vehicle time, wait time, walk time)
- β_2 is a set of coefficients describing travel cost, (e.g., transit fare, automobile operating cost, parking costs)
- β_3 is a set of coefficients describing the specific attributes of the trip interchange (e.g., CBD destination, park and ride lot use)
- β_4 is a set of coefficients describing the influence of each socio-economic characteristic of the traveler (e.g., income group, auto ownership)

The travel time variables are typically disaggregated into in-vehicle and out-of-vehicle time, at a minimum. Out-of-vehicle time may be further stratified into walk time, initial wait, and transfer wait time – the latter two categories being applicable to the transit modes only. Similarly, travel cost is often disaggregated into the more general out-of-pocket cost (i.e., automobile operating cost and transit fare) and destination parking cost.

Location variables in utility expressions may be used to reflect a set of unique geographically based characteristics, such as a Central Business District. Alternatively, these geographic attributes may be represented in the form of land use variables such as employment and/or population density. A wide variety of variables are possible in the socio-economic category (SE) including variables that measure the relative wealth of the trip maker (income or auto ownership) or reflect other household characteristics (i.e., workers per household, licensed drivers per household, etc.). Finally, a mode specific constant reflects the unexplained behavior. The individual coefficients associated with each variable reflect the relative importance of each attribute.

In the simple nested model structure shown in Figure 2.4.1, the formulation employs three multinomial logit models, one for the primary choice of mode among auto and transit, a second level choice among auto submodes (drive-alone and shared-ride) and another second level choice among transit access modes (walk and drive access). In application, the model independently addresses auto submode and transit access choice first. This is expressed as:

$$P_{DA} = \frac{e^{U_{DA}}}{e^{U_{DA}} + e^{U_{SR}}}$$

$$P_w = \frac{e^{U_w}}{e^{U_w} + e^{U_D}}$$

A composite of the utilities of the auto submode and transit access choices then represent auto and transit respectively in the upper tier of the model structure. This composite measure is the natural logarithm of the denominator of the logit model, often termed the "logsum". The logsum term is effectively the total utility provided by the submodes of a particular primary mode. A logsum value is calculated for each of the second level nests as:

$$LogSum_A = -\ln[\,e^{U_{DA}} + e^{U_{SR}}\,]$$

$$LogSum_T = -\ln[\,e^{U_w} + e^{U_D}\,]$$

The logsum terms for the auto submodes and transit access choice then appear in the utility expression for the primary mode level as:

$$P_T = \frac{e^{\theta_T * Logsum_T}}{e^{\theta_T * Logsum_T} + e^{\theta_A * Logsum_A}}$$

The value of the logsum coefficients θ_A and θ_T in the upper tier of the model (i.e., auto versus transit), is an indicator of the degree to which the lower level choices form a subchoice that is distinct from the primary mode alternatives. A value of 1.0 indicates that the lower level modes are not a subchoice but rather are full options equally competitive with the primary modes. In this instance, these lower level choices can be simplified or included directly in the upper level. A value of 0.0 would indicate that the lower level choices are perfect substitutes for each other. Values between 0.0 and 1.0 indicate the extent to which the lower level choices represent a subchoice.

2.4.2 Market Segmentation Considerations

Traditionally, a larger number of trip purposes are maintained in the trip generation and trip distribution models than in mode choice. Common practice has been to compress the subset of non-work purposes into a single purpose because of the similarities in household and individual travel behavior properties when considering the choice of mode. In the case of the OKI/MVRPC mode choice models, five trip purposes are used in trip generation: home-based work, home-based university, home-based school, home-based other and non home-based. Only for three of these purposes are mode choice models estimated. Home-based university trips are included with home-based work trips, so that a single mode choice model is estimated for these two trip purposes. This is necessary because there are not enough observations to estimate a separate home-based university mode choice model. In model calibration and application, university trips are again considered as a separate purpose, with their own calibration targets and mode-specific constants. All home-based school trips out of trip generation are transit trips, so no mode split is required.

Time-of-day is also an important market segmentation variable. For model estimation, peak period levels of service and cost are appended to trips that start during the peak period, while off-peak characteristics are appended to trips that start during the off-peak period. This allows for the estimation of a single set of model coefficients per trip purpose. However, in model calibration separate mode-specific constants are calculated for the peak and the off peak periods.

Another element of the market segmentation strategy is the stratification of alternative specific constants (i.e., bias coefficients) by an indicator of wealth or socio-economic status.

The HBW stratification intends to capture the availability of a car for each worker in the household. It can be reasonably expected that, in households where there are more workers than cars, the likelihood of share-riding or transit use would be higher than in households with equal or higher number of autos than workers. The HBW market is segmented into 4 groups:

0 Cars per household
Cars per household < Workers per household
Cars per household = Workers per household
Cars per household > Workers per household

For HBO market, a segmentation based on household auto ownership (0, 1, 2, 3 or more autos per household) is used.

The final element of the market segmentation strategy is the use of the potential for walking to transit to calculate walk times. This segmentation stems not from behavioral considerations, as is for example the use of auto ownership, but from the need to better represent actual walking times at the origin and destination ends of a trip. This segmentation recognizes that on any given zone, some trip-makers will have easy access to transit, others will require a long walk, and yet others will start or end their trip too far to walk to transit. Consequently, the walking time to transit will vary within each market segment. This is a considerable improvement over the practice of assuming that everyone is at the same average distance to transit. This transit access market segmentation is used only in model application.

To apply the transit walk access segmentation, the transit market is segmented into seven groups, depending on the proportion of trips within short, long, or no walk, both at the origin and destination zones (see Table 2.4.1). For the OKI/MVRPC model, a short walk is 1/6 of a mile or less, and a long walk is between 1/6 and 1/3 of a mile. Within each market segment, the transit walk time is estimated as the minimum of a pre-specified time (see Table 2.4.2) and the walk time estimated from the transit skims.

Table 2.4.1 – Walk Distance to Transit Market Segmentation

	Destination Zone			
Origin Zone	**Walk Distance**	*Short*	*Long*	*No Walk*
	Short	short -> short	short -> long	No Transit
	Long	long -> short	long -> long	
	No Walk	drive -> short	drive -> long	

Table 2.4.2 – Maximum Walk Time (Sum of Access & Egress)

Market Segment	Maximum Walk Time (min)	
	Walk to Transit	*Drive to Transit*
short -> short	10	5
short -> long	15	10
long -> short	15	5
long -> long	20	10
drive -> short	-	5
drive -> long	-	10

2.4.3 Logsum Coefficients

Since the data do not support the estimation of a nesting structure, the logsum coefficients to be used in the application program were synthesized from other metropolitan area models. The values for the OKI/MVRPC mode choice models are listed in Table 2.4.3.

Table 2.4.3 – Logsum Coefficients

Mode	Losum Coefficient
Shared Ride	0.55
Auto Submodes	0.85
Transit Submodes	0.85

2.4.4 Home-Based Work Model

The HBW utility expressions are listed below. In these equations, all times are expressed in minutes and all costs are expressed in 1995 cents. "LB" stands for local bus and "EB" stands for express bus. The "$K???_{TM}$" terms are the mode specific constants, stratified by time period (T) and market segment (M). Please refer to Table 2.4.5 for the constants. Note that parking and auto operating costs are not shared among a vehicle's occupants, consistent with the finding that most carpools are composed of members of the same household.

In model application, utilities corresponding to lower level choices are divided by the appropriate logsum coefficients. Hence, U(drive-alone) is divided by 0.85, while all the other utilities are divided by the product (0.85*0.55).

The final HBU utility expressions are identical to the HBW utility functions, with the exception of the mode-specific constants, which were specifically calibrated for HBU mode share data (please see Table 2.4.7).

- $U(\text{drive-alone})_{TM}$ = -0.0248 * (highway travel time + terminal parking time) +
  -0.0021 * (parking cost + auto operating cost) +
  KDA_{TM}

- $U(\text{share-ride 2})_{TM}$ = -0.0248 * (highway travel time + terminal parking time) +
  -0.0021 * (parking cost + auto operating cost)

- $U(\text{share-ride 3+})_{TM}$ = -0.0248 * (highway travel time + terminal parking time) +
  -0.0021 * (parking cost + auto operating cost) +
  $K3P_{TM}$

- $U(\text{LB,walk})_{TM}$ = -0.0248 * in-vehicle time +
  -0.0876 * (centroid walk time + transfer walk time) +
  -0.0409 * first wait time +
  -0.0461 * transfer wait time +
  -0.0021 * fare +
  $KLBW_{TM}$

- $U(\text{LB, p\&r})_{TM}$ = -0.0248 * (in-vehicle time + drive access time) +

-0.0876 * (centroid walk time + transfer walk time) +
-0.0409 * first wait time +
-0.0461 * transfer wait time +
-0.0021 * (fare + p&r park cost + access auto oper. cost) +
$KLBP_{TM}$

- $U(LB, k\&r)_{TM}$ = -0.0248 * (in-vehicle time + drive access time) +
  -0.0876 * (centroid walk time + transfer walk time) +
  -0.0409 * first wait time +
  -0.0461 * transfer wait time +
  -0.0021 * (fare + access auto operating cost) +
  $KLBK_{TM}$

- $U(EB,walk)_{TM}$ = -0.0248 * in-vehicle time +
  -0.0876 * (centroid walk time + transfer walk time) +
  -0.0409 * first wait time +
  -0.0461 * transfer wait time +
  -0.0021 * fare +
  $KEBW_{TM}$

- $U(EB, p\&r)_{TM}$ = -0.0248 * (in-vehicle time + drive access time) +
  -0.0876 * (centroid walk time + transfer walk time) +
  -0.0409 * first wait time +
  -0.0461 * transfer wait time +
  -0.0021 * (fare + p&r park cost + access auto oper. cost) +
  $KEBP_{TM}$

- $U(EB, k\&r)_{TM}$ = -0.0248 * (in-vehicle time + drive access time) +
  -0.0876 * (centroid walk time + transfer walk time) +
  -0.0409 * first wait time +
  -0.0461 * transfer wait time +
  -0.0021 * (fare + access auto operating cost) +
  $KEBK_{TM}$

2.4.5 Home-Based Other Model

The HBO utility expressions are listed below. In these equations, all times are expressed in minutes and all costs are expressed in 1995 cents. "LB" stands for local bus and "EB" stands for express bus. The "K???$_{TM}$" terms are the mode specific constants, stratified by time period (T) and market segment (M). Please refer to Table 2.4.6 for the constants. Note that parking and auto operating costs are not shared among a vehicle's occupants, consistent with the finding that most carpools are composed of members of the same household.

In model application, utilities corresponding to lower level choices are divided by the appropriate logsum coefficients. Hence, U(drive-alone) is divided by 0.85, while all the other utilities are divided by the product (0.85*0.55).

- U(drive-alone)$_{TM}$ = -0.0085 * (highway travel time + terminal parking time) +
  -0.0017 * (parking cost + auto operating cost) +
  KDA$_{TM}$

- U(share-ride 2) $_{TM}$ = -0.0085 * (highway travel time + terminal parking time) +
  -0.0017 * (parking cost + auto operating cost)

- U(share-ride 3+) $_{TM}$ = -0.0085 * (highway travel time + terminal parking time) +
  -0.0017 * (parking cost + auto operating cost) +
  K3P$_{TM}$

- U(LB,walk) $_{TM}$ = -0.0085 * in-vehicle time +
  -0.0169 * (centroid walk time + transfer walk time) +
  -0.0169 * first wait time +
  -0.0169 * transfer wait time +
  -0.0017 * fare +
  KLBW$_{TM}$

- U(LB, p&r) $_{TM}$ = -0.0085 * (in-vehicle time + drive access time) +
  -0.0169 * (centroid walk time + transfer walk time) +
  -0.0169 * first wait time +
  -0.0169 * transfer wait time +
  -0.0017 * (fare + p&r park cost + access auto oper. cost) +
  KLBP$_{TM}$

- U(LB, k&r) $_{TM}$ = -0.0085 * (in-vehicle time + drive access time) +
  -0.0169 * (centroid walk time + transfer walk time) +

-0.0169 * first wait time +
-0.0169 * transfer wait time +
-0.0017 * (fare + access auto operating cost) +
$KLBK_{TM}$

- $U(EB,walk)_{TM}$ = -0.0085 * in-vehicle time +
  -0.0169 * (centroid walk time + transfer walk time) +
  -0.0169 * first wait time +
  -0.0169 * transfer wait time +
  -0.0017 * fare +
  $KEBW_{TM}$

- $U(EB, p\&r)_{TM}$ = -0.0085 * (in-vehicle time + drive access time) +
  -0.0169 * (centroid walk time + transfer walk time) +
  -0.0169 * first wait time +
  -0.0169 * transfer wait time +
  -0.0017 * (fare + p&r park cost + access auto oper. cost) +
  $KEBP_{TM}$

- $U(EB, k\&r)_{TM}$ = -0.0085 * (in-vehicle time + drive access time) +
  -0.0169 * (centroid walk time + transfer walk time) +
  -0.0169 * first wait time +
  -0.0169 * transfer wait time +
  -0.0017 * (fare + access auto operating cost) +
  $KEBK_{TM}$

2.4.6 Non-Home-Based Model

The NHB utility expressions are listed below. In these equations, all times are expressed in minutes and all costs are expressed in 1995 cents. "LB" stands for local bus and "EB" stands for express bus. The "$K???_{TM}$" terms are the mode specific constants, stratified by time period (T) and market segment (M). Please refer to Table 2.4.7 for the constants. Note that parking and auto operating costs are not shared among a vehicle's occupants, consistent with the finding that most carpools are composed of members of the same household.

In model application, utilities corresponding to lower level choices are divided by the appropriate logsum coefficients. Hence, U(drive-alone) is divided by 0.85, while all the other utilities are divided by the product (0.85*0.55).

- $U(\text{drive-alone})_{TM}$ =
  -0.0265 * (highway travel time + terminal parking time) +
  -0.0030 * (parking cost + auto operating cost) +
  KDA_{TM}

- $U(\text{share-ride 2})_{TM}$ =
  -0.0265 * (highway travel time + terminal parking time) +
  -0.0030 * (parking cost + auto operating cost)

- $U(\text{share-ride 3+})_{TM}$ =
  -0.0265 * (highway travel time + terminal parking time) +
  -0.0030 * (parking cost + auto operating cost) +
  $K3P_{TM}$

- $U(\text{LB,walk})_{TM}$ =
  -0.0265 * in-vehicle time +
  -0.0663 * centroid walk time +
  -0.0623 * transfer walk time +
  -0.0405 * first wait time +
  -0.0301 * transfer wait time +
  -0.0030 * fare +
  $KLBW_{TM}$

- $U(\text{LB, p\&r})_{TM}$ =
  -0.0265 * in-vehicle time +
  -0.0588 * drive access time +
  -0.0663 * centroid walk time +
  -0.0623 * transfer walk time +
  -0.0405 * first wait time +
  -0.0301 * transfer wait time +
  -0.0030 * (fare + p&r park cost + access auto oper. cost) +
  $KLBP_{TM}$

- $U(\text{LB, k\&r})_{TM}$ =
  -0.0265 * in-vehicle time +
  -0.0588 * drive access time +

-0.0663 * centroid walk time +
-0.0623 * transfer walk time +
-0.0405 * first wait time +
-0.0301 * transfer wait time +
-0.0030 * (fare + access auto operating cost) +
$KLBK_{TM}$

- $U(EB,walk)_{TM}$ =
  -0.0265 * in-vehicle time +
  -0.0663 * centroid walk time +
  -0.0623 * transfer walk time +
  -0.0405 * first wait time +
  -0.0301 * transfer wait time +
  -0.0030 * fare +
  $KEBW_{TM}$

- $U(EB, p\&r)_{TM}$ =
  -0.0265 * in-vehicle time +
  -0.0588 * drive access time +
  -0.0663 * centroid walk time +
  -0.0623 * transfer walk time +
  -0.0405 * first wait time +
  -0.0301 * transfer wait time +
  -0.0030 * (fare + p&r park cost + access auto oper. cost) +
  $KEBP_{TM}$

- $U(EB, k\&r)_{TM}$ =
  -0.0265 * in-vehicle time +
  -0.0588 * drive access time +
  -0.0663 * centroid walk time +
  -0.0623 * transfer walk time +
  -0.0405 * first wait time +
  -0.0301 * transfer wait time +
  -0.0030 * (fare + access auto operating cost) +
  $KEBK_{TM}$

Tables 2.4.6 – 2.4.8 show the mode-specific constants. For non-available modes, such as express mode for off-peak period travel, the constants were set to zero. A constant value of –15.0 also indicates a non-available mode. The following assumptions were made regarding the constants of modes not available in the base year: the constants for light rail have been set equal to the local bus constants, while the constants for commuter rail have been set equal to the express bus constants.

Note that for model calibration, constants are added at all levels of the nest. Moreover, additional constants have been added to the equations within any given level of the nest. Given that a logit model requires *N-1* constants (where *N* is the number of choices), the latter is not strictly necessary. However, the additional constant helps to speed the convergence of the calibration process. This additional constant does not, in any way, affect the computation of modal probabilities; exactly the same probabilities would be obtained if one constant were set to zero and all others were scaled accordingly. Please refer to Figure 2.4.5 for the location of each constant in the mode choice nest.

Figure 2.4.2 – Location of Mode-Specific Constants in the Choice Nest

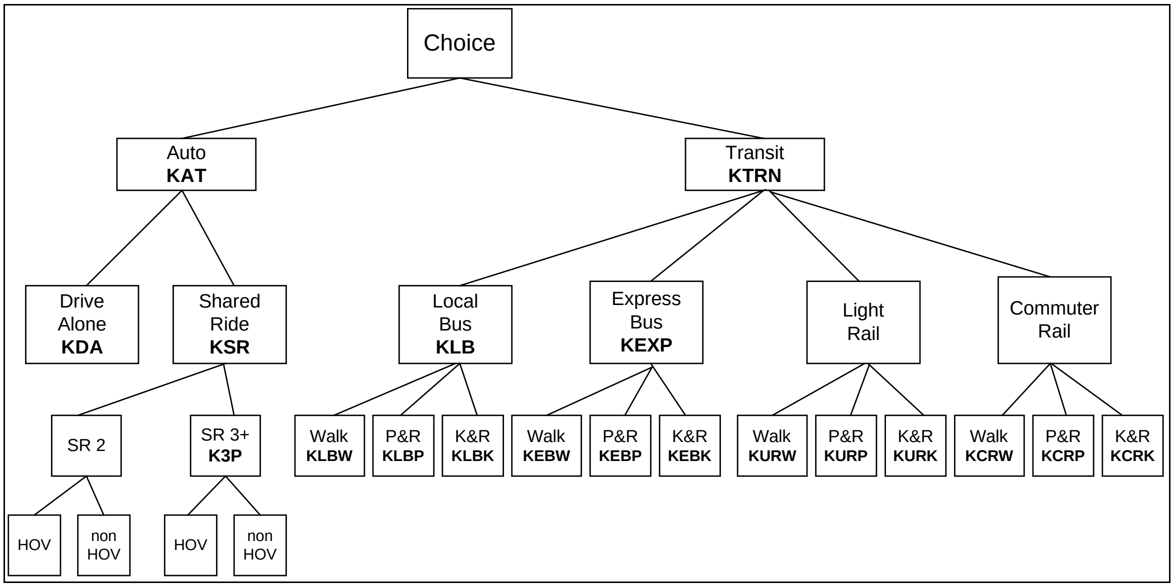


Table 2.4.4 – Mode-Specific Constants, HBW

Constant Name	Constant Description	Peak Period 0 cars	Peak Period car<wrk	Peak Period car=wrk	Peak Period car>wrk	Off Peak Period 0 cars	Off Peak Period car<wrk	Off Peak Period car=wrk	Off Peak Period car>wrk
KAT	Auto Modes	0.187	0.290	0.599	1.125	-0.517	0.396	0.860	1.657
KSR	Shared-Ride	0.000	-0.504	-1.153	-1.295	0.000	-0.285	-1.165	-1.293
KDA	Drive Alone	0.000	0.504	1.153	1.295	0.000	0.285	1.165	1.293
K3P	S.R. 3 person	-0.660	-0.498	-0.453	-0.530	-0.663	-0.313	-0.546	-0.673
KLBP	Local bus, p&r	-2.668	-0.739	-0.425	-0.224	-15.000	-2.027	-0.615	-0.822
KLBK	Local bus, k&r	-1.765	-1.287	-1.691	-1.320	-1.614	-1.080	-1.562	-0.927
KLBW	Local bus, walk	1.984	1.318	1.136	0.922	2.130	1.772	1.358	1.330
KEBP	Exp. bus, p&r	-0.874	-0.556	-0.055	0.078	0.000	0.000	0.000	0.000
KEBK	Exp. bus, k&r	-15.000	-0.644	-1.954	-15.000	0.000	0.000	0.000	0.000
KEBW	Exp. bus, walk	1.894	1.225	1.223	1.101	0.000	0.000	0.000	0.000
KEXP	Express bus	-1.492	-0.532	-0.634	-0.527	-15.000	-15.000	-15.000	-15.000
KLB	Local bus	1.492	0.532	0.634	0.527	0.000	0.000	0.000	0.000
KTRN	Transit Modes	-0.186	-0.284	-0.581	-1.149	0.512	-0.396	-0.863	-1.644
KURP	*Light rail, p&r*	*-2.668*	*-0.739*	*-0.425*	*-0.224*	*-15.000*	*-2.027*	*-0.615*	*-0.822*
KURK	*Light rail, k&r*	*-1.765*	*-1.287*	*-1.691*	*-1.320*	*-1.614*	*-1.080*	*-1.562*	*-0.927*
KURW	*Light rail, walk*	*1.984*	*1.318*	*1.136*	*0.922*	*2.130*	*1.772*	*1.358*	*1.330*
KPCRCBD	*Com.rail CBD, p&r*	*-0.874*	*-0.556*	*-0.055*	*0.078*	*0.000*	*0.000*	*0.000*	*0.000*
KKCRCBD	*Com.rail CBD, k&r*	*-15.000*	*-0.644*	*-1.954*	*-15.000*	*0.000*	*0.000*	*0.000*	*0.000*
KWCRCBD	*Com.rail CBD, walk*	*1.894*	*1.225*	*1.223*	*1.101*	*0.000*	*0.000*	*0.000*	*0.000*
KPCROTH	*Com.rail other, p&r*	*-0.874*	*-0.556*	*-0.055*	*0.078*	*0.000*	*0.000*	*0.000*	*0.000*
KKCROTH	*Com.rail other, k&r*	*-15.000*	*-0.644*	*-1.954*	*-15.000*	*0.000*	*0.000*	*0.000*	*0.000*
KWCROTH	*Com.rail other, walk*	*1.894*	*1.225*	*1.223*	*1.101*	*0.000*	*0.000*	*0.000*	*0.000*
KCR	*Commuter rail*	*-1.492*	*-0.532*	*-0.634*	*-0.527*	*-15.000*	*-15.000*	*-15.000*	*-15.000*
KRAL	*Light rail*	*1.492*	*0.532*	*0.634*	*0.527*	*0.000*	*0.000*	*0.000*	*0.000*

Modes that do not exist in the region in the base year (1995) are in italics.

Table 2.4.5 – Mode-Specific Constants, HBO

Constant		Peak Period				Off Peak Period			
Name	Constant Description	0 cars	car<wrk	car=wrk	car>wrk	0 cars	car<wrk	car=wrk	car>wrk
KAT	Auto Modes	1.070	2.120	2.673	3.064	-0.222	1.928	2.631	2.668
KSR	Shared-Ride	0.000	0.024	0.241	-0.019	0.000	-0.170	0.077	-0.059
KDA	Drive Alone	0.000	-0.024	-0.241	0.019	0.000	0.170	-0.077	0.059
K3P	S.R. 3 person	0.001	-0.084	0.004	-0.104	-0.226	-0.423	-0.133	-0.217
KLBP	Local bus, p&r	-4.275	-1.078	-0.715	-1.726	-15.000	-1.326	-1.547	-1.442
KLBK	Local bus, k&r	-15.000	-2.462	-1.201	-15.000	-15.000	-1.703	-15.000	-15.000
KLBW	Local bus, walk	2.047	1.555	1.130	1.874	0.000	1.645	1.903	1.850
KEBP	Exp. bus, p&r	-15.000	-0.595	-1.565	-0.504	0.000	0.000	0.000	0.000
KEBK	Exp. bus, k&r	-15.000	-15.000	-15.000	-0.504	0.000	0.000	0.000	0.000
KEBW	Exp. bus, walk	0.000	1.578	2.396	0.970	0.000	0.000	0.000	0.000
KEXP	Express bus	-0.788	-1.082	-1.118	0.125	-15.000	-15.000	-15.000	-15.000
KLB	Local bus	0.788	1.082	1.118	-0.125	0.000	0.000	0.000	0.000
KTRN	Transit Modes	-1.078	-2.167	-2.769	-3.140	0.219	-1.996	-3.086	-3.497
KURP	*Light rail, p&r*	*-4.275*	*-1.078*	*-0.715*	*-1.726*	*-15.000*	*-1.326*	*-1.547*	*-1.442*
KURK	*Light rail, k&r*	*-15.000*	*-2.462*	*-1.201*	*-15.000*	*-15.000*	*-1.703*	*-15.000*	*-15.000*
KURW	*Light rail, walk*	*2.047*	*1.555*	*1.130*	*1.874*	*0.000*	*1.645*	*1.903*	*1.850*
KPCRCBD	*Com.rail CBD, p&r*	*-15.000*	*-0.595*	*-1.565*	*-0.504*	*0.000*	*0.000*	*0.000*	*0.000*
KKCRCBD	*Com.rail CBD, k&r*	*-15.000*	*-15.000*	*-15.000*	*-0.504*	*0.000*	*0.000*	*0.000*	*0.000*
KWCRCBD	*Com.rail CBD, walk*	*0.000*	*1.578*	*2.396*	*0.970*	*0.000*	*0.000*	*0.000*	*0.000*
KPCROTH	*Com.rail other, p&r*	*-15.000*	*-0.595*	*-1.565*	*-0.504*	*0.000*	*0.000*	*0.000*	*0.000*
KKCROTH	*Com.rail other, k&r*	*-15.000*	*-15.000*	*-15.000*	*-0.504*	*0.000*	*0.000*	*0.000*	*0.000*
KWCROTH	*Com.rail other, walk*	*0.000*	*1.578*	*2.396*	*0.970*	*0.000*	*0.000*	*0.000*	*0.000*
KCR	*Commuter rail*	*-0.788*	*-1.082*	*-1.118*	*0.125*	*-15.000*	*-15.000*	*-15.000*	*-15.000*
KRAL	*Light rail*	*0.788*	*1.082*	*1.118*	*-0.125*	*0.000*	*0.000*	*0.000*	*0.000*

Modes that do not exist in the region in the base year (1995) are in italics.

Table 2.4.6 – Mode-Specific Constants, HBU and NHB

Constant		Home Based University		Non Home Based	
Name	Constant Description	Peak	Off Peak	Peak	Off Peak
KAT	Auto Modes	0.953	1.530	1.398	1.435
KSR	Shared-Ride	-0.710	-1.092	-0.408	-0.383
KDA	Drive Alone	0.710	1.092	0.408	0.383
K3P	S.R. 3 person	-0.599	-0.832	-0.222	-0.214
KLBP	Local bus, p&r	-15.000	-15.000	-0.238	-0.652
KLBK	Local bus, k&r	-0.713	-0.552	-0.843	-1.119
KLBW	Local bus, walk	1.584	1.486	0.718	1.159
KEBP	Exp. bus, p&r	-15.000	0.000	0.725	0.000
KEBK	Exp. bus, k&r	-15.000	0.000	-0.766	0.000
KEBW	Exp. bus, walk	0.000	0.000	0.224	0.000
KEXP	Express bus	0.344	-15.000	-0.686	-15.000
KLB	Local bus	-0.344	0.000	0.686	0.000
KTRN	Transit Modes	-0.949	-1.526	-1.652	-1.490
KURP	*Light rail, p&r*	*-15.000*	*-15.000*	*-0.238*	*-0.652*
KURK	*Light rail, k&r*	*-0.713*	*-0.552*	*-0.843*	*-1.119*
KURW	*Light rail, walk*	*1.584*	*1.486*	*0.718*	*1.159*
KPCRCBD	*Com.rail CBD, p&r*	*-15.000*	*0.000*	*0.725*	*0.000*
KKCRCBD	*Com.rail CBD, k&r*	*-15.000*	*0.000*	*-0.766*	*0.000*
KWCRCBD	*Com.rail CBD, walk*	*0.000*	*0.000*	*0.224*	*0.000*
KPCROTH	*Com.rail other, p&r*	*-15.000*	*0.000*	*0.725*	*0.000*
KKCROTH	*Com.rail other, k&r*	*-15.000*	*0.000*	*-0.766*	*0.000*
KWCROTH	*Com.rail other, walk*	*0.000*	*0.000*	*0.224*	*0.000*
KCR	*Commuter rail*	*0.344*	*-15.000*	*-0.697*	*-15.000*
KRAL	*Light rail*	*-0.344*	*0.000*	*0.697*	*0.000*

Modes that do not exist in the region in the base year (1995) are in italics.

2.4.7 Intrazonal Mode Split

The OKI/MVRPC model does not apply the mode choice model to intrazonal trip interchanges. A transit path cannot be built for an intrazonal trip, and hence the mode choice model cannot be applied reliably to this type of trip. Instead, the model splits intrazonal trips among the three auto modes on the basis of a mode split proportion, invariant with respect to any zone characteristic (see Table 2.4.9). These proportions were derived from the OKI Home Interview Survey. The intrazonal mode split for HBU trips was assumed equal as the split for HBW trips.

Table 2.4.7 – Intrazonal Mode Split Proportions

Trip Purpose	Drive Alone	Shared Ride 2	Shared Ride 3+
HBW			
Peak	92%	6%	2%
Off Peak	92%	6%	2%
HBO			
Peak	39%	32%	29%
Off Peak	43%	32%	25%
NHB			
Peak	55%	31%	14%
Off Peak	53%	29%	18%

2.4.8 Mode Choice Model Refinements

In addition to the mode-specific constants listed above, the OKI/MVRPC model includes transit-specific constants. These constants were added to improve the validation of transit boarding, in particular for TANK transit. Table 2.4.10 below lists the values of the transit constants. The summaries above already include the effect of these constants.

Table 2.4.8 – Transit-Specific Constants

Transit Agency	Trip Purpose							
	HBW		HBU		HBO		NHB	
	Peak	OffPk	Peak	OffPk	Peak	OffPk	Peak	OffPk
SORTA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TANK	-0.75	-1.00	0.00	0.00	-0.75	-0.75	-0.75	-0.75
Middletown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hamilton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MVRTA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.5 Airport Passenger and Kings Island Visitor Sub-Models

2.5.1 The Airport Passenger Sub-Model

Airport passengers respond to the availability of transit differently from other types of potential users. Because luggage may increase the difficulty of walking to a transit stop, they are more sensitive to the actual location of the boarding and alighting stations in relation to the actual origin and destination of their trip (e.g., the airport gate and their hotel or office). Unlike regular commuters who can schedule their trip according to transit timetables, the airport passenger traveling from the airport is subject to whatever schedule variance occurs in the preceding flight. Consequently, they are highly sensitive to service frequency. On the return trip to the airport, the air passenger is particularly sensitive to the reliability of the service. Late trains or buses may result in travelers missing flights. If the transit service develops the reputation for being unpredictable, the airport passengers will probably avoid it.

Because the airport passenger market is different from those normally addressed by typical travel demand models, a special airport passenger model was developed for Greater Cincinnati North Kentucky International Airport (CVG). The airport passenger model is executed as part of the regional travel demand model and is based on a series of airport passenger trip tables developed from the 1995 airport passenger survey and scaled to represent anticipated traffic levels for years between 1995- 2030. The district level 1995 airport passenger trip tables are directly from the airport passenger survey. The trip tables are developed for four trip purposes Resident-Business (RB), Nonresident-Business (NB), Resident-nonbusiness (RN), and Nonresident-nonbusiness (NN).

The airport passenger trips are allocated to the regional zones by allocation factors based on the OKI 1995 socio-economic data set. This simulates the trip distribution patterns of airport passengers across the metropolitan area. For each of the four trip purposes Resident-Business (RB), Nonresident-Business (NB), Resident-nonbusiness (RN), and Nonresident-nonbusiness (NN), trips are allocated to TAZs using the following equations:

* Resident-Business: (HH + EMP) / SUMHP
* Nonresident-Business: EMP / SUMEMP
* Resident-Nonbusiness: HH / SUMHH
* Nonresident-Nonbusiness: (HH + EMP) / SUMHP

Where HH is the number of households in the zone, EMP is the employment of the zone, SUMHP is total regional households and employment, SUMEMP is total regional employment, and SUMHH is the total number of households in the region. If the zone is an external,

* All origins: TOTTAZ / TOTCVG

Where TOTTAZ is the total internal-external person trips for the TAZ (external station) being allocated to CVG and TOTCVG is the regional internal-external trips being allocated to CVG.

Person trip tables for future years are calculated in the same way. The number of forecasted airport passenger trips is determined by multiplying 1995 air passenger trips (14,730) by growth rates assumed in the airport master plan. The average growth of enplanements from 1996-2011, according the Cincinnati/Northern Kentucky International Airport Master Plan Update, is 5% per year. This figure is also assumed for years beyond 2011. The trips are distributed to TAZs by using the process described earlier.

After the analysis year airport passenger trips are calculated, an adjustment is made to the number of regional trips to avoid double counting. The airport passenger trips in the analysis are removed by reducing the HBO and EI trip tables by an adjustment percentage. The airport passenger trips are removed after the HBO and EI trip tables go through their respective trip distribution phase.

A modal choice model was developed from the 1995 survey that calculates the person trip shares for each of the various modes of travel to the airport. The trip tables and modal choice models stratify the air passenger market into four sub-markets: Resident business (RB), Non-resident business (NB), Resident non-business (RN), and Non-resident non-business (NN) trips. A list of the 1995 airport passenger trips by purpose is shown in Table 2.5.1.

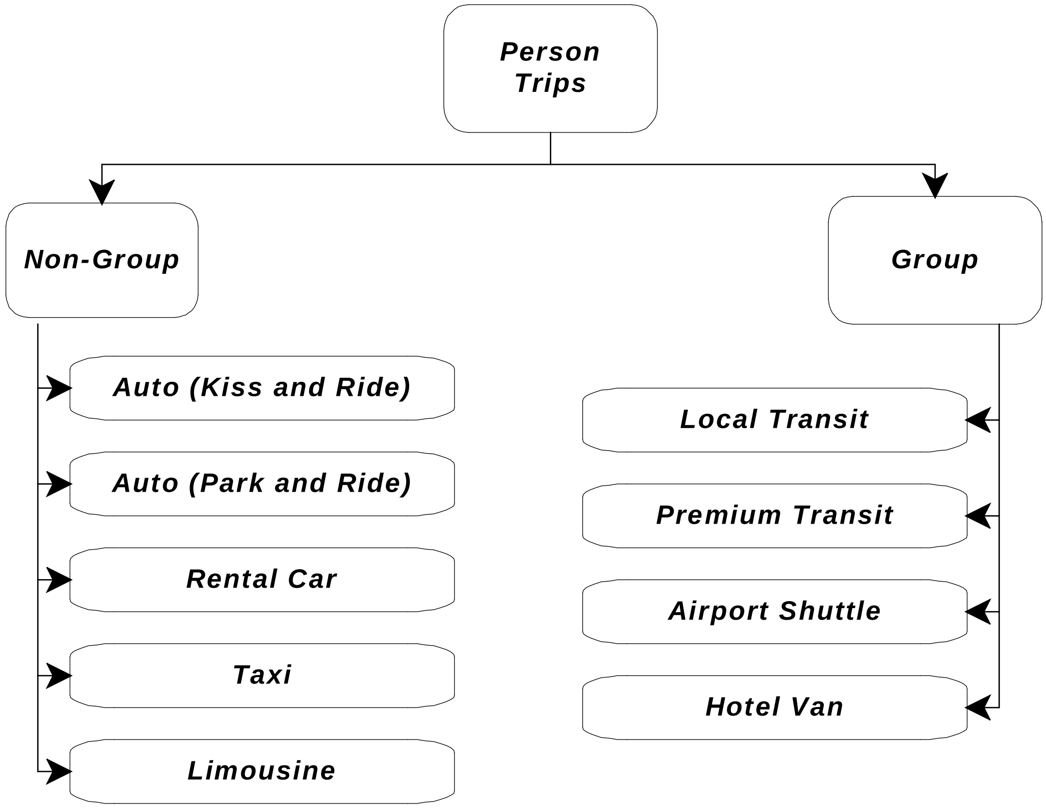
Table 2.5.1 – 1995 Airport Passenger Trips by Purpose

Purpose	Trips
Resident Business	5,544
Non-Resident Business	4,253
Resident Non-Business	2,558
Non-resident Non-business	2,377
Total	14,732

The airport passenger modal choice model is a nested logit formulation estimating the shares of the various modes of access available to CVG. The mode choice model outputs trip tables in P/A format. Figure 2.5.1 shows the structure of airport mode split models. In all, nine different sub-modes are computed:

Group Mode	Non-Group Mode
Premium Transit	Auto (Kiss and Ride)
Local Transit	Auto (Park and Ride)
Airport Shuttle	Rental Car
Hotel Van	Taxi
	Limousine

Figure 2.5.1 – Airport Passenger Modal Choice Model Structure



An adjustment is made to the regional taxi trip table since air passenger taxi trips are computed by the airport passenger sub-model.

Figures 2.5.2 – 2.5.5 show the utility equations for each trip purpose. For the auto cost variable, the highway distance in miles is multiplied by $.30 to produce a general perceived cost of driving to and from the airport. Fourteen dollars (1400 cents) are added to the auto cost to reflect an average parking cost for a typical air trip. Some minutes are added to the terminal times to reflect the extra time needed to park (3 extra minutes), pick up a rental car (10), wait for a taxi or limo (5), or wait for a bus (8). Travel times are obtained from the travel time/cost skim tables developed for the regional travel demand model. Peak times are used for business travel and off-peak times for non-business travel. Transit travel times are taken directly from the transit time and fare skims.

The coefficients were borrowed directly from the Newark Airport model. The constants in the disutility expressions were calibrated to replicate the mode of travel results from the airport passenger survey. The modal bias constant for the premium transit mode were established based on the results of the stated preference portion of the airport passenger survey. .

Occupancy factors, derived from the airport survey and work in other cities, are used to convert the airport passenger auto person trip table to a vehicle trip table. These factors, shown in Table 2.5.2, are used for all airport passenger trip purposes.

Table 2.5.2 – 1995 Airport Passenger Occupancy Factors

Sub-Mode	Occupancy Factor
Auto (Park and ride)	0.71
Auto (Kiss and ride)	0.55
Rental Car	0.57
Taxi	0.37
Limousine	0.41
Hotel Van	0.18
Airport shuttle	0.35
Local Transit	1.00
Premium Transit	1.00

The airport passenger trip table is brought back into the regional model system for highway and transit assignment. All modes, except local and premium transit modes, are merged into a single daily auto table (this is preformed within the sub-model). They are combined with the daily trip table just prior to the time-of-day split according to the following guidelines:

Airport Passenger Trip Purpose	Regional Travel Demand Trip Purpose
Resident Business	Home-based Work
Resident Non-business	Home-based Other
Non-resident Business	Home-based Work
Non-resident Non-business	Home-based Other

Airport passenger transit trips are divided into peak and offpeak periods using factors derived from the airport survey. These factors are shown in Table 2.5.3. Then each trip table is merged with the corresponding (peak or offpeak) regional transit trip table in preparation for transit assignment. These processes are performed within the sub-model.

Table 2.5.3 – Airport Passenger Transit Peak/Offpeak Factors

Purpose and Period	Percentage of Trips
Resident Business, Non-resident Business Peak	0.75
Resident Business, Non-resident Business Offpeak	0.25
Resident Non-business, Non-resident Non-business Peak	0.43
Resident Non-business, Non-resident Non-business Offpeak	0.57

Figure 2.5.2 – Resident Business Airport Passenger Model Utility Equations

U_{ng} = $0.3 * (\ln(T_{ng}))$
T_{ng} = $\exp(U_{AP}) + \exp(U_{AK}) + \exp(U_{RC}) + \exp(U_{taxi}) + \exp(U_{limo})$

U_{AP} = 3.33837 + -.00049[(30) * Hwydist + 1400] + -.03983[Term + 3] + -.01863[IVT / 100)]
U_{AK} = 1.24737 + -.00049[(30) * Hwydist + 200] + -.03983[Term + 3] + -.01863[IVT / 100)]
U_{RC} = 1.24737 + -.00049[(30) * Hwydist + 3500] + -.03983[Term + 10] + -.01863[IVT / 100)]
U_{taxi} = .35737 + -.00049(Fare) + -.03983[Term + 5] + -.01863[IVT]
U_{limo} = 1.24563 + -.00049(Fare) + -.03983[Term + 5] + -.01863[IVT]

U_{gp} = $0.3 * (\ln(T_{gp}))$
T_{gp} = $\exp(U_{van}) + \exp(U_{shut}) + \exp(U_{loc}) + \exp(U_{prem})$

U_{van} = -9.505 + -.00049(Fare) + -.03983[Term + K] + -.01863[IVT]
[K = 10 if origin is CVG, Covington, or downtown Cincinnati district, K = 20 otherwise}]
U_{shut} = -7.895 + -.00049(Fare) + -.03983[Term + 8] + -.01863[IVT]
U_{loc} = -.8767 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]
U_{prem} = .74742 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]

Where:
ng is non-group modes, AP is auto (park and ride), AK is auto (kiss and ride), RC is rental car, taxi is taxi, limo is limousine, gp is group modes, van is hotel van, shut is airport/hotel shuttle, loc is local transit, prem is premium transit,
Hwydist is the highway distance traveled in miles,
Term is the amount of time in minutes between entering the zone and arriving at the airport,
Fare is the charge or fee assessed for the ride in cents,
IVT is the peak highway travel time in minutes for the auto modes or the transit travel time for the transit modes, and
OVT is the average waiting time in minutes (and terminal time, if applicable) for the given submode.

Figure 2.5.3 – Resident Non-Business Airport Passenger Model Utility Equations

U_{ng} = 0.3 * (ln(T_{ng}))
T_{ng} = exp(U_{AP}) + exp(U_{AK}) + exp(U_{RC}) + exp(U_{taxi}) + exp(U_{limo})

U_{AP} = 2.63037 + -.00049[(30) * Hwydist + 1400] + -.03983[Term + 3] + -.01863[IVT]
U_{AK} = 1.77737 + -.00049[(30) * Hwydist + 200] + -.03983[Term + 3] + -.01863[IVT]
U_{RC} = .56737 + -.00049[(30) * Hwydist + 3500] + -.03983[Term + 10] + -.01863[IVT]
U_{taxi} = .37737 + -.00049(Fare) + -.03983[Term + 5] + -.01863[IVT]
U_{limo} = .70737 + -.00049(Fare) + -.03983[Term + 5] + -.01863[IVT]

U_{gp} = 0.3 * (ln(T_{gp}))
T_{gp} = exp(U_{van}) + exp(U_{shut}) + exp(U_{loc}) + exp(U_{prem})

U_{van} = -6.912 + -.00049(Fare) + -.03983[Term + K] + -.01863[IVT]
[K = 10 if origin is CVG, Covington, or downtown Cincinnati district, K = 20 otherwise}]
U_{shut} = -6.332 + -.00049(Fare) + -.03983[Term + 8] + -.01863[IVT]
U_{loc} = -.8767 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]
U_{prem} = .74742 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]

Where:
ng is non-group modes, AP is auto (park and ride), AK is auto (kiss and ride), RC is rental car, taxi is taxi, limo is limousine, gp is group modes, van is hotel van, shut is airport/hotel shuttle, loc is local transit, prem is premium transit,
Hwydist is the highway distance traveled in miles,
Term is the amount of time in minutes between entering the zone and arriving at the airport,
IVT is the in-vehicle travel time in minutes,
Fare is the charge or fee assessed for the ride in cents,
IVT is the peak highway travel time in minutes for the auto modes or the transit travel time for the transit modes, and
OVT is the average waiting time in minutes (and terminal time, if applicable) for the given submode.

Figure 2.5.4 – Non-Resident Business Airport Passenger Model Utility Equations

U_{ng} = $0.3 * (\ln(T_{ng}))$
T_{ng} = $\exp(U_{AP}) + \exp(U_{AK}) + \exp(U_{RC}) + \exp(U_{taxi}) + \exp(U_{limo})$

U_{AP} = 1.22737 + -.00049[(30) * Hwydist + 1400] + -.03983[Term + 3] + -.01863[IVT]
U_{AK} = 2.38737 + -.00049[(30) * Hwydist + 200] + -.03983[Term + 3] + -.01863[IVT]
U_{RC} = 5.19377 + -.00049[(30) * Hwydist + 3500] + -.03983[Term + 10] + -.01863[IVT]
U_{taxi} = 3.35237 + -.00049(Fare) + -.03983[Term + 5] + -.01863[IVT]
U_{limo} = 2.46737 + -.00049(Fare) + -.03983[Term + 5] + -.01863[IVT]

U_{gp} = $0.3 * (\ln(T_{gp}))$
T_{gp} = $\exp(U_{van}) + \exp(U_{shut}) + \exp(U_{loc}) + \exp(U_{prem})$

U_{van} = -1.1225 + -.00049(Fare) + -.03983[Term + K] + -.01863[IVT]
[K = 10 if origin is CVG, Covington, or downtown Cincinnati district, K = 20 otherwise}]
U_{shut} = -.5025 + -.00049(Fare) + -.03983[Term + 8] + -.01863[IVT]
U_{loc} = -.8767 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]
U_{prem} = .74742 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]

Where:
ng is non-group modes, AP is auto (park and ride), AK is auto (kiss and ride), RC is rental car, taxi is taxi, limo is limousine, gp is group modes, van is hotel van, shut is airport/hotel shuttle, loc is local transit, prem is premium transit,
Hwydist is the highway distance traveled in miles,
Term is the amount of time in minutes between entering the zone and arriving at the airport,
IVT is the in-vehicle travel time in minutes,
Fare is the charge or fee assessed for the ride in cents,
IVT is the peak highway travel time in minutes for the auto modes or the transit travel time for the transit modes, and
OVT is the average waiting time in minutes (and terminal time, if applicable) for the given submode.

Figure 2.5.5 – Non-Resident Non-Business Airport Passenger Model Utility Equations

U_{ng} = $0.3 * (\ln(T_{ng}))$
T_{ng} = $\exp(U_{AP}) + \exp(U_{AK}) + \exp(U_{RC}) + \exp(U_{taxi}) + \exp(U_{limo})$

U_{AP} = 3.20737 + -.00049[(30) * Hwydist + 1400] + -.03983[Term + 3] + -.01863[IVT]
U_{AK} = 2.94737 + -.00049[(30) * Hwydist + 200] + -.03983[Term + 3] + -.01863[IVT]
U_{RC} = 4.32737 + -.00049[(30) * Hwydist + 3500] + -.03983[Term + 10] + -.01863[IVT]
U_{taxi} = 1.34737 + -.00049(Fare) + -.03983[Term + 5] + -.01863[IVT]
U_{limo} = 1.88737 + -.00049(Fare) + -.03983[Term + 5] + -.01863[IVT]

U_{gp} = $0.3 * (\log(T_{gp}))$
T_{gp} = $\exp(U_{van}) + \exp(U_{shut}) + \exp(U_{loc}) + \exp(U_{prem})$

U_{van} = -3.2652 + -.00049(Fare) + -.03983[Term + K] + -.01863[IVT]
[K = 10 if origin is CVG, Covington, or downtown Cincinnati district, K = 20 otherwise}]
U_{shut} = -2.7812 + -.00049(Fare) + -.03983[Term + 8] + -.01863[IVT]
U_{loc} = -.8767 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]
U_{prem} = .74742 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]

Where:
ng is non-group modes, AP is auto (park and ride), AK is auto (kiss and ride), RC is rental car, taxi is taxi, limo is limousine, gp is group modes, van is hotel van, shut is airport/hotel shuttle, loc is local transit, prem is premium transit,
Hwydist is the highway distance traveled in miles,
Term is the amount of time in minutes between entering the zone and arriving at the airport,
IVT is the in-vehicle travel time in minutes,
Fare is the charge or fee assessed for the ride in cents,
IVT is the peak highway travel time in minutes for the auto modes or the transit travel time for the transit modes, and
OVT is the average waiting time in minutes (and terminal time, if applicable) for the given submode.

2.5.2 The Kings Island Visitor Sub-Model

Structurally, the Kings Island Visitor model is identical to the Airport Passenger model. The Kings Island visitor sub-model is executed as part of the regional travel demand model. The analysis district level 1995 Kings Island trip table is directly from the Kings Island visitor survey. The trip tables are scaled to represent anticipated visitor levels for years between 1995-2030.

The trips for each analysis district are allocated to the individual TAZ's using allocation factors based on the OKI 1995 demographic file. The distribution of trips to this unique facility differs from that estimated as part of the standard trip purposes. Because the Kings Island sub-model has only one trip purpose and one origin type, trips are distributed to each TAZ using:

- Internal Trips: HH / SUMHH

Where HH is the number of households in the zone and SUMHH is the number of households in the region. If the TAZ is an external:

- External Trips: TOTTAZ / TOTPKI

Where TOTTAZ is the total internal-external person trips for the TAZ (external station) being allocated to Kings Island and TOTPKI is the regional external-internal trips allocated to Kings Island.

Future year person trip tables are calculated in the same way. The number of forecasted visitor trips is determined by multiplying 1995 total visitor trips (5,780) by assumed growth rates. Since amusement parks do not freely distribute their attendance figures, the growth rate was assumed to be equal to the growth in HBO attractions for zone 1014 between 1995 and 2030. This figure (0.1% per year) is assumed for all years beyond 1995. The trips are then distributed to TAZs using the process described earlier.

After the analysis year Kings Island trips are calculated, an adjustment is made to the number of regional trips to avoid double counting. The Kings Island trips in the analysis are removed by reducing the HBO and EI trip tables by an adjustment percentage.

The Kings Island visitor modal choice model is a nested logit formulation estimating the shares of the various modes of access available to Kings Island. Since the data quality regarding the stated-preference portion of the survey was less than desirable, the modal bias constants and coefficients are taken directly from the Resident Non-Business trip purpose of the Airport Passenger Sub-Model. The mode choice model outputs the trip table in P/A format. Only three modes are made available in the Kings Island modal choice model:

Group Mode	Non-Group Mode
Local Transit	Auto (Park and ride)
Premium Transit	

The utility equations for the Kings Island visitor mode choice are shown in Figure 2.5.6. The coefficients for the premium transit mode were established based on the results of the stated preference portion of the air passenger survey. Only offpeak highway and transit skims are used since amusement park trips occur during offpeak hours. As a result, the visitors sub-model is run only once during the model process.

An occupancy factor was calculated from the Kings Island survey data to convert the person trip table to a vehicle trip table. The average auto occupancy is 3.86, and therefore the occupancy factor is .26 (1.00 / 3.86). The transit trip tables use an occupancy factor of 1.00.

Like the airport passenger model, the visitor trip table is brought into the regional model for highway and transit assignment. All modes except for local and premium transit are combined within the sub-model. Then, they are merged into the daily HBO trip table just prior to the four period time-of-day split.

Kings Island transit trips are divided into peak and offpeak periods using factors from the non-work trip purposes from the airport passenger survey. It is assumed that workers may use transit during peak hours if transit is available to the park in future years (no transit service existed in 1995). These transit peak/offpeak factors are shown in Table 2.5.4. These processes are performed within the sub-model. Each transit trip table is then combined with the corresponding regional transit trip table just prior to transit assignment.

Table 2.5.4 – Kings Island Transit Peak/Offpeak Factors

Purpose and Period	Percentage of Trips
Peak Kings Island Visitor Trips	0.43
Offpeak Kings Island Visitor Trips	0.57

Figure 2.5.6 – Kings Island Visitor Model Utility Equations

U_{ng} = $0.3 * (\ln(T_{ng}))$
T_{ng} = $\exp(U_{AP})$

U_{AP} = 2.63037 + -.00049[30 * Hwydist + 1400] +
-.03983[Term + 3] + -.01863[IVT]

U_{gp} = $0.3 * (\ln(T_{gp}))$
T_{gp} = $\exp(U_{loc}) + \exp(U_{prem})$

U_{loc} = -.8767 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]
U_{prem} = .74742 + -.00049(Fare) + -.03983[OVT + 8] + -.01863[IVT]

Where:
ng is non-group modes, AP is auto (park and ride), gp is group modes, loc is local transit, prem is premium transit,
Hwydist is the highway distance traveled in miles,
Term is the amount of time in minutes between entering the zone and arriving at the airport,
IVT is the in-vehicle travel time in minutes,
Fare is the charge or fee assessed for the ride in cents,
IVT is the peak highway travel time in minutes for the auto modes or the transit travel time for the transit modes, and

OVT is the average waiting time in minutes (and terminal time, if applicable) for the given submode.

2.6 Truck Trip Model

The commercial truck trips are estimated by the truck trip model. The truck model is a set of procedures that produces truck trip tables for use in a multi-class traffic assignment. Two truck trip tables (for base year and forecasting year) are developed. The methodology is not behavioral-based due to the non-availability of survey data for commercial vehicle movements. The truck model developed produces truck trip tables for two types of commercial vehicles: single-unit (six-tire trucks) (SU) and multi-unit (three-plus axle combination trucks) (MU).

2.6.1 Base Year Truck Trip Table Development

The truck trips include trips from internal zone to internal zone, internal zone to external station, external station to internal zone, and external station to external station. For external portion (external-external, external-internal and internal-external trips), since trip data are available, the trips are derived by processing the data collected in 1995 /1996 external station trip surveys. In the absence of similar commercial vehicle movement data between internal zones, synthetic matrix estimation (SME) is used to develop the base year internal zone – internal zone truck trip table. Synthetic matrix estimation begins with truck traffic counts on the network links and a truck trip "seed matrix," which is a first-cut attempt at a trip matrix. The algorithm iteratively combines network assignment and matrix balancing methods to produce a final trip matrix that is proportionally related to the seed matrix, but which results in flows that closely match traffic counts along the optimal path between each origin and destination zone pair.

Synthetic matrix estimation is performed at an aggregate level. Contiguous traffic analysis zones (TAZ) with similar employment densities and general land use types (office/retail, industrial, residential, agricultural) are grouped together to form freight traffic zones (FAZ). A system consisting of 161 FAZs is constructed from relatively homogenous groupings of the original 2,425 internal zones of the combined OKI/MVRPC TAZ system, see Figure 2.6.1.

2.6.1.1 Truck Trip Table at Freight Analysis Zone Level

The implementation of this approach is illustrated in Figure 2.6.2. Employment and household data are used to generate productions and attractions (for internal-internal trip portion) for each FAZ. The productions and attractions are then distributed among internal origin - destination pairs, using a gravity model, to create seed matrix estimates for single-unit and multi-unit truck vehicle classes. The seed matrices are adjusted in the SME procedure to produce a set of calibrated truck tables, representing internal-internal truck trips. Estimates of external truck trip ends are derived from data collected in the 1995/1996 External Station Surveys and are then added to the internal-internal trip tables to the form the complete daily trip tables for SU and MU truck types.

Figure 2.6.1 – Freight Analysis Zone (FAZ) System

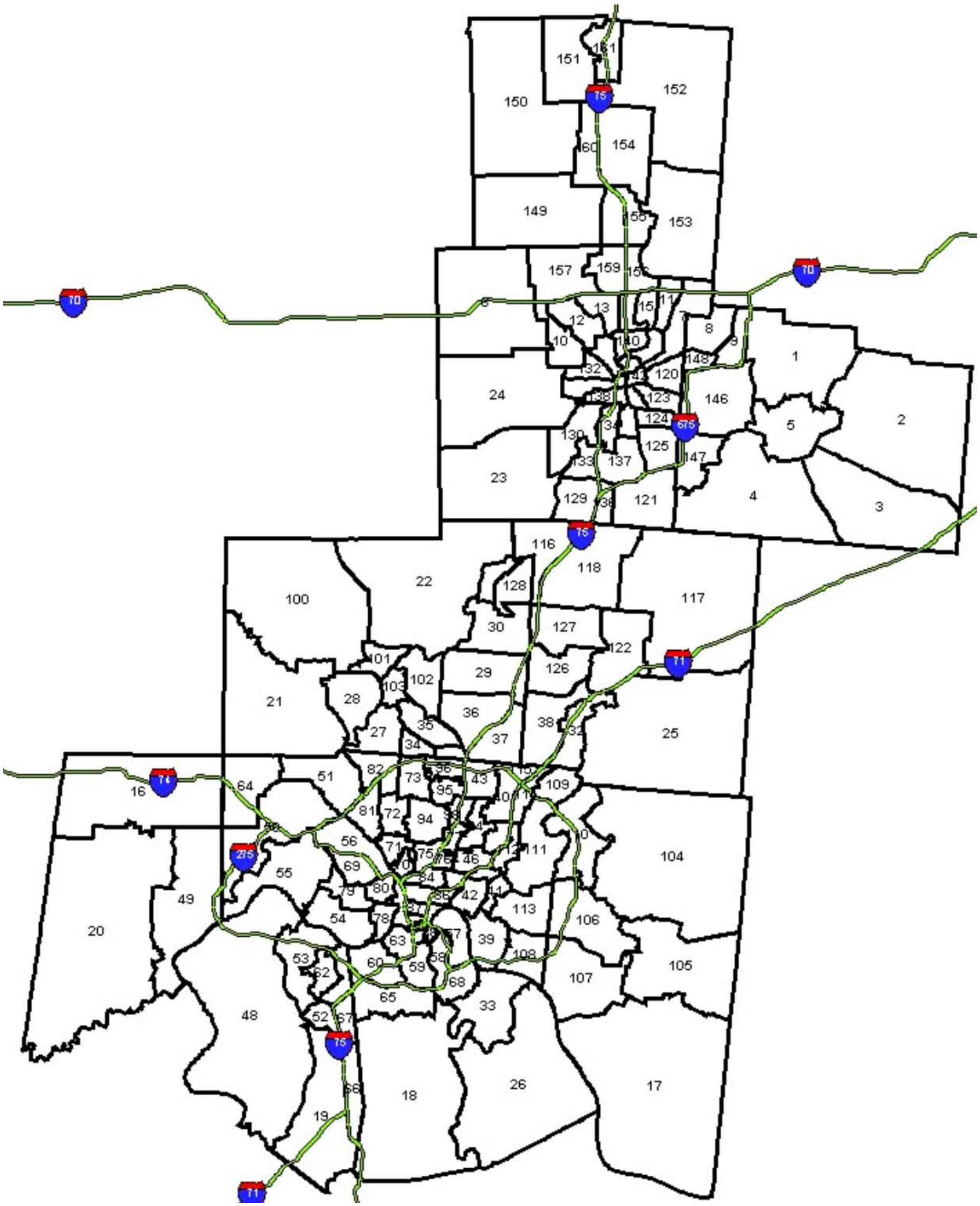
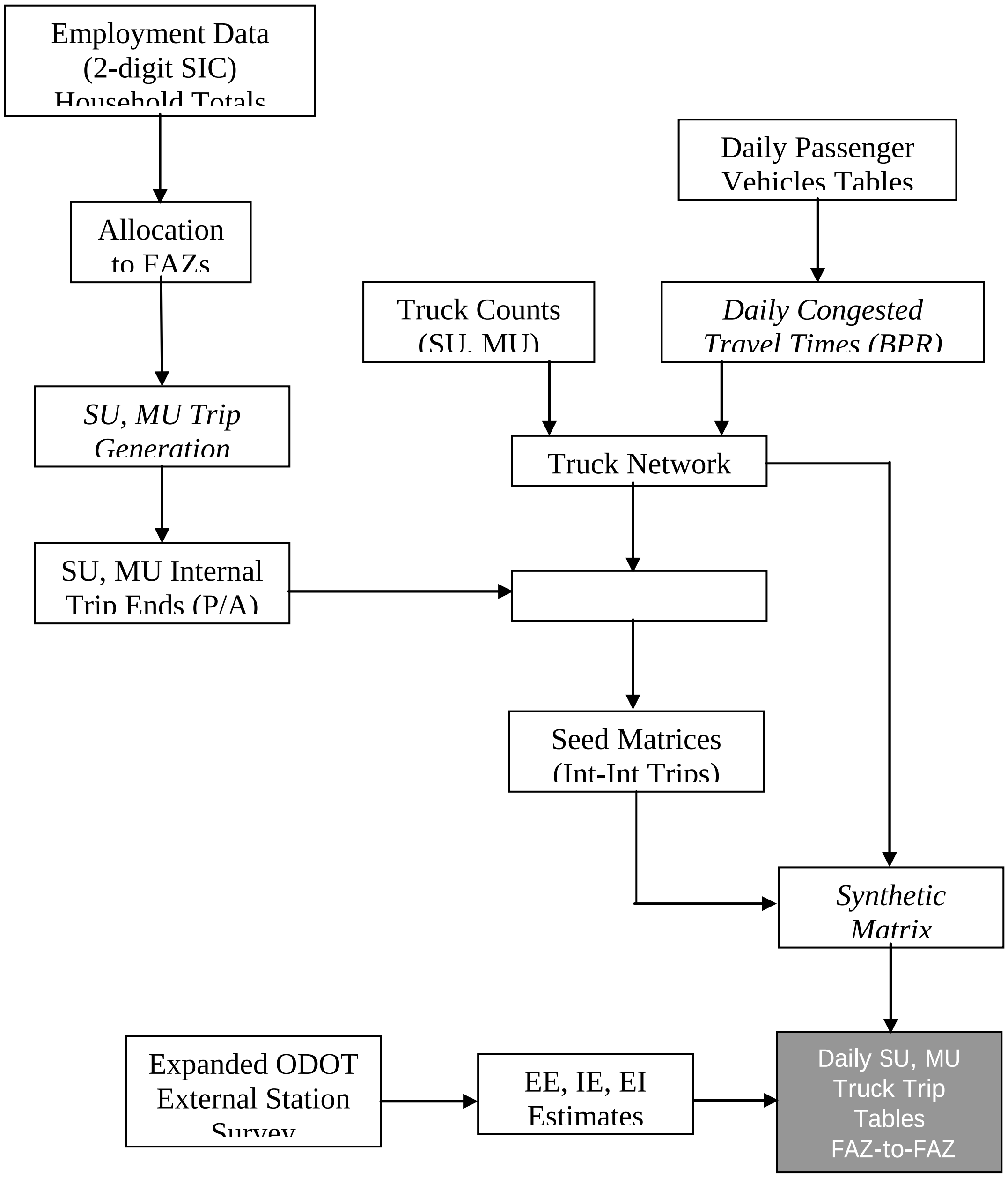


Figure 2.6.2 – Data and Processes Used to Create Base Year Truck Table



The seed matrix is an initial estimate of the FAZ-to-FAZ internal truck trip tables. The seed matrix was constructed by applying standard trip generation and distribution techniques. Lacking commercial vehicle survey data for calibration, the trip generation equations and gravity model impedance functions use modified versions of parameters published in the Quick Response Freight Manual (USDOT 1996) to produce initial estimates of SU and MU truck trip tables. First, the expected numbers of SU and MU truck productions and attractions were generated for each FAZ based on employment and household totals.

$$TKO_i^S = TKD_i^S = TKRate^{S,AMC} * EMP_i^{AMC} + TKRate^{S,MFG} * EMP_i^{MFG} + TKRate^{S,RET} * EMP_i^{RET} + TKRate^{S,OFF} * EMP_i^{OFF} + TKRate^{S,HH} * HH_i$$

Where

TKO_i^S and TKD_i^S are the truck trip origins and destinations (internal – internal trip portion) for truck type S (Su or MU) in freight zone i.

EMP_i^X is the employment of employment type X in freight zone i.

HH_i is the households in freight zone i.

$TKRate^{S,X}$ is the internal – internal truck trip origin/destination rates per employment of employment type X (AMC, MTCLW, R, OS) for truck type S (SU,MU)

$TKRate^{S,HH}$ is the internal – internal truck trip origin/destination rates per household for truck type S (SU,MU)

$$TKRate^{S,X} = QTKRate^{S,X} * CF^S$$

$$TKRate^{S,HH} = QTKRate^{S,HH} * CF^S$$

Where

$QTKRate^{S,X}$ is the truck trip origin or destination rate per employment of employment type X for truck type S as recommended in "Quick Response Freight Manual", see Table 2.6.1 for the rates.

$QTKRate^{S,HH}$ is the truck trip origin or destination rate per household for truck type S as recommended in "Quick Response Freight Manual", see Table 2.6.1 for the rates.

CF^S is the correct factor to remove external-internal / internal-external trips. $CF^{SU} = 0.952$ and $CF^{MU} = 0.683$.

CF^S =[(Regional QRFM Truck Trip Ends)^S – (Regional EI/IE Trip at External Stations)^S] / (Regional QRFM Truck Trip Ends)^S

(Regional QRFM Truck Trip Ends)^S = $\Sigma_{i=1}^{all\ zones}(QTKRate^{S,AMC} * EMP_i^{AMC} + QTKRate^{S,MGF} * EMP_i^{MGF} + QTKRate^{S,R} * EMP_i^{R} + QTKRate^{S,OFF} * EMP_i^{OFF} + QTKRate^{S,HH} * HH_i)$

(Regional EI/IE Trip at External Stations)^S = $\Sigma_{j=1}^{all\ ext\ stations} (\Sigma_{i=1}^{all\ zones} TK_{i,j}^S + \Sigma_{i=1}^{all\ zones} TK_{j,i}^S)$

$TK_{i,j}^S$ is the truck trips from freight zone i to external station j for truck type S (derived from external station trip survey data).

$TK_{j,i}^S$ is the truck trip from external j to freight zone i for truck type S (derived from external station trip survey data).

AMC stands for employment types of agriculture, mining and construction
MFG stands for employment types of manufacturing, transportation, communication, utilities and wholesale trade
RET stands for employment type of retail trade
OFF stands for employment types of offices and service

Table 2.6.1 – QRFM Daily Truck Trip Generation Rates (Origins or Destinations per Employment ($QTKRate^{S,X}$ and $QTKRate^{S,HH}$)

Employment Category	Single-Unit	Multi-Unit
Agriculture, Mining and Construction (SIC 1-19)	0.289	0.174
Manufacturing, Transportation, Communications, Utilities and Wholesale Trade (SIC 20-51)	0.242	0.104
Retail Trade (SIC 52-59)	0.253	0.065
Offices and Service (SIC 60-88)	0.068	0.009
Households	0.099	0.038
Source: Quick Response Freight Manual, USDOT, 1996, p. 4-4		

Next, a gravity model was used to distribute these productions and attractions from freight analysis zone to freight analysis zone. Congested travel time skims were used to calculate friction factors in the gravity model.

$$TK_{i,j}^S = TKO_i^S * [TKD_j^S * f^S(d_{i,j})] / \Sigma_{j=1}^{all\ freight\ zones} [TKD_j^S * f^S(d_{i,j})]$$

Where

$TK_{i,j}^{S}$ is the truck trips of truck type S from freight zone i to freight zone j.

TKO_i^{S} and TKD_i^{s} are the truck trip origins and destinations (internal – internal trip portion) of truck type S (Su or MU) in freight zone i.

$f^{S}(d_{i,j})$ is the friction factors for truck type S from freight zone i to freight zone j. Friction factor is a function of the travel impedance between the freight zones.

$$f(d_{i,j}) = e^{-\alpha(S)*t(i,j)} \text{ if } t(i,j) >= t^{S}$$

$$f(d_{i,j}) = 1 - e^{-\alpha(S)*t(i,j)} \text{ if } t(i,j) < t^{S}$$

Where

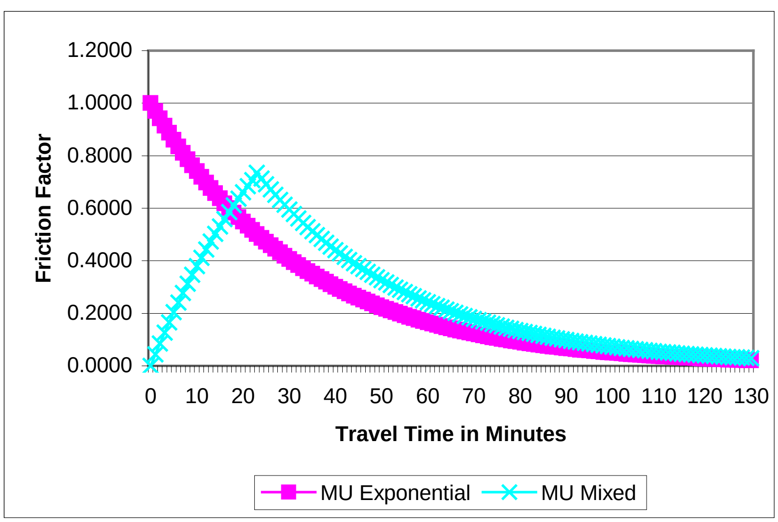
t(i,j) is the travel time from fright zone i to freight zone j.

$\alpha(S)$ is an impedance parameter for truck type S, equal to 0.03 for MU and 0.10 for SU trucks (as recommended in "Quick Response Freight Manual").

t^{S} is the value of the travel time where $e^{-\alpha(S)*t(i,j)} = 1 - e^{-\alpha(S)*t(i,j)}$

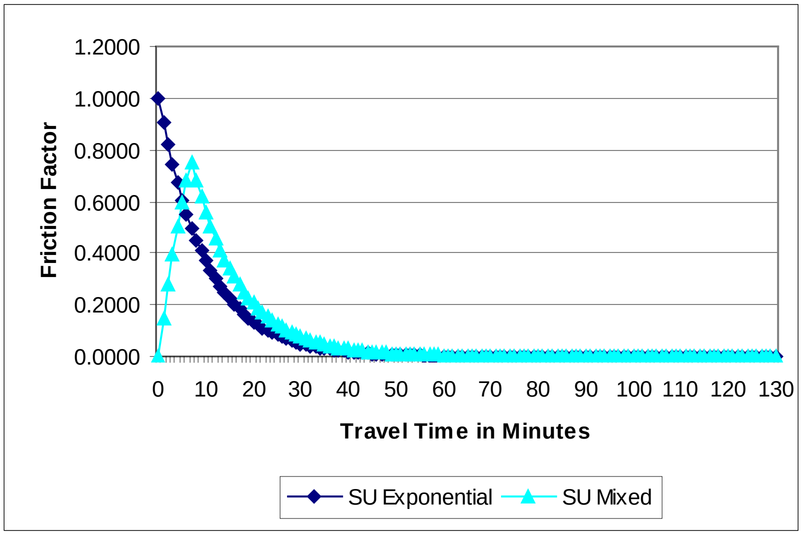
For MU trucks, this is represented in Figure 2.6.3, below, by the curve that first rises, then falls, with an inflection point at about 23 minutes. This type of mixed friction factor distribution is more realistic than the pure exponential form suggested by the "Quick Response Freight Manual" and is closer in shape to empirically derived curves from freight movement studies in other regions. For the sake of visual comparison, this curve has been inflated to match the area under the curve of the original exponential curve. The inflation factor cancels out in the gravity model equations.

Figure 2.6.3 – Synthesized MU Truck Friction Factors Using Mixed Distribution



Similarly, the same mixed distributional form was applied to calculate friction factors for SU truck trips. For SU trucks this distribution looks like the sharply peaked curve shown in Figure 2.6.4, with an inflection point at around seven minutes.

Figure 2.6.4 – Synthesized SU Truck Friction Factors Using Mixed Distribution



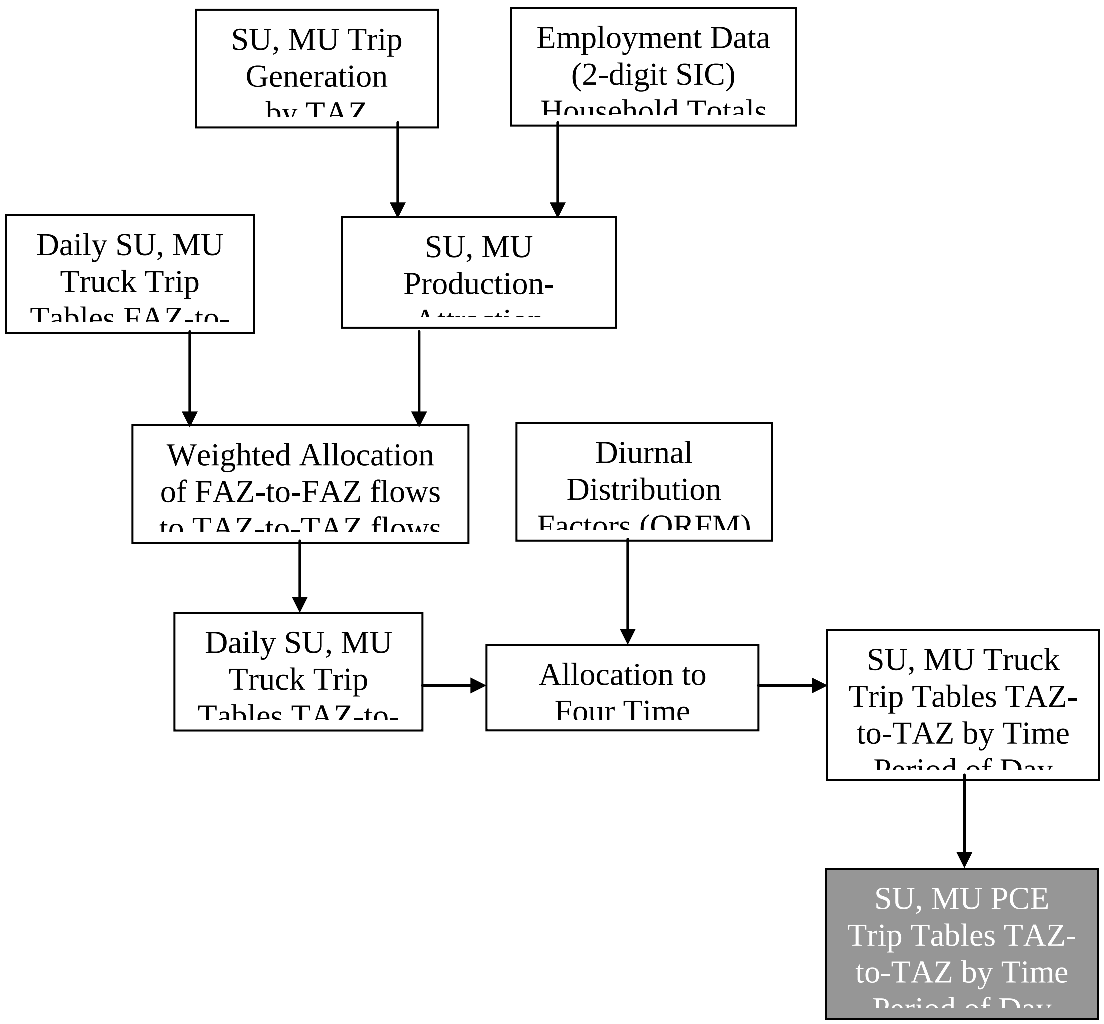
The implications of these "mixed distribution" curves are somewhat longer average trip-lengths in the seed matrix, compared with the exponential formulations. The synthetic trip matrix estimation process will adjust the seed matrix flows to match the truck counts on certain network links, changing the shape of the distribution to some degree. The exceptions are intra-zonal (FAZ) flows, because they are never loaded on the network during the SME process. The final intra-zonal flows will be the same as in the seed matrix.

As a final step, the synthetic matrix estimation algorithm is used to modify the seed matrix interchange values by factoring them up or down, such that when the table is assigned to the truck network the flows come as close as possible to the truck counts on the network links. In order to preserve the EE/EI flows in the external station survey, synthetic matrix estimation applies only to the internal-internal trips. SU and MU truck trip tables are calibrated separately.

2.6.1.2 Truck Trip Table at Traffic Analysis Zone Level

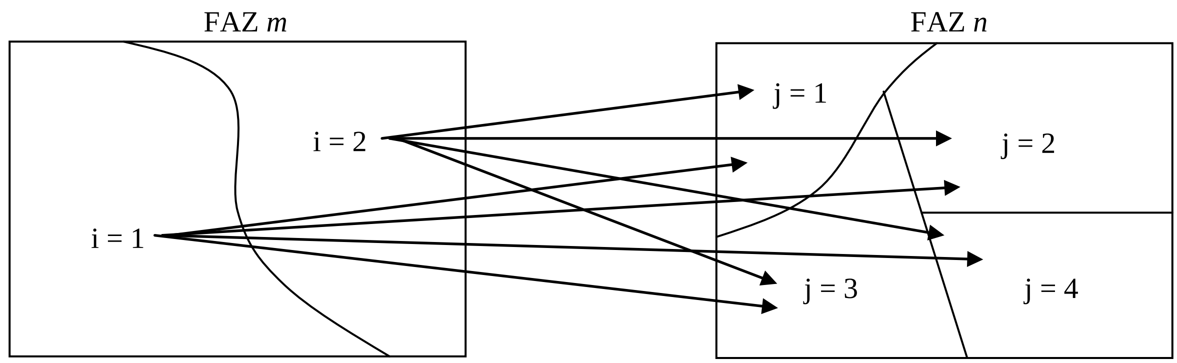
To produce truck trip tables for assignment to the zonal highway network required the re-allocation of FAZ-to-FAZ flows to TAZ-to-TAZ flows and the distribution of these flows across the four time periods of interest. Figure 2.6.5 illustrates these processes, which are described in this section.

Figure 2.6.5 – Steps to Distribute Daily FAZ-to-FAZ Truck Flows to TAZ-to-TAZ Flows by Time Period



The method to convert the internal FAZ-to-FAZ truck trip flows to TAZ-to-TAZ truck trip flows uses the fact that every FAZ was constructed from one or more whole TAZs. Figure 2.6.6 illustrates how flows are allocated from the FAZ pairs to TAZ pairs.

Figure 2.6.6 – Allocation of FAZ Flow m-n to TAZ Flow i-j



For each FAZ-to-FAZ pair, m-n, there are multiple constituent pairs of TAZ-to-TAZ pairs, i-j. Production/attraction weights, W_i were calculated for each TAZ, using linear combinations of 1995 total employment and households. The share of the m-n flow allocated to each i-j pair, was calculated as the product of the TAZ production/attraction weights for each i-j pair, divided by the sum of the products of the production/attraction weights for all of the i-j pairs belonging to the single FAZ pair m-n. Formally, this can be expressed as

$$F_{mn,ij} = F_{mn} * \left(\frac{W_i W_j}{\sum_{ij \in mn} W_i W_j} \right)$$

Where F_{mn} is the flow between FAZs m and n produced by the synthetic matrix estimation of truck trip tables, and $F_{mn,ij}$ is the flow allocated to TAZ pair i-j belonging to FAZ pair m-n. For intra-zonal FAZ flows, the constituent TAZ flows were calculated in the same way.

The truck trip generation coefficients from Table 2.6.1, above, were used to calculate production/attraction weights, W_i. At the TAZ level, employment was not categorized according to the four trip generation coefficients; therefore, a new trip generation coefficient for total employment was calculated as the weighted average of the QRFM coefficients. This resulted in a separate "total employment" weight coefficient for each FAZ, which was then applied to all TAZs belonging to the FAZ.

Formally, the production/attraction weights for SU and MU truck trips were calculated as follows:

$$W_i^{SU} = \beta_m^{SU} * E_i^{TOTAL'95} + 0.099 * H_i^{TOTAL'95}$$

$$W_i^{MU} = \beta_m^{MU} * E_i^{TOTAL'95} + 0.038 * H_i^{TOTAL'95}$$

Where W_i^{SU} and W_i^{MU} are the production/attraction weights for TAZ i for SU and MU truck types, respectively; β_m^{SU} and β_m^{MU} are the new total employment coefficients to be applied to all TAZs in FAZ m; $E_i^{TOTAL'95}$ and $H_i^{TOTAL'95}$ are the 1995 employment and household totals, respectively, for TAZ i. The household coefficients 0.099 and 0.038 for SU and MU trucks, respectively, are from Table 2.6.1.

The formulas used to calculate the new total employment weight coefficients for each FAZ m were

$$\beta_m^{SU} = \frac{0.289 * E_m^{AMC'95} + 0.242 * E_m^{MFG'95} + 0.253 * E_m^{RET'95} + 0.068 * E_m^{OFF'95}}{E_m^{TOTAL'95}}$$

$$\beta_m^{MU} = \frac{0.174 * E_m^{AMC'95} + 0.104 * E_m^{MFG'95} + 0.065 * E_m^{RET'95} + 0.009 * E_m^{OFF'95}}{E_m^{TOTAL'95}}$$

in which $E_m^{AMC'95}, E_m^{MFG'95}, E_m^{RET'95}$ and $E_m^{OFF'95}$ are the FAZ employment figures for the four QRFM categories: agriculture, mining and construction (AMC); manufacturing, transportation, utilities and wholesale (MFG); retail (RET); and office and service (OFF) employment. The corresponding numerical coefficients are from Table 2.6.1. $E_m^{TOTAL'95}$ represents total employment in the FAZ.

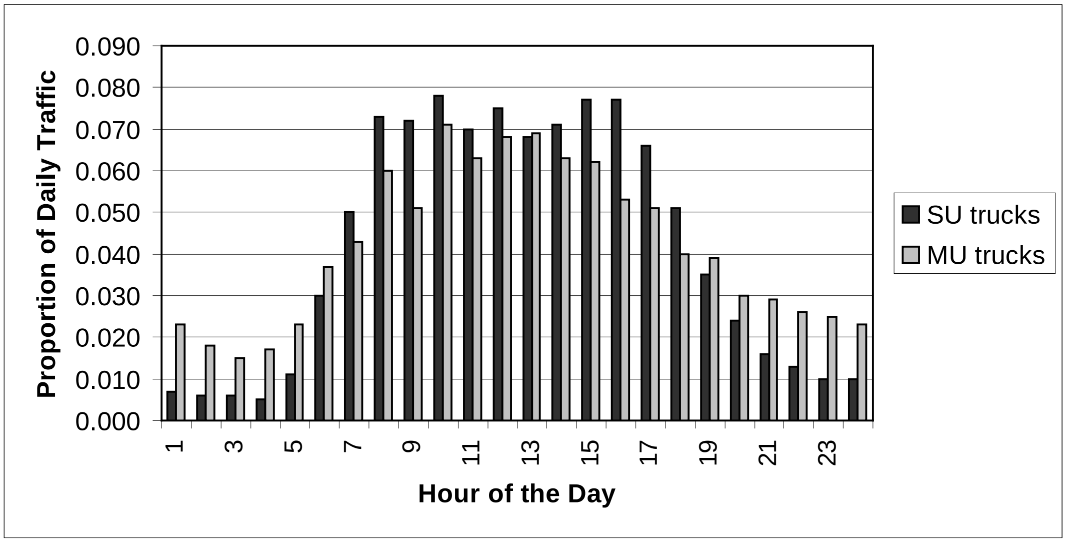
2.6.1.3 Truck Trip Table by Time Period at Traffic Analysis Zone Level

Time period truck trip tables can be constructed from the daily truck trip tables by calculating the percentage of daily SU and MU truck counts that take place in each time period of interest. The truck traffic are modeled for four time periods:

- AM Peak—6:30 AM to 9:00 PM
- Midday—9:00 AM to 3:00 PM
- PM Peak—3:00 PM to 5:30 PM
- Night—5:30 PM to 6:30 AM.

The percentages from the QRFM (Quick Response Freight Manual, USDOT 1996, p. 4-38) are used to derive the diurnal distribution of Su and MU truck traffic for the four time periods. These values are for urban areas, without regard to roadway functional class. This hourly distribution is shown in Figure 2.6.7.

Figure 2.6.7 – Diurnal Distribution of Truck Traffic



In contrast to the dual peak periods typically observed for passenger vehicles, diurnal distributions for trucks are characterized by a single, broader concentration of traffic during the middle portion of the day. SU trucks are apt to travel during business hours, primarily serving local pickups and deliveries. By comparison, MU trucks tend to have a more dispersed diurnal distribution, often traveling late at night and during the early morning hours. Based on these distributions, Table 2.6.2 shows the diurnal factors that were calculated for SU and MU trucks.

Table 2.6.2 – Proportion of Truck Traffic by Time Period

	Model Period		Commercial Trucks	
	From	To	SU	MU
AM Peak	6:00	9:00	0.159	0.129
Mid-day	9:00	15:00	0.475	0.422
PM Peak	15:00	18:30	0.212	0.164
Night	18:30	6:30	0.156	0.286
		Total	1.000	1.000

Eight truck trip tables were created (SU and MU vehicle types by four time periods, AM-peak, Mid-day, PM-peak and Night). The final truck trip table totals are shown in Table 2.6.3.

Table 2.6.3 – Truck Trips by Time Period

	SU Trucks	MU Trucks
AM Peak	22,849	15,742
Mid-day	68,260	51,499
PM Peak	30,465	20,013
Night	22,131	34,780
Daily Total	143,705	122,034

2.6.2 Truck Trip Table Forecasting Procedures

The procedure used to forecast 2030 truck trips involves factoring the 1995 base year daily trip table estimates, accounting for growth in zonal employment and households as well as expected increases in industrial productivity. A Fratar Model is used to estimate forecast year truck trips. Mathematically, the model may be expressed as follows:

$$_{2030}TK_{i,j}^{S} = {}_{1995}TK_{i,j}^{S} * G_i^{S} * G_j^{S} * [\Sigma_j^{all} ({}_{1995}TK_{i,j}^{S}) / \Sigma_j^{all} ({}_{1995}TK_{i,j}^{S} * G_j^{S})]$$

Where:

$_{2030}TK_{i,j}^{S}$ is the forecast year daily truck vehicle trip interchanges from zone/external station i to zone/external station j for truck type S.

$_{1995}TK_{i,j}^{x}$ is the 1995 daily truck vehicle trip interchanges from zone/external station i to zone/external station j for truck type S.

G_i^{S} is the trip growth factors from 1995 to 2030 for truck type S in zone i or external station i.

G_i^{S} is the trip growth factors from 1995 to 2030 for truck type S in zone j or external station j.

$$G_i^{x} = {}_{2030}QTKO_i^{S} / {}_{1995}QTKO_i^{S}$$

$$_{1995}QTKO_i^{S} = QTKRate^{S,AMC} * {}_{1995}EMP_i^{AMC} + QTKRate^{S,MFG} * {}_{1995}EMP_i^{MFG} + QTKRate^{S,RET} * {}_{1995}EMP_i^{RET} + QTKRate^{S,OFF} * {}_{1995}EMP_i^{OFF} + QTKRate^{S,HH} * {}_{1995}HH_i$$

$$_{2030}QTKO_i^{S} = QTKRate^{S,AMC} * D_i^{AMC} * {}_{2030}EMP_i^{AMC} + QTKRate^{S,MFG} * D_i^{MFG} * {}_{2030}EMP_i^{MFG} + QTKRate^{S,RET} * D_i^{RET} * {}_{2030}EMP_i^{RET} + QTKRate^{S,OFF} * D_i^{OFF} * {}_{23030}EMP_i^{OFF} + QTKRate^{S,HH} * {}_{2030}HH_i$$

$D_i^{AMC} = D_m^{AMC}$ for i ε m =
$(1.000*{}_{2030}EMP_m^{AFF} + 1.472*{}_{2030}EMP_m^{Mining} + 1.176*{}_{2030}EMP_m^{Construction}) / ({}_{2030}EMP_m^{AFF} + {}_{2030}EMP_m^{Mining} + {}_{2030}EMP_m^{Cinstruction})$

$D_i^{MFG} = D_m^{MFG}$ for i ε m =
$(2.650*{}_{2030}EMP_m^{DurableMfg} + 1.900*{}_{2030}EMP_m^{NondurableMfg} + 1.421*{}_{2030}EMP_m^{Transp\&Utilities} + 1.806*{}_{2030}EMP_m^{Wholesale}) / ({}_{2030}EMP_m^{DurableMfg} + {}_{2030}EMP_m^{NondurableMfg} + {}_{2030}EMP_m^{Transp\&Utilities} + {}_{2030}EMP_m^{Wholesale})$

$D_i^{RET} = D_m^{RET}$ for i ε m = 1.203

$D_i^{OFF} = D_m^{OFF}$ for i ε m =
$(1.215*{}_{2030}EMP_m^{Service} + 1.592*{}_{2030}EMP_m^{FIRE}) / ({}_{2030}EMP_m^{Service} + {}_{2030}EMP_m^{FIRE})$

Where

${}_yQTKO_i^S$ & ${}_yQTKO_i^S$ are the Truck Trip Origin at zone i for year y

$QTKRate^{S,X}$ is the truck trip origin or destination rate per employment of employment type X for truck type S as recommended in "Quick Response Freight Manual", see Table 2.6.1 for the rates.

$QTKRate^{S,HH}$ is the truck trip origin or destination rate per household for truck type S as recommended in "Quick Response Freight Manual", see Table 2.6.1 for the rates

${}_yEMP_i^{X}$ is the employment of employment type S (AMC, MGF, RET, OFF) and for year y in zone i.

${}_yHH_i$ is the households for year y in zone i.

AMC stands for employment types of agriculture, mining and construction.

MFG stands for employment types of manufacturing, transportation, communication, utilities and wholesale trade.

RET stands for employment type of retail trade.

OFF stands for employment types of offices and service.

D_m^X is the productivity deflection factor for truck type X for freight zone m. The production deflection factors by industrial classification used in calculation are from the industrial output data produced for the Michigan Department of Transportation statewide freight model. See note at the end of this section for details.

${}_yEMP_m^{IC}$ is the employment of industrial class IC (AFF(Agriculture/Fishing/Forestry), Mining, Construction, Durable manufacture, Non-durable manufacture, Transportation & Utility, Wholesale, Retail, Service and FIRE(Finance/Insurance/Real Estate)) for year y in freight zone m. In the cases of five TAZs that had no population or employment in the base year but were projected to have employment and households in 2030, the trip generation rates were used directly to project future trip ends, because growth factors could not be applied.

Factoring is done iteratively to refine trip interchange estimates until the sum of the estimated interchanges produced and attracted to each zone closely match the zone's desired trip productions and attractions (i.e. $\Sigma_i\ [{}_{2030}TK_{i,j}^{x}] = \Sigma_i\ [{}_{1995}TK_{i,j}^{x} * G_j]$).

For the fives zones that had zero truck trips in the base year, the corresponding rows and columns in the base-year table were seeded with values of 0.00001. This seeding was necessary in order for the balancing process to allocate trips to these zones.

The time-of-day factors developed to allocate SU and MU trucks in the base year model are also applied to the 2030 daily truck trip tables to allocate trips to each of the four assignment periods and converted to integer format.

2.6.3 Industry-Specific Productivity Deflation Factors

The purpose of this step is to reflect greater output (more truck trips) per employee over time. Experience in forecasting freight flows from employment data has shown that failure to account for changes in productivity over time can result in a substantial under-prediction of truck traffic.

The productivity deflation factors were developed from industrial output data produced for the Michigan Department of Transportation statewide freight model. The data were expressed in terms of millions of chained dollars of output per employee by ten industry classifications, representing the years 1995 to 2025, with five-year increments after 2000. Projected industry outputs per employee use constant (1992) dollars and reflect increased production rates, which may be attributed to the expected adoption of new technologies and improvements in operating efficiency. Thus, the change in millions of dollars of output per employee between the base year and the forecast year is assumed to result in a proportional growth in truck trips per employee. The average annual growth rates in productivity from 1995 to 2025 were used to produce 2030 productivity rates, as shown in Figure 2.6.8.

Figure 2.6.8 – Expected growth in industrial productivity, 1995 to 2030

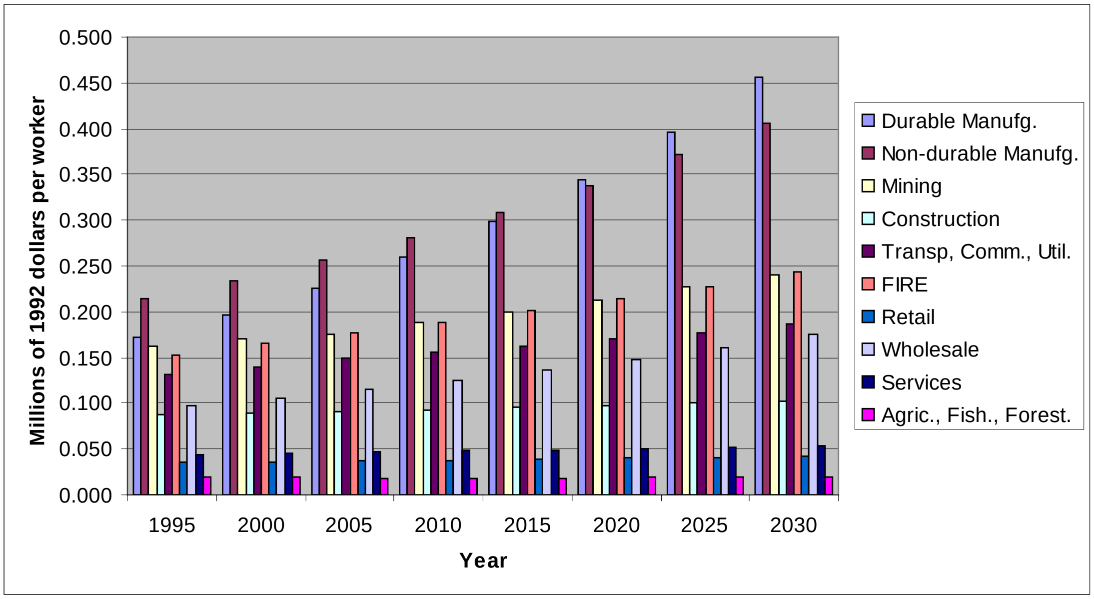


Table 2.6.9, below, shows the forecasted deflation factors corresponding to productivity growth over the 35-year planning horizon, calculated as the ratio of 2030 output per worker to 1995 output per worker, by industry category. Very large productivity growth ratios are predicted for the manufacturing and wholesale trade sectors, while the agriculture, fishing and forestry sector is expected to show no change in productivity.

Table 2.6.4 – Industry Sector Deflation, 1995 to 2030

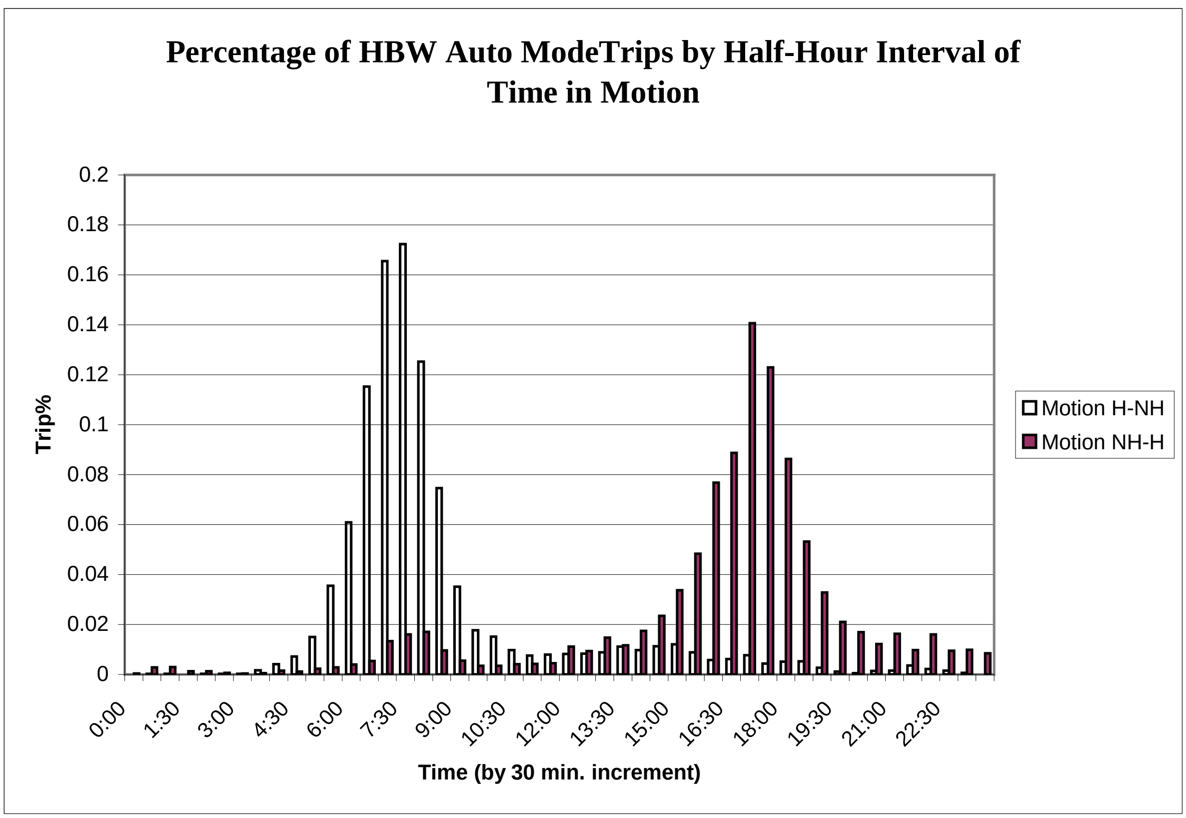
Industry Sector	Ratio: 2030 / 1995 output per worker
Durable Manufacturing	2.650
Non-durable Manufacturing	1.900
Wholesale Trade	1.806
Finance, Insurance & Real Estate (FIRE)	1.593
Mining	1.472
Transportation, Communications & Utilities	1.421
Services	1.215
Retail Trade	1.203
Construction	1.176
Agriculture, Fishing & Forestry	1.000

2.7 Time-of-Day Factors

2.7.1 Time-of-Day Period Distribution Factors

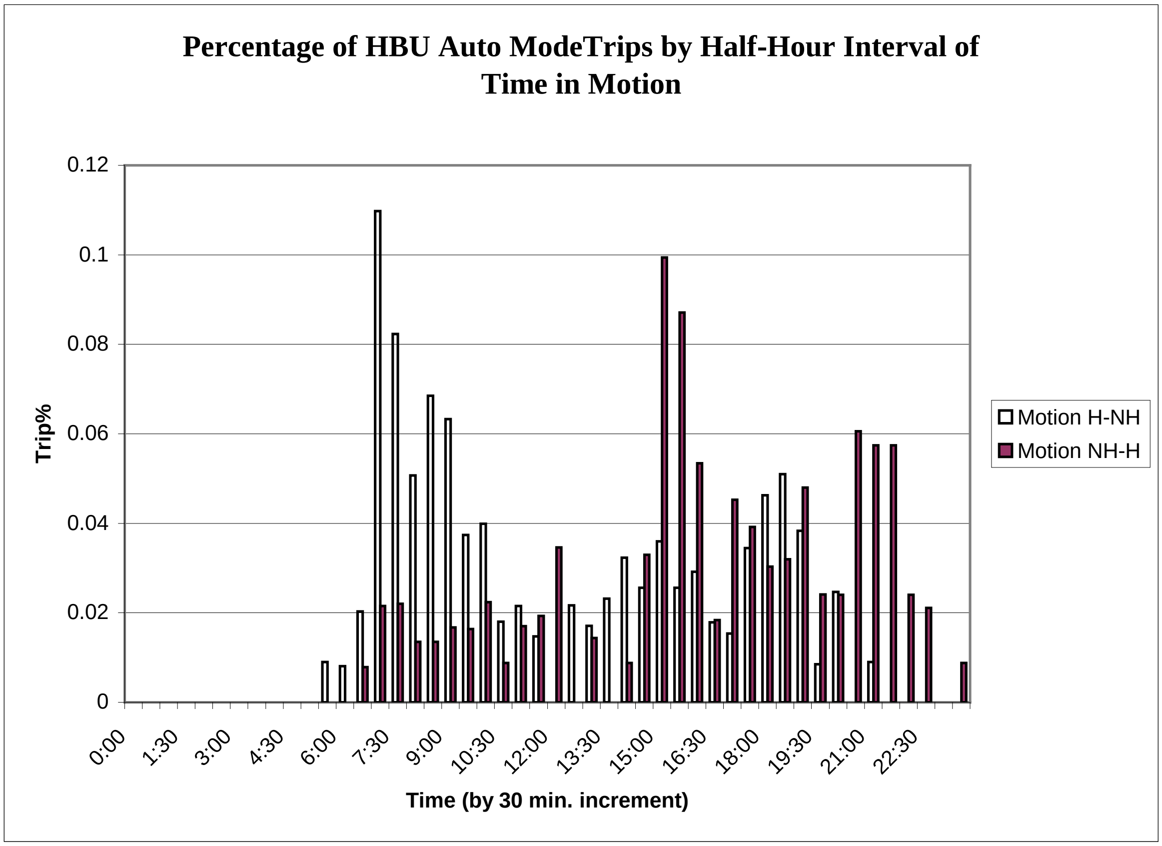
The daily HBW, HBU, HBO, and NHB vehicle trips are distributed among the four time periods using the time in motion program. The time in motion program is a straightforward set of factors that describe the proportion of daily trips that occur in each of 48 half-hour periods of the day. These factors were derived from tabulations of the 1995 OKI Household Trip Survey, using the valid reported start and end times of each trip. These factors are further disaggregated by purpose, mode, direction (production to attraction or attraction to production), and trip event time The trip event time uses a "time in motion" definition, which is defined as the period between the start and end times of a trip and represents the percent of total travel occurring in each 30 minute period. The distribution of auto trips in motion for HBW, HBU, HBO and NHB are shown in Figures 2.7.1 – 2.7.4. The time-of-day factors are developed for four time periods: AM peak, Midday, PM peak and Night. Examination of the trip diurnal distribution patterns (see Figure 2.7.5) suggests the definition for the four periods as shown in Table 2.7.1. The time-of-day factors are shown in Table 2.7.2.

Figure 2.7.1 – Trip Diurnal Distribution for Home-Based Work Auto Trips



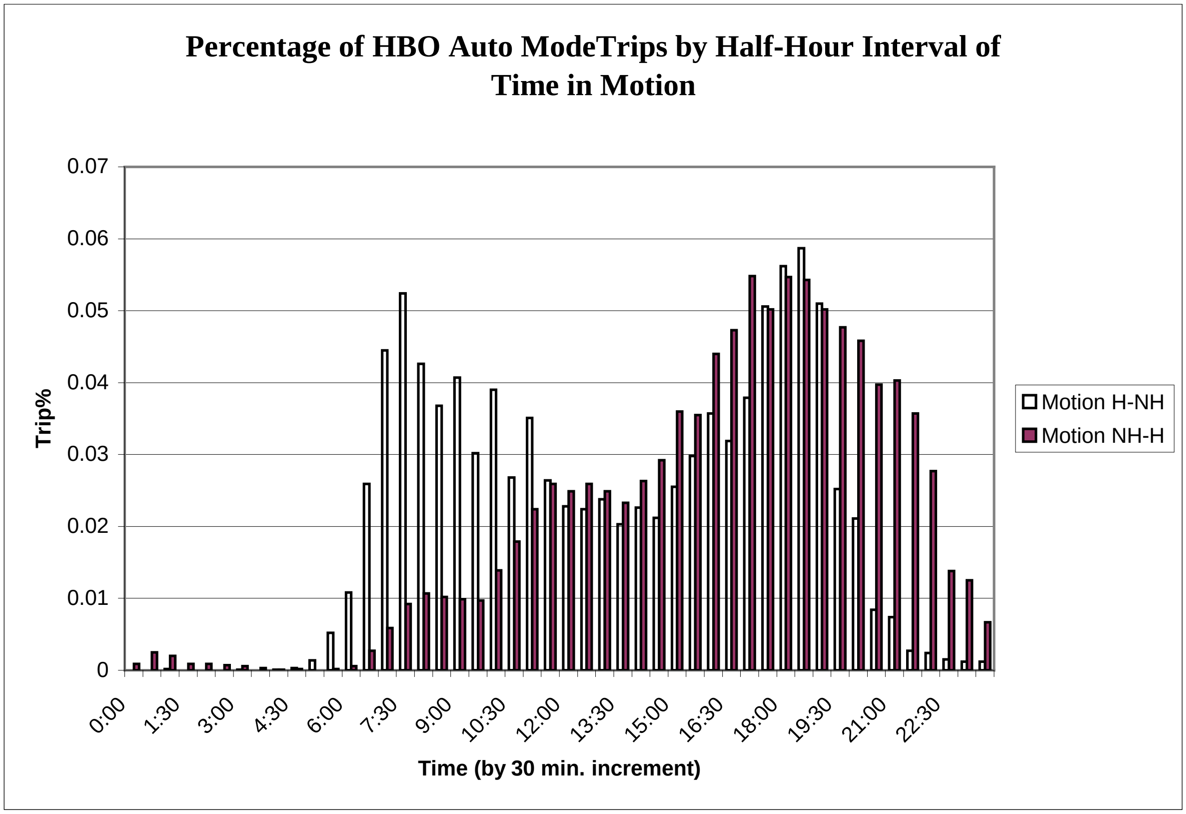
Note : Motion H-NH : Trips from home to non-home in motion ; Motion NH-H : Trips from non-home to home.

Figure 2.7.2 – Trip Diurnal Distribution for Home-Based University Auto Trips



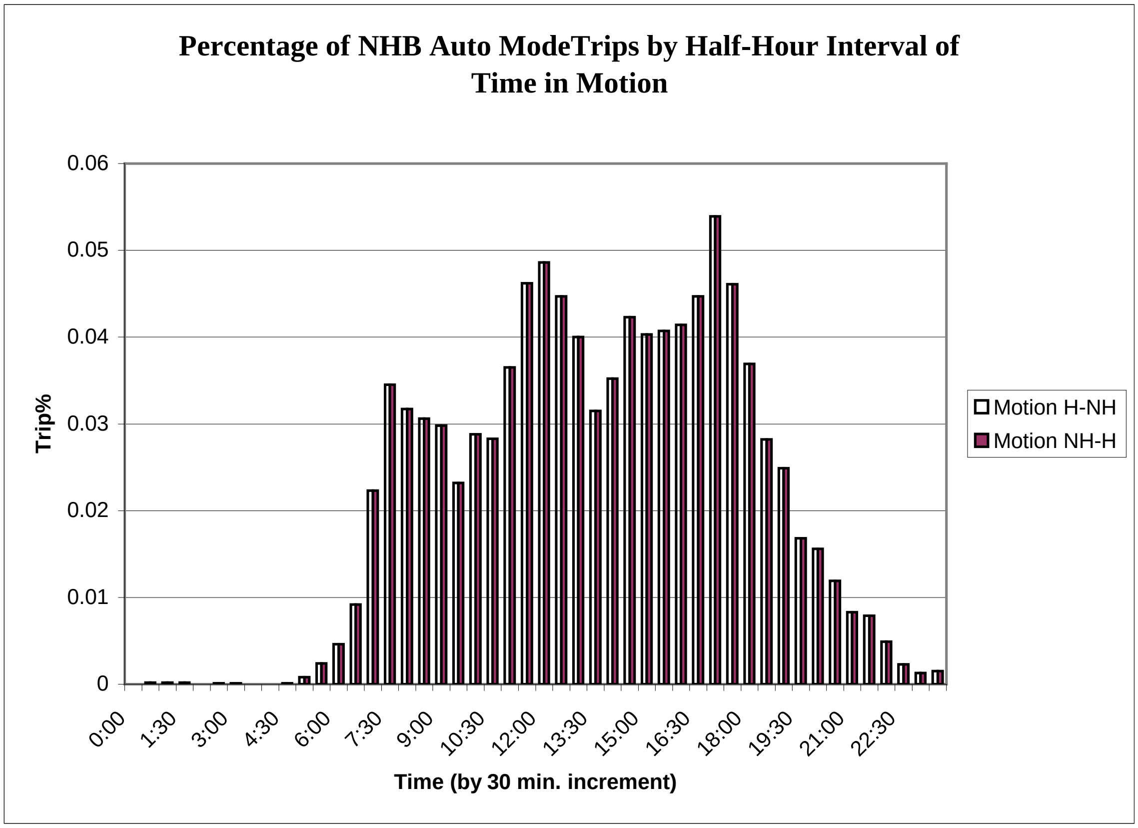
Note : Motion H-NH : Trips from home to non-home in motion ; Motion NH-H : Trips from non-home to home

Figure 2.7.3 – Trip Diurnal Distribution for Home-Based Other Auto Trips



Note : Motion H-NH : Trips from home to non-home in motion ; Motion NH-H : Trips from non-home to home

Figure 2.7.4 – Trip Diurnal Distribution for Non-Home-Based Auto Trips



Note : Motion H-NH : Trips from home to non-home in motion ;   Motion NH-H : Trips from non-home to home

Figure 2.7.5 – Trip Diurnal Distribution for All Trips

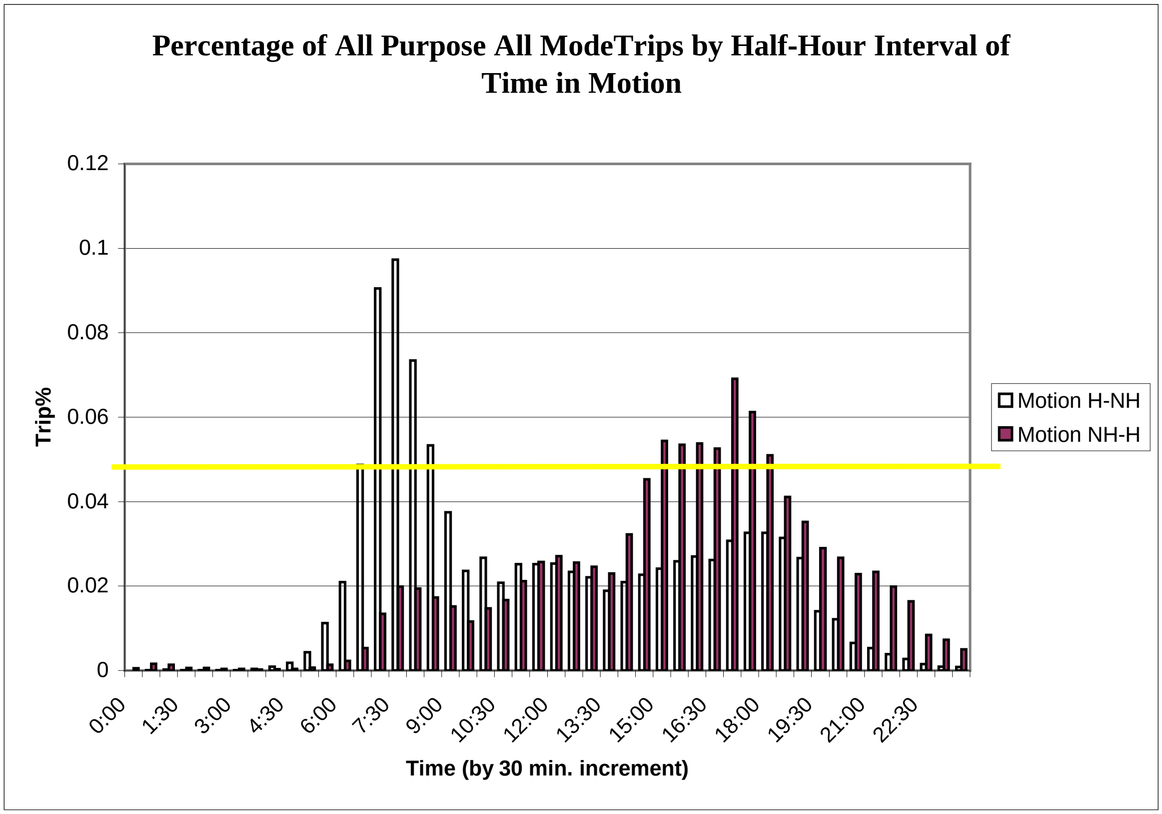


Table 2.7.1 – Definition of Time-of-Day Periods

Time Period	Hours	Length
AM Peak	6:30 am – 9:00 am	2.5 Hours
Midday	9:00 am – 3:00 pm	6 Hours
PM Peak	3:00 pm – 6:30 pm	3.5 Hours
Night	6:30 pm – 6:30 am	12 Hours

Table 2.7.2 – Time-of-Day Factors by Purpose for Vehicle Trips

Time Period	HBW		HBU		HBO		NHB	
	Home to Non-Home	Non-Home to Home	Home to Non-Home	Non-Home to Home	Home to Non-Home	Non-Home to Home	Home to Non-Home	Non-Home to Home
AM Peak	0.64	0.06	0.27	0.06	0.18	0.03	0.10	0.10
Midday	0.23	0.12	0.38	0.20	0.37	0.26	0.47	0.47
PM Peak	0.05	0.60	0.20	0.37	0.27	0.32	0.30	0.30
Night	0.09	0.22	0.14	0.36	0.19	0.38	0.13	0.13

Note: Some columns may not sum to 1.00 due to rounding, based on auto mode only

The time in motion program reads the person trip tables by mode as output by the modal choice model. The program splits the daily trips into four periods: AM peak, midday, PM peak, and night. With the use of motion program there is no need for additional “balancing” of the trip tables from P/A to O/D format; it is accomplished by the program. Since the resulting trip tables represent specific time periods, each one is no longer in balance. If all four tables are summed, however, the total daily trips leaving a zone will approximately equal the trips entering the zone, with allowance for integer rounding error. For example, assume a HBW production trip (i.e., home to work) is assigned to the AM peak period, and the return trip (i.e., work to home) is assigned to the PM peak period.

Time of day data from the Greater Cincinnati Northern Kentucky International Airport passenger trip and Kings Island visitor trip surveys are not felt to be strong enough to base a 4 period time of day split. Therefore, they are included in time in motion program.

Time-of -day period factors for truck trips are derived using the truck traffic distribution data (see Figure 2.7.5) from FHWA 1996 report “ Quick Response Freight Manual”. The factors are shown in Table 2.7.3.

Figure 2.7.6 – Diurnal Distribution of Truck Traffic

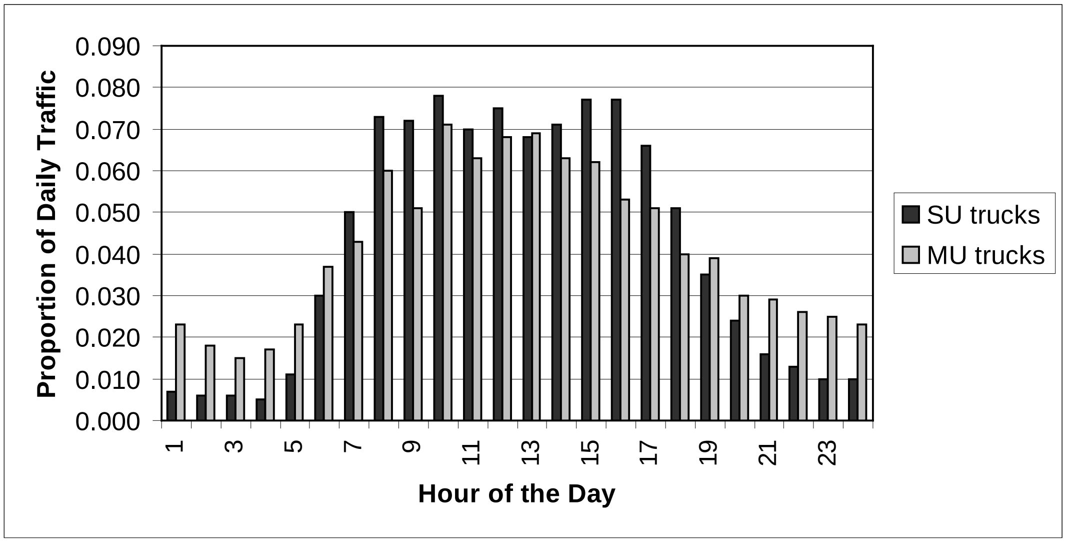


Table 2.7.3 – Time-of-Day Factors for Truck Trips

Truck Type	Time-of-Day Period			
	AM Peak	Midday	PM Peak	Night
Single Unit	0.159	0.475	0.212	0.156
Multiple Unit	0.129	0.422	0.164	0.286

Time period data for EI, and EE trip purposes was unavailable. Their time of day factors were asserted (see Table 2.7.4). EI time of day factors were made to show that most EI trips take place in the midday and PM peak periods. No speculation about EE trips could be made and therefore these trips are assumed to be spread equally throughout the day.

Table 2.7.4 – Time of Day Factors for EI and EE Trip Purposes

Trip Purpose	AM Peak Percentage	Midday Percentage	PM Peak Percentage	Night Percentage
Taxi	40%	10%	40%	10%
EI	22%	28%	30%	20%
EE	25%	25%	25%	25%

The daily trip tables are split across the four periods. Trip tables for these purposes are then balanced after time of day splitting but before they are merged to the AM peak, midday, PM peak, and night trip tables.

After all trip tables are collapsed in 20 time-of-day trip tables (5 vehicle mode s and 4 time periods), they are assigned to a period-specific highway network (see Table 2.7.5). Period-specific highway networks were developed because some link characteristics vary by time of day. Street parking, especially downtown, during the midday and night periods reduce the number of lanes open to traffic.

Table 2.7.5 – Highway Network Assignment

Trip Table	Highway Network
AM Peak	AM
Midday	Midday
PM Peak	PM
Night	Midday

(A) Peak Hour Factors

Peak hour factors represent the quantity of traffic occupying the highway system during the peak hour of a period. Figure 2.7.5 shows the percentage of trips (HBW, HBU, HBO, HBSC and NHB trip combined) by half-hour of time in motion. For example, approximately 18.7% of all home to non-home person trips take place in the AM peak period. Dividing this figure by 36.3%, the percentage of home to non-home person trips in the AM period, a peak hour factor of .53 is produced. The same technique was applied to the other three time periods. During the regional validation phase, the peak hour factors were adjusted slightly. The final peak hour factors are shown in Table 2.7.6.

Table 2.7.6 – Peak Hour Factors

Time Period	Peak Hour Factor
Morning (AM)	.53
Midday (MD)	.23
Afternoon (PM)	.35
Night (NT)	.36

2.8 Highway and Transit Trip Assignment

The trip tables derived in the previous phases summarize the travel patterns without regard for actual roadways and transit routes used to make the connection between traffic zones/external stations. In this last phase, the actual roadways and transit routes used by the trip interchanges between traffic zones/external stations are determined, and thus the traffic volumes on the roadways and ridership on the transit routes are estimated

2.8.1 Time of Day and Vehicle Occupancy Factoring

Prior to trip assignment, the trip tables produced by all the previous model steps (mode choice, airport and King's Island sub-models, EI trip distribution model, EE fratar model, taxi fratar model and truck model) need to be consolidated into the modes and time periods required by the assignment method. In terms of modes, the model requires that all auto trips be allocated into five modes: single-occupant cars, two-occupant cars, three or more occupant cars, single unit trucks and multiple unit trucks. In terms of time periods, the model requires that trips be allocated to four periods: AM or morning peak (6:30 AM to 9:00 AM), MD or midday (9:00 AM to 3:00 PM), PM or evening peak (3:00 PM to 6:30 PM) and NT or night (6:30 PM to 6:30 AM).

In order to obtain the trip tables that correspond to each of these time periods and modes, the model performs the following matrix consolidation operations:

- Vehicle occupancy factoring
- Time of day factoring
- Production/Attraction to Origin/Destination format conversion
- Sub-model trip consolidation

2.8.2 Vehicle Occupancy Factoring and Sub-Model Trip Consolidation

The trip tables produced by the mode choice model are in units of person trips. Each table needs to be converted to units of vehicle trips prior to assignment. Thus, all tables for the two-person shared ride mode are divided by a factor of 2, and all tables for the three or more shared ride mode are divided by the average 3+ occupancy. Table 2.8.1 shows average occupancies by trip purpose.

Table 2.8.1 – Average Vehicle Occupancy

Trip Purpose	Average 3+ Auto Occupancy
HBW	3.77
HBO	3.61
HBU	3.77
NHB	3.75

The CVG Airport and King's Island sub-models produce trip tables already factored to vehicle units. The EE and EI trip tables and taxi and truck tables are expressed in vehicle units as well.

After applying the occupancy factors, the CVG Airport and King's Island trips are added to the HBW and HBO trip tables. The airport's business trips are added the HBW trip tables, while the non-business trips are added to the HBO trip tables. All King's Island trips are added to the HBO trip tables.

In preparation for time of day factoring, peak and off peak period trips are summed up, so that daily trip tables, by mode and trip purpose, are input to the next modeling step.

2.8.3 Time of Day Factoring and PA to OD Format Conversion

The daily vehicle trips are allocated into four time periods of the day used for highway assignment. See Table 2.8.2 for the definition of time periods. The allocation is achieved via use of time of day or diurnal factors. A time of day factor gives the proportion of total trips (by purpose) that are in-motion during a certain period of the day.

Time of day factoring is the process of allocating daily trips (by purpose and mode) into the time periods used for highway assignment. The allocation is achieved via use of time of day or diurnal factors. A time of day factor gives the proportion of total trips (by purpose) that are in-motion during a certain period of the day.

The time of day factors derived from tabulations of OKI’s 1995 household trip survey using the valid reported start and end times of each trip. These factors are further disaggregated by purpose, mode, direction (production to attraction or attraction to production), and trip event time. The trip event time uses a “time in motion” definition, which is defined as the period between the start and end times of a trip and represents the percent of total travel occurring in each 30 minute period. See Section 2.7 for details.

The diurnal factors are structured by direction, hence the PA to OD conversion occurs simultaneously as the time of day factoring. These factors are applied to HBW, HBO, HBU and NHB trips, after they have been augmented with the airport and King's Island trips. Table 2.8.3 shows the diurnal factors.

Table 2.8.2 – Definition of Time-of-Day Periods

Time Period	Hours	Length
AM Peak	6:30 am – 9:00 am	2.5 Hours
Midday	9:00 am – 3:00 pm	6 Hours
PM Peak	3:00 pm – 6:30 pm	3.5 Hours
Night	6:30 pm – 6:30 am	12 Hours

Table 2.8.3 – Time-of-Day Factors by Purpose for Vehicle Trips

Time Period	HBW		HBU		HBO		NHB	
	Home to Non-Home	Non-Home to Home	Home to Non-Home	Non-Home to Home	Home to Non-Home	Non-Home to Home	Home to Non-Home	Non-Home to Home
AM Peak	0.64	0.06	0.27	0.06	0.18	0.03	0.10	0.10
Midday	0.23	0.12	0.38	0.20	0.37	0.26	0.47	0.47
PM Peak	0.05	0.60	0.20	0.37	0.27	0.32	0.30	0.30
Night	0.09	0.22	0.14	0.36	0.19	0.38	0.13	0.13

EE, EI and taxi trips are factored into time periods separately. The factors applied to these trips were shown in Table 2.8.4. These tables are always expressed in OD format.

Table 2.8.4 – Taxi and External Trip Diurnal Factors

Trip Purpose	Time Period			
	AM	MD	PM	NT
Taxi	40%	10%	40%	10%
EI	22%	28%	30%	20%
EE	25%	25%	25%	25%

Single and multiple unit truck trip tables by time period (OD format) are obtained from the truck model. See Section 2.6 for details.

2.8.4 Highway Assignment Methodology

The travel demand model uses multi-class equilibrium assignment to load trips onto the highway networks. Five trip classes or modes are considered, three for passenger traffic (single-occupant cars, two-occupant cars, three or more occupant cars) and two for truck traffic (single unit trucks and multiple unit trucks). This class separation allows the modeling of restrictions in network usage, to represent for example HOV lanes, which should be used only by multiple occupant vehicles, or truck prohibitions, to keep multiple unit trucks from using certain streets.

This model employs an equilibrium assignment procedure for highway loading. Equilibrium, in the context of transportation assignments, occurs when no trip can be made without increasing the total travel time of all trips in the network. The equilibrium assignment process incorporates this equilibrium theory while taking into effect the relationship between demand and capacity.

Equilibrium assignment consists of an iterative series of all-or-nothing traffic assignments with an adjustment of travel speeds based on algorithms involving speed, volume, and link capacity. The final assignment is a linear combination of the all-or-nothing loads of each iteration.

Highway assignments are performed in three separate steps of the model: initial loop, feedback loops and final loop. The purpose of the initial and feedback loops is to calculate congested peak period speeds to feed back into trip distribution and mode choice. Thus, only the AM trips are assigned during these loops. The full set of highway networks (AM, MD, PM and NT) are loaded at the end of the feedback process, once the AM assignment has converged.

The model uses the travel speed – traffic relationship equations to calculate loaded travel time on roadway links. The travel speed – traffic relationship equations are used to calculate the degradation in free-flow speed (i.e. the congested speed) that results from non-zero traffic volumes. There are five equations developed for this model, one for each group of roadway facility type. Mathematically the relationship may be expressed as

$$T_l^h = {}_oT_l * [1 + a *(V^h/C_l)^b]$$

Where

T_l^h is the loaded travel time in hour h on link l.
${}_oT_l$ is the free-flow speed on link l.
V_l^h is the traffic volume in hour h on link l
C_l is the hourly capacity on link l
a, b are the coefficients.

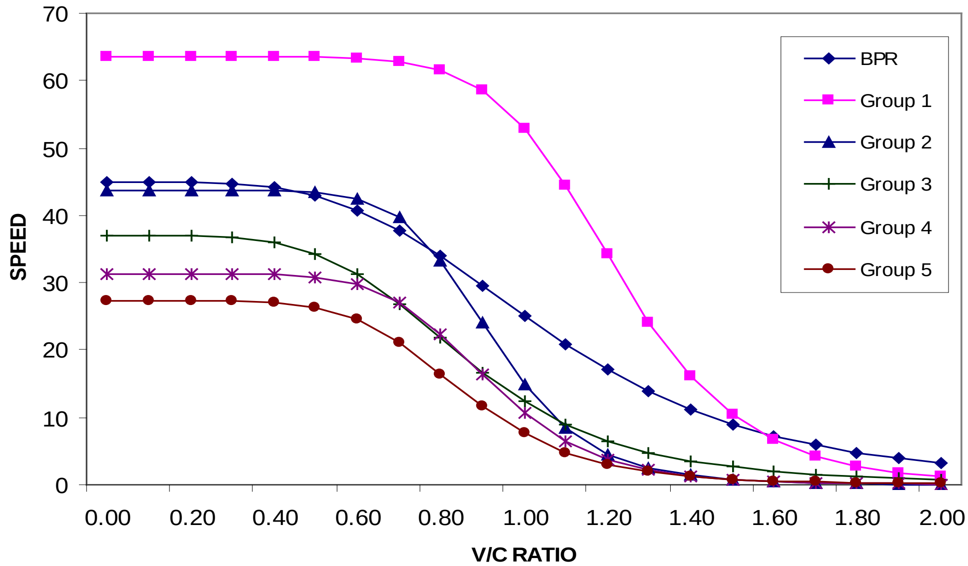
The coefficients are different for different group of roadway facility type. This allows for more realistic speed degradation for a particular type of highway. The data used to calibrate the equations are generated primarily based on the procedures of Highway Capacity Manual (HCM). The HCM procedures have been slightly customized before being applied to the OKI roadway classifications. The derived values for the coefficient are shown in Table 2.8.5. For more details please see the "Development of Classified Speed / Capacity Table and Speed-Volume Relationships".

Figure 2.8.1 shows the equations. Also shown in the figure is the BPR (Bureau of Public Road) equation traditionally used in travel demand modeling.

Table 2.8.5 – Coefficients in Travel Speed – Traffic Volume Relationship Equations

Group	Facility Type	a	b
1	freeways, ramp controlled expressways	0.200	8.00
2	expressways, freeway-to-freeway ramps, on-ramps, rural arterials	0.195	8.16
3	arterials with four-way stop	0.198	4.67
4	urban major roads, off-ramps	0.196	7.18
5	minor roads	0.259	6.12

Figure 2.8.1 – Travel Speed – Traffic Volume Relationships



In this multi-class assignment, the link volume input to the travel speed – traffic volume relationship equation is the sum of all vehicle modes using the link. In particular, truck vehicles are counted as one unit each, instead of factoring them to passenger car equivalents. The effect of trucks on traffic flow speed is considered instead by a reduction in link capacity. These capacity reductions follow Highway Capacity Manual procedures, and are important primarily in links with long steep uphill grades. The reductions apply only to a subset of freeway and expressway links in the OKI portion of the highway network. For details see, technical report Technical Report "Development of Classified Speed / Capacity Table and Speed-Volume Relationships".

In addition to these customized travel speed – traffic volume equations, two other sets of parameters are used: the capacity factor and the time and distance factors.

The peak hour factors are necessary to factor up hourly capacities to values representative of the time period being considered in the assignment. The peak hour factor indicates, for each assignment period, what proportion of trips occurs in the most congested hour of each time period. These values were derived from the time-in-motion data, see Table 2.8.6.

Table 2.8.6 – Peak Hour Factors

Trip Assignment Period		Peak Hour Factor
Morning (AM)	6:30 AM - 9:00 AM	0.53
Midday (MD)	9:00 AM - 3:00 PM	0.23
Evening (PM)	3:00 PM - 6:30 PM	0.35
Night (NT)	6:30 PM - 6:30 AM	0.36

Time and distance factors are used to calculate a composite impedance, which in turn is used to find the minimum path between each origin and destination during assignment. The standard methodology is to use a time factor of 1.0 and a distance factor of 0.0, which results in minimum travel time paths and a travel time user equilibrium. The model uses a time factor of 0.414 and a distance factor of 0.46. The effect of the distance factor is to favor less circuitous, but slower, paths.

An important feature of the model is to feed the link loaded speeds back into trip distribution and modal choice phases. This is done in loops. The model incorporates a convergence algorithm to check, at the end of each feedback loop, whether the model has converged. If it has not, then the estimated speeds are fed back to the highway network build step and the full model run is repeated until convergence is reached.

The following two criteria need to be met for the model to converge:

- Link convergence: at least 95% of all links have an assigned ADT volume that is within 10% of the volume assigned in the previous model iteration.
- Trip table convergence: at least 95% of the OD interchanges have a number of trips that is within 10% of the trips estimated for the OD interchange in the previous model iteration.

The trip table convergence is applied at the district level (i.e., 300x300 trip table instead of a 2531x2531 trip table). Districts with less than 10 trips are not included in the convergence check, because oftentimes the convergence criteria are exceeded simply due to bucket rounding.

The convergence checks are performed on the basis of weighted links and OD interchanges, where the weight factor is the link volume or the OD trips. Thus, high volume links weigh more heavily in the convergence calculation than low volume links, so that the model is less likely to converge if there are high errors on the major facilities than if there are high errors on the low volume roads (and similarly for the trip table).

In order to reduce the number of feedback loops required to reach convergence, the model uses the method of successive averages to feed the estimated AM volumes back to trip distribution. At any given model iteration *k*, the feedback volume for link *i* is the average of all the volumes estimated for link *i* up to that iteration, that is:

$$Volume_i^k = \frac{1}{k} * \sum_{n=1}^{k} Volume_i^n$$

With the application of this method, the 1995 model setup reaches convergence in three full model iterations (one initial loop and two feedback loops). Tables 2.8.7 and 2.8.8 show the final link and trip table convergence distributions.

Table 2.8.7 – Link Convergence Report

Percent Difference	Number of Links	Total Volume	Cumulative No. of Links	
			Unweighted	Weighted (*)
0.00 - 0.05	23,116	27,066,988	70.56	86.41
0.05 - 0.10	5,012	2,763,214	85.85	95.23
0.10 - 0.15	1,913	897,117	91.69	98.10
0.15 - 0.20	985	369,897	94.70	99.28
0.20 - 0.25	533	122,681	96.33	99.67
0.25 - 0.30	275	53,678	97.16	99.84
0.30 - 0.35	235	20,333	97.88	99.90
0.35 - 0.40	154	13,090	98.35	99.95
0.40 - 0.45	55	4,451	98.52	99.96
0.45 - 0.50	141	4,014	98.95	99.97
0.50 - 0.55	23	1,951	99.02	99.98
0.55 - 0.60	38	562	99.14	99.98
0.60 - 0.65	8	165	99.16	99.98
0.65 - 0.70	31	352	99.26	99.98
0.70 - 0.75	30	243	99.35	99.98
0.75 - 0.80	7	350	99.37	99.99
0.80 - 0.85	6	591	99.39	99.99
0.85 - 0.90	6	196	99.40	99.99
0.90 - 0.95	4	132	99.42	99.99
0.95 - 1.00	138	272	99.84	99.99
1.00 - ++	53	3,467	100.00	100.00

(*) The link weight factor is the link volume.

Table 2.8.8 – Final Trip Table Convergence Report

Percent Difference	Number of OD Pairs	Total Trips	Cumulative No. of Ods	
			Unweighted	Weighted (*)
0.00 - 0.05	9,348	856,244	64.18	88.07
0.05 - 0.10	2,756	72,409	83.10	95.52
0.10 - 0.15	1,427	27,552	92.90	98.35
0.15 - 0.20	650	10,589	97.36	99.44
0.20 - 0.25	230	3,363	98.94	99.79
0.25 - 0.30	82	1,178	99.51	99.91
0.30 - 0.35	53	661	99.87	99.98
0.35 - 0.40	13	141	99.96	99.99
0.40 - 0.45	5	55	99.99	100.00
0.45 - 0.50	1	6	100.00	100.00
0.50 - ++	0	0	100.00	100.00

(*) The OD weight factor is the OD volume.

2.8.5 Transit Assignment Procedures

Transit assignment is the process of allocating person trips from the trip tables to the transit network. It is run in the feedback model loop only as there is little need for an assignment in the first model loop. For validation purpose, HBSC transit trips are not assigned to the transit networks.

The assignment process begins by combining the transit trips into peak and offpeak trip tables. The HBW, HBU, HBO, NHB, airport passenger, and Kings Island transit trip tables from the modal choice phase are already separated by (peak and offpeak) period, so only a trivial matrix manipulation process is required. The HBW, HBU, HBO, and NHB peak person trips and peak transit trips from the CVG airport and Kings Island sub-models are added to form a new peak transit trip table. Likewise, the HBW, HBU, HBO, and NHB offpeak person trips and any offpeak transit from CVG airport and Kings Island transit trips are added to form a new offpeak transit trip table.

After all the tables have been assembled, the eight transit assignments are performed for each time period: local bus with walk access, local bus with drive access, express bus with walk access, express bus with drive access, light rail with walk access, light rail with drive access, commuter rail with walk access and commuter rail with drive access. The trips are assigned using an all-or-nothing algorithm to the corresponding transit path. After the assignment are performed, the peak loadings are combined into a single peak loaded transit network. The same procedure is executed for the offpeak transit assignment. To obtain daily loads, the user must add the peak period and offpeak period loadings.

Transit assignment is performed at a peak/offpeak level (as opposed to the highway assignments, which are at a 4-period time of day level because the assignments are made in “production-attraction” (P-A) format rather than “origin-destination” (O-D) format. When assigning tables in P-A format, both the production trip and the return trip are loaded onto the networks. P-A format is preferable to O-D format since transit service is asymmetrical in the peak periods. It also prevents outbound “steal-a-ride” trips since the access modes are coded only from the “home” zone. If this were not the case, a person could travel via bus to a park/ride lot and then ride by auto to his/her destination (a.k.a. a “steal-a-ride” trip). Coding the appropriate access modes in O-D format while accounting for these unintended consequences is quite difficult within the current TRANPLAN structure.

2.9 Post Model Processing

Post model processing is a collection of modules which processes the input and output of the four-phase travel demand model to produce aggregate measurements to allow planners to assess the performance of the model, evaluate the effectiveness of transportation strategies and provide information to decision makers. Post model processing may be described in the following six groups:

Socioeconomic Data: The socioeconomic data are regarded by many planners as good indicators of potential travel demand. The land use data such as household and employment depicts the magnitude and distribution of the potential travel demand. The demographic data such as household size, work participation and automobile ownership depicts propensity of trip making frequency and choice of using transportation service. An analysis of the aggregate socioeconomic data would provide information on "ballpark" changes in travel demand for analysts to check the model performance and provide travel magnitude to help decision makers formulate policies on transportation supply provision.

Transportation Supply: The travel magnitude and distribution also depend on the highway and transit service provided. The configuration of roadways, their composition in terms of roadway class and associated travel speeds, road length and lanes depicts the highway service supply. The configuration of transit lines, service span, and their associated service frequencies and travel times depicts the supply of transit service.

Trip Characteristics: Trip characteristics include the number of trips, trip composition, trip rate, trip length, modal share, and vehicle occupancy. An analysis of the trip characteristics helps the analyst to judge the appropriateness of the input data (i.e. land use strategies, travel demand management strategies, highway system and transit service) and evaluate the performance of the travel demand model.

Transportation System Performance: Transportation system performance is an indication of the volume and efficiency of the various components of a transportation system in handling the demand for travel. The acceptance of a transportation system depends on the system performance. System performance indicators include vehicle miles of travel and vehicle hours of travel by autos, average auto travel speed, average highway load factor (i.e. traffic volume and roadway capacity ratio), passenger miles of travel and passenger hours of travel by transit users, and the transit load factor (i.e. passenger to transit vehicle capacity ratio).

Economic Impacts: Another factor important to evaluate a transportation system is the cost to build, operate and maintain it. Total costs and annualized costs are important to decision makers who need this information to decide if projects are acceptable or how much funding to raise or appropriate. Since the funds for a transportation system are from the tax payers who are also the users of the system, the user's cost of making their trips should be included in this cost analysis.

Energy and Environmental Impacts: While the cost of a transportation system probably is the most important consideration, energy efficiency and air quality associated with the transportation system are also important in deciding the acceptability of the system. The Intermodal Surface

Transportation Efficiency Act of 1991 requires that the emissions associated with a transportation system should meet air quality conformity rules as set forth in the 1990 Clean Air Act Amendment.

Environmental Justice Impact: Additional measures are needed to allow for assessing the impacts to EJ population groups (minority, low income, elderly, disabled, and zero-car household) relative to the general population. The measures include average travel time, job / service opportunity and congested vehicle mile of travel.

The data are tabulated separately for OKI region, MVRPC region and OKI/MVRPC combined region.

In the following sections the equations used to calculate the measurements, group by group, are described.

2.9.1 Socioeconomic Data

The socioeconomic data maintained by OKI consists of various independent variables. It contains records of zonal information such as area type, households, population, labor force, autos owned, and employment, area of the zone etc. These variables are used by most of the travel forecasting procedures at one time or the other. The following equations are used to calculate the socio-economic data by area type and for the region.

$$POP = \Sigma_{at}^{all} POP_{at} = \Sigma_{at}^{all} \Sigma_{i}^{all\ \varepsilon\ at} [PersonPerHH_i * HH_i]$$

$$HH = \Sigma_{at}^{all} HH_{at} = \Sigma_{at}^{all} \Sigma_{i}^{all\ \varepsilon\ at} HH_i$$

$$EMP = \Sigma_{at}^{all} EMP_{at} = \Sigma_{at}^{all} \Sigma_{i}^{all\ \varepsilon\ at} EMP_i$$

$$LABOR = \Sigma_{at}^{all} LABOR_{at} = \Sigma_{at}^{all} \Sigma_{i}^{all\ \varepsilon\ at} [WorkerPerHH_i * HH_i]$$

$$AUTO = \Sigma_{at}^{all} AUTO_{at} = \Sigma_{at}^{all} \Sigma_{i}^{all\ \varepsilon\ at} [AutoPerHH_i * HH_i]$$

Where

i is the zone number.

"at" is area type, at=1 for CBD, at=2 for URBAN and at=3 for SUBURBAN and at=4 for RURAL.

at_i (as it appears in the equations above and in many parts of this document) represents the same meaning as at(i). However, some times in description at(i) is used instead of at_i to maintain the readability of the document.

POP, POP_{at} and $PersonPerHH_i$ are the regional population, population in the zones with area type "at" and the average person per household in zone i, respectively.

HH, HH_{at} and HH_i are the number of households in the region, in the zones with area type "at" and in zone i, respectively.

LABOR, $LABOR_{at}$ and $WorkerPerHH_i$ are the labor force in the region, in the zones with area type "at" and the average workers per household in zone i, respectively.

EMP, EMP_{at} and EMP_i are the employment in the region, the zones with area type "at" and zone i, respectively.

AUTO, $AUTO_{at}$ and $AutoPerHH_i$ are the autos in the region, in the zones with area type "at" and the average autos per household in zone i.

2.9.2 The Transportation Supply

The equations to calculate the road-miles, lane-miles, highway speeds, transit service runs, average transit speed, transit VMT (vehicle miles traveled) and transit VHT (vehicle hours traveled), average transit fare in cents (in 1995 $) are described in this section. The transit variables such as VMT, VHT and service runs are based on the 12 hr. operation simulated in the transit network. The PM peak period service is treated as the same as the AM peak period service. A factor (Tf) of 1.26 is applied to the 12 hr. VMT and VHT to derive 24 hr. VMT and VHT. The factor of 1.26 was derived from data provided by transit operators.

(A) Highway system

$$d^{rm} = \Sigma_{fc}^{all,\ fc\neq 7} [d^{rm}_{fc}] = \Sigma_{fc}^{all,\ fc\neq 7} [\Sigma_{l}^{all\varepsilon fc,\ fc\neq 7} (d_l)]$$

$$d^{lm} = \Sigma_{fc}^{all,\ fc\neq 7} [d^{lm}_{fc}] = \Sigma_{fc}^{all,\ fc\neq 7} \Sigma_{fc}^{all\varepsilon fc,\ fc\neq 7}{}_{l} [d_l * Lanes_l]$$

$${}_{o}s_{fc} = \Sigma_{l}^{all\varepsilon fc,\ fc\neq 7} [{}_{o}s_{fc} * d_l] / \Sigma_{l}^{all\varepsilon fc,\ fc\neq 7} [d_l]$$

Where

d^{rm} is the summation of road miles for all links in the highway network, excluding the centroid connector links.

d^{lm} is the summation of lane miles for all links in highway network, excluding the centroid connector links.

"fc" is the functional class that can be 0,1..9. fc_l is the functional class of highway link l. Refer to Table 2.9.1 for their classification

"l" is the directional link l in the highway network.

d_l is the distance in miles for highway link l.

d_{fc}^{rm} is the road miles for the highway links with functional class "fc".

d_{fc}^{lm} is the lane miles for the highway links with functional class "fc".

$Lanes_l$ are the maximum number of lanes for highway link l.

${}_o s_l$ is the free flow speed for highway link l in mph.

${}_o s_{fc}$ is the average free flow speed in mph for highway links with functional class "fc" in mph weighted by link distance.

fc = 7 is the functional class for centroid connectors.

(B) Transit system

$$VMT_{TR} = \Sigma_{line}^{all} [Runs_{line} * d_{line}]$$

$$VHT_{TR} = \Sigma_{line}^{all} \Sigma_{period}^{all} [(Runs_{line}^{period} * t_{line}^{period}) / 60]$$

$$Fare^{daily}_{TR} = \{\Sigma_i^{all}\Sigma_l^{all}\Sigma_{period}^{all} [(f^{period}_{TR} * T_{i,j,TR}) * Cost^{period}_{i,j,TR(fare)}\} / \Sigma^{all}_i\Sigma^{all}_l T_{i,j,TR}$$

$$Runs_{line} = \Sigma_{Period}^{all} [Runs_{line}^{period}]$$

$$Runs_{line}^{period} = ts^{Period} / ({}_{line}h^{period} / 60)$$

$$d_{line} = \Sigma_l^{l\varepsilon line} [d_l]$$

$$t_{line}^{period} = \Sigma_l^{all\varepsilon line} [t_l^{period}]$$

$$s_{TR}^{period} = \Sigma_l^{all} [d_l / (t_l^{period} / 60 * d_l) / \Sigma_l^{all} d_l]$$

Where

VMT_{TR} is the transit vehicle miles of travel for the 12 hrs. transit service modeled.

VHT_{TR} is the transit vehicle hours of travel for the 12 hrs. transit service modeled.

"line" is the transit service route along which the bus travels, which is a sequence of links. A "line" is an one-way transit service route.

d_{line} is the length of the transit line "line" in miles calculated as sum of distance of transit links (d_l) along line "line".

d_l is the length of the highway or transit link in miles.

$Runs_{line}$ is the total number of one way transit runs on line "line" during modeled transit operation period (12 hrs).

$Runs_{line}^{period}$ is the total number of one way runs on line "line" during period "period" (where period. AM, MIDDAY, PM where PM is set to equal AM).

t_{line}^{period} is the summation of the travel times in minutes along the transit links belonging to line "line" during period "period".

t_l^{period} is the transit travel time in minutes along transit link l, during period "period". The travel time is calculated in minutes for each link l and for each period "period" in the transit link file. $t_l^{period} = d_l / (s_l^{period} * busfactor_g)$ for link l ε roadway group g. s_l^{period} is the highway speed for link l in time period “period”. And $busfactor_g$ is the bus-auto speed equivalency factor for road group g.

$Fare_{TR}^{daily}$ is the daily average transit fare per transit trip in cents (in 2000 $). The average transit fare is the weighted average of the fares for the different periods of the day.

$Cost_{i,j,TR(fare)}^{period}$ is the average transit fare, in cents (in 2000 $), for the trip interchanges from zone i to zone j during period "period" of the day. The AM and PM fares are the same.

ts^{period} is the duration in hours of the transit service for period "period" of the day. The duration corresponding to AM is 3 hrs (6-9 am), MIDDAY is 6 hours (9am-3pm) and PM is 3 hrs (3-6 pm).

f_{TR}^{period} is the fraction of the 12 hrs. modeled transit trips that occur in period "period". Corresponding to AM (6-9 am), MIDDAY (9am-3pm) and PM (3-6 pm) the value of these fractions are 0.30, 0.40 and 0.30 respectively. These values are obtained from the data collected by the local transit operation services.

$T_{i,j,TR}$ is the total transit person trip interchanges from zone i to zone j.

h_{line}^{period} is the transit service headway in minutes for transit service line "line" for time period “period”.

s_{TR}^{period} is the weighted average travel speed in mph for the transit service during the transit service period "period".

Table 2.9.1 – Roadway Functional Classification (fc)

Functional Class	fc
Interstate/freeway	1
major arterial	2
minor arterial	3
major collector	4
minor collector	5
local	6
centroid connector	7
ramp	8
expressway	9

2.9.3 Trip Characteristics

The equations to calculate the regional person and vehicle trips, trips per person, trips by mode and reduction of vehicle trips due to transit and shared ride; trip lengths in miles & minutes, by mode - TR & auto and a few other terms are derived in this section.

Regional Daily Person Trips = $T = \Sigma_i^{all}\Sigma_l^{all} [T_{i,j}^{peak} + T_{i,j}^{offpeak}] = \Sigma_x^{all} \Sigma_i^{all} \Sigma_i^{all} [T_{i,j}^{peak,x} + T_{i,j}^{offpeak,x}]$

where x ε hbw, hbu, hbo, hbsc, nhb, truck, taxi, ee, ei

Regional Daily Transit Person Trips = $T_{TR} = \Sigma_x^{all} \Sigma_i^{all} \Sigma_j^{all} [T_{i,j,TR}^{peak,x} + T_{i,j,TR}^{offpeak,x}]$

where x ε hbw, hbu, hbo, hbsc, nhb

Regional Daily Auto Person trips = $T_{auto} = \Sigma_i^{all} \Sigma_j^{all} [T_{i,j,auto}^{peak} + T_{i,j,auto}^{offpeak}]$

$= \Sigma_i^{all} \Sigma_j^{all} [\Sigma_x^{all} (T_{i,j,DA}^{peak,x} + T_{i,j,SR}^{peak,x} + T_{i,j,DA}^{offpeak,x} + T_{i,j,SR}^{offpeak,x}) + T_{i,j}^{truck} + T_{i,j}^{taxi} + T_{i,j}^{ei} + T_{i,j}^{ee}]$

where x ε hbw, hbu, hbo, nhb

Daily Person Trips per HH = T / HH

Daily Person Trips per Person = T / POP

Share of Person Trip by Mode m = $\%T_m = 100 * \Sigma_x^{all} \Sigma_i^{all} \Sigma_j^{all} [T_{i,j,m}^{x}] / \Sigma_x^{all} \Sigma_i^{all} \Sigma_j^{all} \Sigma_m^{all} [T_{i,j,m}^{peak,x} + T_{i,j,m}^{offpeak,x}]$

where m ε DA, SR, TR; x ε hbw, hbu, hbo, nhb

Share of Auto Person Trips = $\%T_{auto} = \%T_{DA} + \%T_{SR}$

Regional Daily Vehicle Trips = $V = \Sigma_i^{all} \Sigma_j^{all} \Sigma_{period}^{all} V_{i,j}^{period}$

Daily Vehicle Trips per HH = V / HH

Daily Vehicle Trips per Person = V / POP

Daily Auto Trip Reduction Due to TR = $\Sigma_x^{all}\ \Sigma_i^{all}\ \Sigma_j^{all}\ [(T_{i,j,TR}^{peak,x} + T_{i,j,TR}^{offpeak,x}) / Occ_{i,j}^{x}]$

Daily Auto Trip Reduction Due to SR = $\Sigma_x^{all}\ \Sigma_i^{all}\ \Sigma_j^{all}\ [T_{i,j,SR}^{peak,x} + T_{i,j,SR}^{offpeak,x} - V_{i,j,SR}^{peak,x} - V_{i,j,SR}^{offpeak,x}]$

where x ε hbw, hbu, hbo, nhb

$Occ_{i,j}^{x} = (T_{i,j,SR}^{peak,x} + T_{i,j,SR}^{peak,x} + T_{i,j,SR}^{offpeak,x} + T_{i,j,SR}^{offpeak,x}) / (V_{i,j}^{peak,x} + V_{i,j}^{offpeak,x})$

for x ε hbw, hbu, hbo, nhb

$TripLength_{auto(mile)}^{peak} = PMT_{auto}^{peak,matrix} / T_{auto}^{peak} = \Sigma^{all}_x\ \Sigma^{all}_i\ [(T_{i,j,auto}^{peak} * d_{i,j,auto}^{peak}) / T_{auto}^{peak}]$

$TripLength_{auto(mile)}^{offpeak} = PMT_{auto}^{offpeak,matrix} / T_{auto}^{offpeak} = \Sigma^{all}_x\ \Sigma^{all}_i\ [(T_{i,j,auto}^{offpeak} * d_{i,j,auto}^{offpeak}) / T_{auto}^{offpeak}]$

$TripLength^{x}{}_{mile}^{peak} = \Sigma_x^{all}\ \Sigma_i^{all}\ [(T_{i,j}^{peak,x} * d_{i,j,auto}^{peak}) / \Sigma_x^{all}\ \Sigma_i^{all}\ T_{i,j}^{peak,x}]$

$TripLength^{x}{}_{mile}^{offpeak} = \Sigma_x^{all}\ \Sigma_i^{all}\ [(T_{i,j}^{offpeak,x} * d_{i,j,auto}^{offpeak}) / \Sigma_x^{all}\ \Sigma_i^{all}\ T_{i,j}^{offpeak,x}]$

$TripLength_{auto(min)}^{peak} = PHT_{auto}^{peak,matrix} / T_{auto}^{peak} = \Sigma_x^{all}\ \Sigma_i^{all}\ [(T_{i,j,auto}^{peak} * d_{i,j,auto}^{peak}) / T_{auto}^{peak}]$

$TripLength_{auto(min)}^{offpeak} = PHT_{auto}^{offpeak,matrix} / T_{auto}^{offpeak} = \Sigma_x^{all}\ \Sigma_i^{all}\ [(T_{i,j,auto}^{offpeak} * d_{i,j,auto}^{offpeak}) / T_{auto}^{offpeak}]$

$TripLength^{x}{}_{min}^{peak} = \Sigma_x^{all}\ \Sigma_i^{all}\ [(T_{i,j}^{peak,x} * t_{i,j,auto}^{peak}) / \Sigma_x^{all}\ \Sigma_i^{all}\ T_{i,j}^{peak,x}]$

$TripLength^{x}{}_{min}^{offpeak} = \Sigma_x^{all}\ \Sigma_i^{all}\ [(T_{i,j}^{offpeak,x} * t_{i,j,auto}^{offpeak}) / \Sigma_x^{all}\ \Sigma_i^{all}\ T_{i,j}^{offpeak,x}]$

Where x ε hbw, hbu, hbo, nhb, hbsc, taxi, truck, ee, ei

$TripLength_{TR(mile)} = (PMT_{TR}^{peak} + PMT_{TR}^{offpeak}) / (T_{TR}^{peak} + T_{TR}^{offpeak})$

$TripLength_{TR(mile)} = (PHT_{TR}^{peak} + PHT_{TR}^{offpeak}) / (T_{TR}^{peak} + T_{TR}^{offpeak})$

Where

T is the total daily person trips in the region for the entire day for an average day of the year.

$T_{i,j}^{peak}$ is the total peak period person trip interchanges from zone i to zone j.

$T_{i,j}^{offpeak}$ is the total offpeak period person trip interchanges from zone i to zone j.

$T_{i,j}^{peak,x}$ is the peak period person trip interchanges from zone i to zone j for trip purpose "x".

$T_{i,j}^{offpeak,x}$ is the offpeak period person trip interchanges from zone i to zone j for trip purpose "x".

T_{TR}^{peak} is the peak period person transit trips in the region for an average weekday of the year.

$T_{TR}^{offpeak}$ is the offpeak period person transit trips in the region for an average weekday of the year.

$T_{i,j,TR}^{peak,x}$ is the peak period transit trip interchanges from zone i to zone j for the trip purpose "x".

$T_{i,j,TR}^{offpeak,x}$ is the offpeak period transit trip interchanges from zone i to zone j for the trip purpose "x".

T_{auto}^{peak} is the peak period auto person trip interchanges in the region.

$T_{auto}^{offpeak}$ is the offpeak period auto person trip interchanges in the region.

$T_{i,j,auto}^{peak}$ is the peak period auto person trip interchanges from zone i to zone j.

$T_{i,j,auto}^{offpeak}$ is the offpeak period auto person trip interchanges from zone i to zone j.

"Daily Person Trips Per HH" is the regional average daily person trips per households.

HH is the total households in the region.

POP is the total population in the region.

"Daily Person Trips Per Person" is the regional average daily person trips per person.

$\%T_m$ is the regional modal share in percentage of person trips belonging to mode m, where m. (DA,SR,TR). The "auto" mode represents DA+SR.

$T_{i,j,m}^{x,peak,x}$ is the peak period person trip interchanges from zone i to zone j for trip purpose "x" and by mode "m".

$T_{i,j,m}^{x,offpeak,x}$ is the offpeak period person trip interchanges from zone i to zone j for trip purpose "x" and by mode "m".

V is the total daily vehicle trips in the region, including trips for HBW, HBU, HBO, NHB, TRUCK, TAXI, EE, EI trip purposes. These vehicular trips are for the entire day for an average day of the year.

$V_{i,j}^{peak}$ is the peak period vehicle trip interchanges from zone i to zone j.

$V_{i,j}^{offpeak}$ is the offpeak period vehicle trip interchanges from zone i to zone j.

"Daily Vehicle Trips Per HH" is the regional average daily vehicle trips per households.

"Daily Vehicle Trips Per Person" is the regional average daily vehicle trips per person.

"Daily Auto Trip Reduction Due to TR" is the reduction in daily vehicle trips in the region due to transit
riders.

"Daily Auto Trip Reduction Due to SR" is the reduction in daily vehicle trips in the region due to ride sharing.

$T_{i,j,DA}^{peak,x}$ is the peak period person trip interchanges from zone i to zone j for trip purpose "x" by drive-alone mode..

$T_{i,j,DA}^{offpeak,x}$ is the offpeak period person trip interchanges from zone i to zone j for trip purpose "x" by drive-alone mode..

$T_{i,j,SR}^{peak,x}$ is the peak period person trip interchanges from zone i to zone j for trip purpose "x" by shared ride mode.

$T_{i,j,SR}^{offpeak,x}$ is the offpeak period person trip interchanges from zone i to zone j for trip purpose "x" by shared ride mode.

$V_{i,j}^{peak,x}$ is the peak period vehicle trip interchanges from zone i to zone j for trip purpose "x".

$V_{i,j}^{offpeak,x}$ is the offpeak period vehicle trip interchanges from zone i to zone j for trip purpose "x".

$Occ_{i,j}^{x}$ is the average auto occupancy for auto trips from zone i to zone j for trip purpose x. Where $x_{.}$ (HBW, HBU, HBO, NHB).

$t_{i,j,auto}^{peak}$ is the in-vehicle travel time for autos in minutes for the trip interchanges from zone i to zone j in peak period.

$t_{i,j,auto}^{offpeak}$ is the in-vehicle travel time for autos in minutes for the trip interchanges from zone i to zone j in offpeak period.

$d_{i,j,auto}^{peak}$ is the distance in miles along the peak minimum path between zone i and zone j by auto for peak period ($\sum d_l$ along the shortest path for peak period).

$d_{i,j,auto}^{offpeak}$ is the distance in miles along the offpeak minimum path between zone i and zone j by auto for offpeak period ($\sum d_l$ along the shortest path for offpeak period).

$TripLength_{auto(miles)}^{peak}$ is the average peak vehicle trip length in miles for auto trips.

$TripLength_{auto(miles)}^{offpeak}$ is the average offpeak vehicle trip length in miles for auto trips.

$TripLength_{auto(min)}^{peak}$ is the average peak vehicle trip lengths in minutes for auto trips.

$TripLength_{auto(min)}^{offpeak}$ is the average offpeak vehicle trip lengths in minutes for auto trips.

$PMT_{auto}^{peak,matrix}$ is the peak auto person miles of travel for an average weekday of the year calculated using person trip table and distance skim matrix.

$PMT_{auto}^{offpeak,matrix}$ is the offpeak auto person miles of travel for an average weekday of the year calculated using person trip table and distance skim matrix.

$PHT_{auto}^{peak,matrix}$ is the peak auto person hours of travel for an average weekday of the year calculated using person trip table and time skim matrix.

$PHT_{auto}^{offpeak,matrix}$ is the offpeak auto person hours of travel for an average weekday of the year calculated using person trip table and time skim matrix.

$TripLength_{TR(miles)}$ is the daily average trip length in miles for the transit trips.

$TripLength_{TR(minutes)}$ is the daily average trip length in minutes, for the transit trips.

PMT_{TR}^{peak} is the peak transit passenger miles of travel.

$PMT_{TR}^{offpeak}$ is the offpeak transit passenger miles of travel.

PHT_{TR}^{peak} is the peak transit passenger hours of travel.

$PHT_{TR}^{offpeak}$ is the offpeak transit passenger hours of travel.

2.9.4 Transportation System Performance

In this section the equations for calculating average travel speeds, VMT, VHT are calculated for highway and transit networks are described. Transit ridership information and some other terms are defined.

(A) Highway System

$s_{auto} = VMT_{auto}^{network} / VHT_{auto}^{network}$

$V_l = \sum_{period}^{all} V_l^{period}$

$VC^{peak\ hr} = \Sigma_l^{all} [((V_l / 10)^2 / C_l) / \Sigma_l^{all} (V_l / 10)]$

$VMT_{auto}^{network} = \Sigma_l^{all}\ d_l * V_l$

$V_{i,j} = \sum_{period}^{all} V_{i,j}^{period}$

$VMT_{auto}^{matrix} = \Sigma_i^{all} \Sigma_j^{all}\ [d_{i,j} * V_{i,j}]$

$VMTperHH_{auto} = VMT_{auto}^{network} / HH$

$VMTperPerson_{auto} = VMT_{auto}^{network} / POP$

$VHT_{auto}^{network} = \Sigma_l^{all} \Sigma_{h=1}^{24} [t_l^h * V_l^h / 60]$

where $V_l^h = V_l * \%Hf_{at(l), fc(l)}^{\ h} / 100$

$t_l^h = {}_o t_l * (1 + a(r)\ (V_l^h / C_l)^{b(r)})$ for link l ε roadway group r

$VHTperHH_{auto} = VHT_{auto}^{network} / HH$

$VHTperPerson_{auto} = VHT_{auto}^{network} / POP$

$VMT_{auto}^{network,peak} = \Sigma_l^{all} d_l * V_l^{peak\ hr}$

where $V_l^{peak\ hr} = V_l * 0.10$

$VHT_{auto}^{network,peak\ hr} = \Sigma_l^{all} t_l^{peak\ hr} * V_l^{peak\ hr} / 60$

Where $t_l^{peak\ hr} = {}_o t_l * (1 + a(r)\ (V_l^{peak\ hr} / C_l)^{b(r)})$ for link l ε roadway group r

$S_{auto}^{peak} = VMT_{auto}^{network,\ peak\ hr} / VHT_{auto}^{network,peak\ hr}$

Where

s_{auto} is the system wide average loaded highway speed in mph.

$VC^{peak\ hr}$ is the region wide average loaded peak hour volume/capacity ratio for the highway system.

d_l is the distance in miles for link l in highway network.

V_l^{period} is the traffic volume for highway link l in time period "period". There are four time periods: AM peak, Midday, PM peak and Night.

V_l is the daily traffic volume for highway link l measured in vehicles/day. $V_l = V_l^{AM} + V_l^{MD} + V_l^{PM} + V_l^{NT}$. V_l^{AM}, V_l^{MD}, V_l^{PM}, and V_l^{NT} are the highway link volume for AM peak, midday, PM peak and night periods.

V_l^h is the hourly traffic volume for highway link l during hour h measured in vehicles/hour.

$V_l^{peak\ hr}$ is the peak hour link traffic volume for highway link l in vehicle per hour, which is assumed to be 10% of daily link traffic volume.

C_l is the hourly capacity of highway link l measured in vehicles/hour.

t_l^h is the travel time in minutes for highway link l during hour h of the day.

$t_l^{peak\ hr}$ is the peak hour travel time in minutes for highway link l.

r = (1, 2, 3, 4, 5) for roadway group code for speed-capacity relationship equations

$(1+ a(r)\ (V^h_l / C_l)^{b(r)})$ = Speed-volume relationship equation for group r:

$1 + 0.2 * (V/C)^8$	for group 1 (freeways, ramps controlled expressways)
$1 + 0.195 * (V/C)^{8.16}$	for group 2 (expressways, freeway-to-freeway ramps, on-ramps, rural arterials)
$1 + 0.198 * (V/C)^{4.67}$	for group 3 (arterials with four-way stop)
$1 + 0.196 * (V/C)^{7.18}$	for group 4 (urban major roads, off-ramps)
$1 + 0.259 * (V/C)^{6.12}$	for group 5 (minor roads)

${}_ot_l$ is the free flow travel time in minutes for traffic along highway link l. It is calculated as $d_l(\text{miles})/{}_os_l(\text{mph})$.

${}_os_l$ is the free flow speed in mph coded in highway network for link l.

$\%Hf_{at(l),fc(l)}^h$ is the hourly factor applied to daily link volume to obtain volume for hour h.

Hf depends on area type and functional class of the link. Refer to Table 2.9.2 for values of Hf. Values of at(l), fc(l) are obtained from the highway network link record. Refer to Table 2.9.1 for more information on fc(l).

$VMT_{auto}^{network}$ is the total daily vehicle miles of travel of the loaded highway network calculated as link distance times link volume.

$d_{i,j,auto}^{offpeak}$ is the distance in miles along the highway offpeak minimum time path between zone i and zone j.

$V_{i,j}^{period}$ is the vehicle trip interchanges from zone i to zone j in time period “period”.

$V_{i,j}$ is the daily vehicle trip interchanges from zone i to zone j.

VMT_{auto}^{matrix} is calculated as product of vehicle trip matrix and distance skim matrix. This method represents VMT for "all or nothing" traffic assignment without capacity restraint. This variable is not used in any other calculations, however it is provided for comparison with $VMT_{auto}^{network}$.

HH is the number of households in the region.

POP is the regional population.

"VMTPerHH" is the regional average daily vehicle travel miles of travel per household.

"VMTPerPerson" is the regional average daily vehicle travel miles of travel per person.

$VHT_{auto}^{network}$ is the total daily vehicle hours of travel of the loaded highway network.

"VHTPerHH" is the regional average daily vehicle hours of travel per household.

"VHTPerPerson" is the regional average daily vehicle hours of travel per person.

$VMT_{auto}^{network,peak\ hr}$ is the daily peak hour vehicle miles of travel of the loaded highway network.

$VHT_{auto}^{network,peak\ hr}$ is the daily peak hour vehicle hours of travel of loaded highway network.

$s_{auto}^{peak,hr}$ is the system wide average peak hour highway speed in mph.

(B) Transit System

$$s_{TR} = VMT_{TR} / VHT_{TR}$$

$$Ridership_{TR} = \Sigma_{line}^{all} (Ridership_{line}^{peak} + Ridership_{line}^{offpeak})$$

$$PMT_{TR} = \Sigma_{l}^{all} (Ridership_{l}^{peak} + Ridership_{l}^{offpeak}) * d_{l}$$

$$PHT_{TR} = \Sigma_{l}^{all} [(Ridership_{l}^{peak} * t^{peak}{}_{l} + Ridership_{l}^{offpeak} * t^{offpeak}{}_{l})] / 60]$$

$PMilePerTRMile = PMT_{TR} / (VMT_{TR} * Tf)$

$PhourPerTRHour = PHT_{TR} / (VHT_{TR} * Tf)$

Where

s_{TR} is the system wide transit speed in mph.

VMT_{TR} is the transit vehicle miles of travel for the 12 hrs. transit service modeled.

VHT_{TR} is the transit vehicle hours of travel for the 12 hrs. transit service modeled.

$Ridership_{TR}$ is the daily transit ridership.

$Ridership_{line}$ is the daily transit ridership on the transit line "line", which is obtained in transit assignment phase.

$Ridership_{l}$ is the daily transit ridership on transit link l, which is obtained in transit assignment phase.

$Ridership_{line}^{peak}$ is the peak period (AM peak and PM peak periods) transit ridership on the transit line "line", which is obtained in transit assignment phase.

$Ridership_{line}^{offpeak}$ is the offpeak period (Midday and night periods) transit ridership on the transit line "line", which is obtained in transit assignment phase.

$Ridership_{l}^{peak}$ is the peak period (AM peak and PM peak periods) transit ridership on transit link l, which is obtained in transit assignment phase.

$Ridership_{l}^{offpeak}$ is the offpeak period (Midday and night periods) transit ridership on transit link l, which is obtained in transit assignment phase.

PMT_{TR} is the daily transit passenger miles of travel.

PHT_{TR} is the daily transit passenger hours of travel.

t_{l}^{peak} is the average peak transit vehicle travel time in minutes along the transit link l during the peak period (AM peak).

$t_{l}^{offpeak}$ is the average offpeak transit vehicle travel time in minutes along the transit link l during the offpeak period (Midday).

d_{l} is length of the transit link in miles.

Tf is the transit conversion factor, 1.26.

"PMilePerTRMile" is the transit passenger miles traveled per transit vehicle miles of operation.

"PHourPerTRHour" is the transit passenger hours traveled per vehicle hours of operation.

Table 2.9.2 – Traffic Hourly Distribution Factors by Area Type & Road Type

Hour h	$\%Hf_{at,fc}^{h}$					
	Urban (at=1,2,3)			Rural (at=4)		
	Freeway & Interstate (f_c = 1,9)	Arterial (f_c = 2,3,8)	Collector (f_c= 4,5,6)	Freeway & Interstate (f_c = 1,9)	Arterial (f_c = 2,3,8)	Collector (f_c= 4,5,6)
1	1.783	1.455	1.435	1.672	1.849	1.366
2	1.878	1.615	2.131	1.798	1.9	1.848
3	2.059	2.064	2.244	2.101	2.332	2.462
4	2.206	2.337	2.529	2.236	2.534	2.877
5	2.678	2.972	3.002	2.801	3.308	3.484
6	4.016	3.882	4.187	4.621	6.032	5.591
7	6.433	5.547	6.496	7.629	8.661	8.161
8	7.881	6.828	7.258	8.333	8.747	8.788
9	6.506	6.412	6.796	6.708	7.019	6.491
10	5.347	5.82	5.88	5.593	5.686	5.372
11	5.016	5.664	5.253	5.196	5.636	5.089
12	5.114	6.156	5.797	5.138	5.416	4.916
13	5.241	6.245	5.852	5.066	5.139	4.913
14	5.156	5.757	5.439	5	4.848	4.715
15	5.351	5.768	5.83	5.082	4.742	4.586
16	5.978	6.162	5.919	5.56	5.009	5.129
17	6.293	6.18	5.405	6.496	4.882	5.34
18	5.581	5.266	4.903	5.598	4.16	5.113
19	3.896	3.756	3.64	3.709	3.311	4.212
20	2.788	2.816	2.765	2.458	2.221	2.79
21	2.331	2.241	2.145	2.028	1.741	2.111
22	2.337	1.98	1.962	1.888	1.82	1.943
23	2.291	1.676	1.826	1.708	1.436	1.54
24	1.84	1.401	1.306	1.581	1.571	1.163
Total	100	100	100	100	100	100

Note: h=1 from 12am - 1pm, h=24 from 11pm-12am.

(C) Highway Congestion

The equations to calculate the measures of congestion of the highway system are described in this section. The regional congestion measures developed consist of the following:

(1) Congested daily and peak hour vehicle miles of travel (VMT)
(2) Congested daily and peak hour lane-mile-hours
(3) Recurring vehicle hours of delay (VHD)/day due to congestion
(4) Incident vehicle hours of delay (VHD)/ day due to congestion
(5) Annual time loss cost due to congestion
(6) Annual additional vehicle operating cost due to congestion
(7) Urban roadway congestion index (RCI)
(8) Rural roadway congestion index (RCI)

$$VMT_{network}^{urban\ freeway} = \sum_{l,}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} [d_l * V_l]$$

$$VMT_{network}^{urban\ non\text{-}freeway} = \sum_{l,}^{fc(l)\ \varepsilon\ 2\ldots or\ 8\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} [d_l * V_l]$$

$$VMT_{network}^{rutal\ freeway} = \sum_{l,}^{fc(l)\ \varepsilon\ 1 or\ 9\ and\ at(l)\ \varepsilon\ 4} [d_l * V_l]$$

$$VMT_{network}^{rural\ non\text{-}freeway} = \sum_{l,}^{fc(l)\ \varepsilon\ 2\ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4} [d_l * V_l]$$

$$VMT_{network}^{urban\ freeway,\ peak\ hour} = \sum_{l,}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} [d_l * V_l * \%Hf_{at(l),\ fc(l)}^{\ highest}]$$

$$VMT_{network}^{urban\ non\text{-}freeway,\ peak\ hour} = \sum_{l,}^{fc(l)\ \varepsilon\ 2\ldots or\ 8\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} [d_l * V_l * \%Hf_{at(l),\ fc(l)}^{\ highest}]$$

$$VMT_{network}^{rutal\ freeway,\ peak\ hour} = \sum_{l,}^{fc(l)\ \varepsilon\ 1 or\ 9\ and\ at(l)\ \varepsilon\ 4} [d_l * V_l * \%Hf_{at(l),\ fc(l)}^{\ highest}]$$

$$VMT_{network}^{rural\ non\text{-}freeway,\ peak\ hour} = \sum_{l,}^{fc(l)\ \varepsilon\ 2\ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4} [d_l * V_l * \%Hf_{at(l),\ fc(l)}^{\ highest}]$$

$$LMTH_{network}^{urban\ freeway} = \sum_{l,}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} \sum_{h=1}^{24} [t_l^h * d_l * Lane_l / 60]$$

$$LMTH_{network}^{urban\ non\text{-}freeway} = \sum_{l,}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} \sum_{h=1}^{24} [t_l^h * d_l * Lane_l / 60]$$

$$LMTH_{network}^{rutal\ freeway} = \sum_{l,}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 4} \sum_{h=1}^{24} [t_l^h * d_l * Lane_l / 60]$$

$$LMTH_{network}^{rural\ non\text{-}freeway} = \sum_{l,}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4} \sum_{h=1}^{24} [t_l^h * d_l * Lane_l / 60]$$

$$LMTH_{network}^{urban\ freeway,\ peak\ hour} = \sum_{l,}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} [t_l^{highest} * d_l * Lane_l / 60]$$

$LMTH_{network}^{urban\ non\text{-}freeway,\ peak\ hour} =$
$\sum_{l,}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} [t_l^{highest} * d_l * Lane_l / 60]$

$LMTH_{network}^{rutal\ freeway,\ peak\ hour} = \sum_{l,}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 4} [t_l^{highest} * d_l * Lane_l / 60]$

$LMTH_{network}^{rural\ non\text{-}freeway,\ peak\ hour} = \sum_{l,}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4} [t_l^{highest} * d_l * Lane_l / 60]$

$Congested\ VMT_{network}^{urban\ freeway} =$
$\sum_{l}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} \sum_{h}^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} [d_l * V_l^h]$

$Congested\ VMT_{network}^{urban\ non\text{-}freeway} =$
$\sum_{l}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} \sum_{h}^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} [d_l * V_l^h]$

$Congested\ VMT_{network}^{rural\ freeway} =$
$\sum_{l}^{fc(l)\ \varepsilon\ 1\ or9\ and\ at(l)\ \varepsilon\ 4} \sum_{h}^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} [d_l * V_l^h]$

$Congested\ VMT_{network}^{rural\ non\text{-}freeway} =$
$\sum_{l}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4} \sum_{h}^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} [d_l * V_l^h]$

$Congested\ VMT\%_{network}^{urban\ freeway} =$
$Congested\ VMT_{network}^{urban\ freeway} / VMT_{network}^{urban\ freeway}$

$Congested\ VMT\%_{network}^{urban\ non\text{-}freeway} =$
$Congested\ VMT_{network}^{urban\ non\text{-}freeway} / VMT_{network}^{urban\ non\text{-}freeway}$

$Congested\ VMT\%_{network}^{rural\ freeway} =$
$Congested\ VMT_{network}^{rural\ freeway} / VMT_{network}^{rutal\ freeway}$

$Congested\ VMT\%_{network}^{rural\ non\text{-}freeway} =$
$Congested\ VMT_{veh}^{rural\ non\text{-}freeway} / VMT_{network}^{rural\ non\text{-}freeway}$

$Congested\ VMT_{veh}^{urban\ freeway,\ peak\ hour} =$
$\sum_{l}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3\ and\ LOS(ft(l))\ \varepsilon\ D,E,F} [d_l * V_l * \%Hf_{at(l),\ fc(l)}^{highest}]$

$Congested\ VMT_{veh}^{urban\ non\text{-}freeway,\ peak\ hour} =$
$\sum_{l}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3\ and\ LOS(ft(l))\ \varepsilon\ D,E,F} [d_l * V_l * \%Hf_{at(l),\ fc(l)}^{highest}]$

$Congested\ VMT_{veh}^{rural\ freeway,\ peak\ hour} =$
$\sum_{l}^{fc(l)\ \varepsilon\ 1\ or9\ and\ at(l)\ \varepsilon\ 4\ and\ LOS(ft(l))\ \varepsilon\ D,E,F} [d_l * V_l * \%Hf_{at(l),\ fc(l)}^{highest}]$

$Congested\ VMT_{veh}^{rural\ non\text{-}freeway,\ peak\ hour} =$
$\sum_{l}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4\ and\ LOS(ft(l))\ \varepsilon\ D,E,F} [d_l * V_l * \%Hf_{at(l),\ fc(l)}^{highest}]$

$Congested\ VMT\%_{veh}^{urban\ freeway,\ peak\ hour} =$

$$\text{Congested VMT}_{network}^{\text{urban freeway, peak hour}} / \text{VMT}_{network}^{\text{urban freeway, peak hour}}$$

$$\text{Congested VMT\%}_{veh}^{\text{urban non-freeway, peak hour}} = \text{Congested VMT}_{network}^{\text{urban non-freeway, peak hour}} / \text{VMT}_{network}^{\text{urban non-freeway, peak hour}}$$

$$\text{Congested VMT\%}_{network}^{\text{rural freeway, peak hour}} = \text{Congested VMT}_{network}^{\text{rural freeway, peak hour}} / \text{VMT}_{network}^{\text{rutal freeway, peak hour}}$$

$$\text{Congested VMT\%}_{network}^{\text{rural non-freeway, peak hour}} = \text{Congested VMT}_{network}^{\text{rural non-freeway, peak hour}} / \text{VMT}_{network}^{\text{rural non-freeway, peak hour}}$$

$$\text{Congested LMTH}_{network}^{\text{urban freeway}} = \sum_l^{fc(l)\ \varepsilon\ 1 \text{ or } 9 \text{ and } at(l)\ \varepsilon\ 1,2 \text{ or } 3} \sum_h^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} [t_l^h * d_l * Lane_l / 60]$$

$$\text{Congested LMTH}_{network}^{\text{urban non-freeway}} = \sum_l^{fc(l)\ \varepsilon\ 2 \ldots \text{ or } 8 \text{ and } at(l)\ \varepsilon\ 1,2 \text{ or } 3} \sum_h^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} [t_l^h * d_l * Lane_l / 60]$$

$$\text{Congested LMTH}_{network}^{\text{rural freeway}} = \sum_l^{fc(l)\ \varepsilon\ 1 \text{ or } 9 \text{ and } at(l)\ \varepsilon\ 4} \sum_h^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} [t_l^h * d_l * Lane_l / 60]$$

$$\text{Congested LMTH}_{network}^{\text{rural non-freeway}} = \sum_l^{fc(l)\ \varepsilon\ 2 \ldots \text{ or } 8 \text{ and } at(l)\ \varepsilon\ 4} \sum_h^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} [t_l^h * d_l * Lane_l / 60]$$

$$\text{Congested LMTH\%}_{network}^{\text{urban freeway}} = \text{Congested LMTH\%}_{network}^{\text{urban freeway}} / \text{LMTH\%}_{network}^{\text{urban freeway}}$$

$$\text{Congested LMTH\%}_{network}^{\text{urban non-freeway}} = \text{Congested LMTH\%}_{network}^{\text{urban non-freeway}} / \text{LMTH\%}_{network}^{\text{urban non-freeway}}$$

$$\text{Congested LMTH\%}_{network}^{\text{rural freeway}} = \text{Congested LMTH\%}_{network}^{\text{rural freeway}} / \text{LMTH\%}_{network}^{\text{rural freeway}}$$

$$\text{Congested LMTH\%}_{network}^{\text{rural non-freeway}} = \text{Congested LMTH\%}_{network}^{\text{rural non-freeway}} / \text{LMTH\%}_{network}^{\text{rural non-freeway}}$$

$$\text{Congested LMTH}_{network}^{\text{urban freeway, peak hour}} = \sum_l^{fc(l)\ \varepsilon\ 1 \text{ or } 9 \text{ and } at(l)\ \varepsilon\ 1,2 \text{ or } 3 \text{ and } LOS(ft(l))\ \varepsilon\ D,E,F} [t_l^{highest} * d_l * Lane_l / 60]$$

$$\text{Congested LMTH}_{network}^{\text{urban non-freeway, peak hour}} = \sum_l^{fc(l)\ \varepsilon\ 2 \ldots \text{ or } 8 \text{ and } at(l)\ \varepsilon\ 1,2 \text{ or } 3 \text{ and } LOS(ft(l))\ \varepsilon\ D,E,F} [t_l^{highest} * d_l * Lane_l / 60]$$

$$\text{Congested LMTH}_{network}^{\text{rural freeway}} = \sum_l^{fc(l)\ \varepsilon\ 1 \text{ or } 9 \text{ and } at(l)\ \varepsilon\ 4 \text{ andLOS}(ft(l))\ \varepsilon\ D,E,F} [t_l^{highest} * d_l * Lane_l / 60]$$

$$\text{Congested LMTH}_{network}^{\text{rural non-freeway}} =$$

$$\sum_{l}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4\ and\ LOS(ft(l))\ \varepsilon\ D,E,F} [t_{l}^{highest} * d_{l} * Lane_{l} / 60]$$

$$\text{Congested LMTH\%}_{network}^{urban\ freeway,\ peak\ hour} = \text{Congested LMTH\%}_{network}^{urban\ freeway,\ peak\ hour} / \text{LMTH\%}_{network}^{urban\ freeway,\ peak\ hour}$$

$$\text{Congested LMTH\%}_{network}^{urban\ non\text{-}freeway,\ peak\ hour} = \text{Congested LMTH\%}_{network}^{urban\ non\text{-}freeway,\ peak\ hour} / \text{LMTH\%}_{network}^{urban\ non\text{-}freeway,\ peak\ hour}$$

$$\text{Congested LMTH\%}_{network}^{rural\ freeway,\ peak\ hour} = \text{Congested LMTH\%}_{network}^{rural\ freeway,\ peak\ hour} / \text{LMTH\%}_{network}^{rural\ freeway,\ peak\ hour}$$

$$\text{Congested LMTH\%}_{network}^{rural\ non\text{-}freeway,\ peak\ hour} = \text{Congested LMTH\%}_{network}^{rural\ non\text{-}freeway,\ peak\ hour} / \text{LMTH\%}_{network}^{rural\ non\text{-}freeway,\ peak\ hour}$$

$$\text{Recurring VHD}_{network}^{urban\ freeway} = \sum_{l}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} \sum_{h}^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} \{[t_{l}^{h} - {}_{c}t_{l}] * V_{l}^{h} / 60\}$$

$$\text{Recurring VHD}_{network}^{urban\ non\text{-}freeway} = \sum_{l}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} \sum_{h}^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} \{[t_{l}^{h} - {}_{c}t_{l}] * V_{l}^{h} / 60\}$$

$$\text{Recurring VHD}_{network}^{rural\ freeway} = \sum_{l}^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 4} \sum_{h}^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} \{[t_{l}^{h} - {}_{c}t_{l}] * V_{l}^{h} / 60\}$$

$$\text{Recurring VHD}_{network}^{rural\ non\text{-}freeway} = \sum_{l}^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4} \sum_{h}^{LOS(ft(l),\ h)\ \varepsilon\ D,E,F} \{[t_{l}^{h} - {}_{c}t_{l}] * V_{l}^{h} / 60\}$$

$$\text{Incident VHD}_{network}^{urban\ freeway} = \text{Recurring VHD}_{veh}^{urban\ freeway} * \text{Incident-Recurring Ratio}^{freeway}$$

$$\text{Incident VHD}_{network}^{urban\ non\text{-}freeway} = \text{Recurring VHD}_{veh}^{urban\ non\text{-}freeway} * \text{Incident-Recurring Ratio}^{non\text{-}freeway}$$

$$\text{Incident VHD}_{network}^{rural\ freeway} = \text{Recurring VHD}_{veh}^{rural\ freeway} * \text{Incident-Recurring Ratio}^{freeway}$$

$$\text{Incident VHD}_{network}^{rural\ non\text{-}freeway} = \text{Recurring VHD}_{veh}^{rural\ non\text{-}freeway} * \text{Incident-Recurring Ratio}^{non\text{-}freeway}$$

$$\text{Annual Time Loss Cost Due to Congestion}^{urban} = \text{Recurring VHD}_{network}^{urban\ freeway} + \text{Recurring VHD}_{network}^{urban\ non\text{-}freeway} + \text{Incident VHD}_{network}^{urban\ freeway} + \text{Incident VHD}_{network}^{urban\ non\text{-}freeway}) * \text{Vehicle Occupancy} * \text{Cost of Time} * \text{WRKYR}$$

Annual Time Loss Cost Due to Congestion^{rural} =
Recurring $VHD_{network}^{rural\ freeway}$ + Recurring $VHD_{network}^{rural\ non\text{-}freeway}$ +
Incident $VHD_{network}^{rural\ freeway}$ + Incident $VHD_{network}^{rural\ non\text{-}freeway}$) *
Vehicle Occupancy * Cost of Time * WRKYR

Annual Additional Vehicle Operating Cost Due to Congestion^{urban} =
$Cost_{hwy(operating\ due\ to\ Congestion)}^{daily}$ * WRKYR

$$RCI^{urban} = [(VMT^{urban\ freeway})^2 / LM^{urban\ freeway} * (VMT^{urban\ non\text{-}freeway})^2 / LM^{urban\ non\text{-}freeway}] / [13{,}000 * VMT^{urban\ freeway} + 5{,}000 * VMT^{urban\ non\text{-}freeway}]$$

$$RCI^{rural} = [(VMT^{rural\ freeway})^2 / LM^{rural\ freeway} * (VMT^{rural\ non\text{-}freeway})^2 / LM^{rural\ non\text{-}freeway}] / [13{,}000 * VMT^{rural\ freeway} + 5{,}000 * VMT^{rural\ non\text{-}freeway}]$$

$$RCI = [(VMT^{urban\ freeway} + VMT^{rutal\ freeway})^2 / LM^{freeway} * (VMT^{urban\ non\text{-}freeway} + VMT^{rural\ non\text{-}freeway})^2 / LM^{non\text{-}freeway}] / [13{,}000 * (VMT^{urban\ freeway} + VMT^{rural\ freeway}) + 5{,}000 * (VMT^{urban\ non\text{-}freeway} + VMT^{rural\ non\text{-}freeway})]$$

$$LM^{urban\ freeway} = \sum_l^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 1,2\ or\ 3} d_l * Lane_l$$

$$LM^{rural\ freeway} = \sum_l^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 4} d_l * Lane_l$$

$$LM^{rural\ freeway} = \sum_l^{fc(l)\ \varepsilon\ 1\ or\ 9\ and\ at(l)\ \varepsilon\ 4} d_l * Lane_l$$

$$LM^{rural\ freeway} = \sum_l^{fc(l)\ \varepsilon\ 2\ \ldots\ or\ 8\ and\ at(l)\ \varepsilon\ 4} d_l * Lane_l$$

Where

$VMT_{network}^{urban\ freeway}$ is the daily vehicle mile of travel on urban freeways in the highway network

$VMT_{network}^{urban\ non\text{-}freeway}$ is the daily vehicle mile of travel on urban non-freeways in the highway network

$VMT_{network}^{rural\ freeway}$ is the daily vehicle mile of travel on rural freeways in the highway network

$VMT_{network}^{rural\ non\text{-}\ freeway}$ is the daily vehicle mile of travel on rural non-freeways in the highway network

$VMT_{network}^{urban\ freeway,\ peak\ hour}$ is the peak hour vehicle mile of travel on urban freeways in the highway network

$VMT_{network}^{urban\ non\text{-}freeway,\ peak\ hour}$ is the peak hour vehicle mile of travel on urban non-freeways in the highway network

$VMT_{network}^{rural\ freeway,\ peak\ hour}$ is the peak hour vehicle mile of travel on rural freeways in the highway network

$VMT_{network}^{rural\ non\text{-}\ freeway,\ peak\ hour}$ is the peak hour vehicle mile of travel on rural non-freeways in the highway network

$LMTH_{network}^{urban\ freeway}$ is the daily lane mile hour of travel on urban freeways in the highway network

$LMTH_{network}^{urban\ non\text{-}freeway}$ is the daily lane mile hour of travel on urban non-freeways in the highway network

$LMTH_{network}^{rural\ freeway}$ is the daily lane mile hour of travel on rural freeways in the highway network

$LMTH_{network}^{rural\ non\text{-}\ freeway}$ is the daily lane mile hour of travel on rural non-freeways in the highway network

$LMTH_{network}^{urban\ freeway,\ peak\ hour}$ is the peak hour lane mile hour of travel on urban freeways in the highway network

$LMTH_{network}^{urban\ non\text{-}freeway,\ peak\ hour}$ is the peak hour lane mile hour of travel on urban non-freeways in the highway network

$LMTH_{network}^{rural\ freeway,\ peak\ hour}$ is the peak hour lane mile hour of travel on rural freeways in the highway network

$LMTH_{network}^{rural\ non\text{-}\ freeway,\ peak\ hour}$ is the peak hour lane mile hour of travel on rural non-freeways in the highway network

Congested $VMT_{network}^{urban\ freeway}$ is the daily congested vehicle mile of travel on urban freeways in the highway network

Congested $VMT_{network}^{urban\ non\text{-}freeway}$ is the daily congested vehicle mile of travel on urban non-freeways in the highway network

Congested $VMT_{network}^{rural\ freeway}$ is the daily congested vehicle mile of travel on rural freeways in the highway network

Congested $VMT_{network}^{rural\ non\text{-}\ freeway}$ is the daily congested vehicle mile of travel on rural non-freeways in the highway network

Congested $VMT_{network}^{urban\ freeway,\ peak\ hour}$ is the peak hour congested vehicle mile of travel on urban freeways in the highway network

$\text{Congested VMT}_{\text{network}}^{\text{urban non-freeway, peak hour}}$ is the peak hour congested vehicle mile of travel on urban non-freeways in the highway network

$\text{Congested VMT}_{\text{network}}^{\text{rural freeway, peak hour}}$ is the peak hour congested vehicle mile of travel on rural freeways in the highway network

$\text{Congested VMT}_{\text{network}}^{\text{rural non- freeway, peak hour}}$ is the peak hour congested vehicle mile of travel on rural non-freeways in the highway network

$\text{Congested VMT\%}_{\text{network}}^{\text{urban freeway}}$ is the percentage of daily vehicle mile of travel on urban freeways in the highway network in congested condition.

$\text{Congested VMT\%}_{\text{network}}^{\text{urban non-freeway}}$ is the percentage of daily vehicle mile of travel on urban non-freeways in the highway network in congested condition.

$\text{Congested VMT\%}_{\text{network}}^{\text{rural freeway}}$ is the percentage of daily vehicle mile of travel on rural freeways in the highway network in congested condition.

$\text{Congested VMT\%}_{\text{network}}^{\text{rural non- freeway}}$ is the percentage of daily vehicle mile of travel on rural non-freeways in the highway network in congested condition.

$\text{Congested VMT\%}_{\text{network}}^{\text{urban freeway, peak hour}}$ is the percentage of peak hour vehicle mile of travel on urban freeways in the highway network in congested condition.

$\text{Congested VMT\%}_{\text{network}}^{\text{urban non-freeway, peak hour}}$ is the percentage of peak hour vehicle mile of travel on urban non-freeways in the highway network in congested condition.

$\text{Congested VMT\%}_{\text{network}}^{\text{rural freeway, peak hour}}$ is the percentage of peak hour vehicle mile of travel on rural freeways in the highway network in congested condition.

$\text{Congested VMT\%}_{\text{network}}^{\text{rural non- freeway, peak hour}}$ is the percentage of peak hour vehicle mile of travel on rural non-freeways in the highway network in congested condition.

$\text{Congested LMTH}_{\text{network}}^{\text{urban freeway}}$ is the daily congested lane mile hour of travel on urban freeways in the highway network

$\text{Congested LMTH}_{\text{network}}^{\text{urban non-freeway}}$ is the daily congested lane mile hour of travel on urban non-freeways in the highway network

$\text{Congested LMTH}_{\text{network}}^{\text{rural freeway}}$ is the daily congested lane mile hour of travel on rural freeways in the highway network

$\text{Congested LMTH}_{\text{network}}^{\text{rural non- freeway}}$ is the daily congested lane mile hour of travel on rural non-freeways in the highway network

$\text{Congested LMTH\%}_{\text{network}}^{\text{urban freeway}}$ is the percentage of daily lane mile hour of travel on urban freeways in the highway network in congested condition.

$\text{Congested LMTH\%}_{\text{network}}^{\text{urban non-freeway}}$ is the percentage of daily lane mile hour of travel on urban non-freeways in the highway network

$\text{Congested LMTH\%}_{\text{network}}^{\text{rural freeway}}$ is the percentage of daily lane mile hour of travel on rural freeways in the highway network in congested condition

$\text{Congested LMTH\%}_{\text{network}}^{\text{rural non- freeway}}$ is the percentage of lane mile hour of travel on rural non-freeways in the highway network in congested condition

$\text{Congested LMTH}_{\text{network}}^{\text{urban freeway, peak hour}}$ is the peak hour congested lane mile hour of travel on urban freeways in the highway network

$\text{Congested LMTH}_{\text{network}}^{\text{urban non-freeway, peak hour}}$ is the peak hour congested lane mile hour of travel on urban non-freeways in the highway network

$\text{Congested LMTH}_{\text{network}}^{\text{rural freeway, peak hour}}$ is the peak hour congested lane mile hour of travel on rural freeways in the highway network

$\text{Congested LMTH}_{\text{network}}^{\text{rural non- freeway, peak hour}}$ is the peak hour congested lane mile hour of travel on rural non-freeways in the highway network

$\text{Congested LMTH\%}_{\text{network}}^{\text{urban freeway, peak hour}}$ is the percentage of peak hour lane mile hour of travel on urban freeways in the highway network in congested condition.

Congested $LMTH\%_{network}^{urban\ non\text{-}freeway,\ peak\ hour}$ is the percentage of peak hour lane mile hour of travel on urban non-freeways in the highway network

Congested $LMTH\%_{network}^{rural\ freeway,\ peak\ hour}$ is the percentage of peak hour lane mile hour of travel on rural freeways in the highway network in congested condition

Congested $LMTH\%_{network}^{rural\ non\text{-}\ freeway,\ peak\ hour}$ is the percentage of peak hour lane mile hour of travel on rural non-freeways in the highway network in congested condition

Recurring $VHD_{network}^{urban\ freeway}$ is the daily recurring vehicle hours of delay due to congestion on urban freeways in the highway network

Recurring $VHD_{network}^{urban\ non\text{-}freeway}$ is the daily recurring vehicle hours of delay due to congestion on urban non-freeways in the highway network

Recurring $VHD_{vnetwork}^{rural\ freeway}$ is the daily recurring vehicle hours of delay due to congestion on rural freeways in the highway network

Recurring $VHD_{network}^{rural\ non\text{-}freeway}$ is the daily recurring vehicle hours of delay due to congestion on rural non-freeways in the highway network

Incident $VHD_{network}^{urban\ freeway}$ is the daily incident vehicle hours of delay due to congestion on urban freeways in the highway network

Incident $VHD_{network}^{urban\ non\text{-}freeway}$ is the daily incident vehicle hours of delay due to congestion on urban non-freeways in the highway network

Incident $VHD_{network}^{rural\ freeway}$ is the daily incident vehicle hours of delay due to congestion on rural freeways in the highway network

Incident $VHD_{network}^{rural\ non\text{-}freeway}$ is the daily incident vehicle hours of delay due to congestion on rural non-freeways in the highway network

Annual Time Loss Cost Due to $Congestion^{urban}$ is the annual user's cost due to the time lost in congestion on urban roads (1990 dollars).

Annual Time Loss Cost Due to $Congestion^{rural}$ is the annual user's cost due to the time lost in congestion on rural roads (1990 dollars).

V_l is the daily traffic volume on link l (vehicles per day)

d_l is the distance of roadway link l (miles)

$Lane_l$ is the number of lanes for roadway link l

t_l^h is the loaded travel time for roadway link l in hour h (minutes).

$t_l^h = {}_o t_l * (1+ a(r) (V_l^h / C_l)^{b(r)})$ for link l ε roadway group r

${}_c t_l$ is the loaded travel time for roadway link l at Level of Service C (minutes).

${}_c t_l = {}_o t_l * (1+ a(r) (VC_{c(r)})^{b(r)})$ for link l ε roadway group r

$VC_{c(r)}$ is volume-capacity ratio\n for level of service C for roadway group r

r = (1, 2, 3, 4, 5) for roadway group code for speed-capacity relationship equations

$(1+ a(r) (V^h_l / C_l)^{b(r)})$ = Speed-volume relationship equation for group r:

$1 + 0.2 * (V/C)^8$	for group 1 (freeways, ramps controlled expressways)
$1 + 0.195 * (V/C)^{8.16}$	for group 2 (expressways, freeway-to-freeway ramps, on-ramps, rural arterials)
$1 + 0.198 * (V/C)^{4.67}$	for group 3 (arterials with four-way stop)
$1 + 0.196 * (V/C)^{7.18}$	for group 4 (urban major roads, off-ramps)
$1 + 0.259 * (V/C)^{6.12}$	for group 5 (minor roads)

${}_o t_l$ is the freeflow travel time for link l (minutes).

${}_o t_l = d_l / {}_o s_l * 60$

${}_o s_l$ is the freeflow speed for link l (mph)

s_l^h is the loaded speed in hour h for link l (mph)

$s_l^h = d_l / t_l^h * 60$

V_l^h is the traffic volume on link l in hour h (vehicles per hour)

$V_l^h = V_l * \%Hf_{at(l), fc(l)}^{\ h} / 100$

C_l is the capacity for roadway link l (vehicles per hour)

$\%Hf_{at(l), fc(l)}^{\ h}$ is the % of daily traffic occur in hour h for a roadway of area type “at” and functional class “fc”, see Table 2.9.2.

fc (l) is the functional class for roadway link l, see Table 2.9.1.

$t_l^{highestthe}$ is the loaded travel time for link l in hour with highest h%Hf $_{at(l),\,fc(l)}{}^{h}$ (minutes).

%Hf $_{at(l),\,fc(l)}{}^{highest}$ is the highest hourly traffic volume % for a road o of area type “at” and functional class “fc”.

LOS(ft, h) is the level of service in hour h for roadways of facility type “ft” Level of service is defined by v/c (volume/capacity) ratio. See Table 2.9.3 for definition various levels of service.

ft (l) is the facility type for roadway link l, see table 2.9.3.

Table 2.9.3 – Definition of Roadway Levels of Service

Roadway Class	Facility Type Code, ft		Max. V/C Ratios For LOS				
	Facility Type 1	Facility Type 2	A	B	C	D	E
Freeway, Short Upgrade, > 5% Trucks	1	11	0.30	0.48	0.71	0.88	1.00
Freeway, Short Upgrade, < 5% Trucks	1	12	0.30	0.48	0.71	0.88	1.00
Freeway, Long Upgrade, > 5% Trucks	1	13	0.30	0.48	0.71	0.88	1.00
Freeway, Long Upgrade, < 5% Trucks	1	14	0.30	0.48	0.71	0.88	1.00
Freeway, Rolling	1	21	0.30	0.48	0.71	0.88	1.00
Freeway, Downhill	1	22	0.30	0.48	0.71	0.88	1.00
Freeway, level, Close Int. Spacing	1	31	0.30	0.48	0.71	0.88	1.00
Freeway,Level, Long Int. Spacing	1	32	0.30	0.48	0.71	0.88	1.00
Expressways, Ramp Control	2	11	0.30	0.48	0.71	0.88	1.00
Expressways, Signal Control	2	12	0.70	0.83	0.88	0.94	1.00
Major Road, Sparse Int., Signals	4	12	0.70	0.83	0.88	0.94	1.00
Ramp, Fway-Fway	3	11	0.70	0.83	0.88	0.94	1.00
Ramp, On	3	12	0.70	0.83	0.88	0.94	1.00
Major Road, Sparse Int., No Signals	4	11	0.70	0.83	0.88	0.94	1.00
Major Road, Sparse Int., 4-way Stop	4	13	0.54	0.72	0.79	0.94	1.00
Ramp, Off	3	13	0.67	0.81	0.86	0.96	1.00
Major Road, Dense Int., Residential	4	21	0.67	0.81	0.86	0.96	1.00
Major Road, Dense Int., Access Control	4	22	0.67	0.81	0.86	0.96	1.00
Major Road, Dense Int., Blocking Control	4	23	0.67	0.81	0.86	0.96	1.00
Major Road, CBD	4	31	0.67	0.81	0.86	0.96	1.00
Major Road, Dense Int., No Blocking Con.	4	24	0.67	0.81	0.86	0.96	1.00
Minor Road, Signals, Sparse Int.	5	11	0.60	0.75	0.80	0.91	1.00
Minor Road, Signals, Dense Int.	5	12	0.60	0.75	0.80	0.91	1.00
Minor Road, Signals, Intermediate Int.	5	13	0.60	0.75	0.80	0.91	1.00

v/c(h) is traffic volume –capacity ratio for hour h

Incident-Recurring Ratio^{freeway} and Incident-Recurring Ratio^{freeway} are the ratio of indent VHD and recurring VHD for freeways and non-freeways. For Cincinnati area the ration are 0.80 and 1,1 (adopted form Texas Transportation Institute Report)

Vehicle Occupancy is the average vehicle occupancy, 1.25 persons per vehicle

Cost of Time is the value of time, $9.87 (in 1990 dollars)

WRKYR is the number of working days in a year use to convert daily highway statistics to annual, 250 days.

$Cost_{hwy(operating\ due\ to\ Congestion)}^{daily}$ is the additional daily vehicle operating cost due to congestion.

$$Cost_{hwy(operating\ due\ to\ Congestion)}^{daily} = \Sigma_{h=1}^{24} \Sigma_{k}^{all} \Sigma_{l}^{all} VMT_{h,k,l} * [Unit\ Cost_{(oper),k} * (CostAdjust_{k,s(h,l)} - CostAdjust_{k,,s(o,l)})]$$

Where

$VMT_{h,k,l}$ is the vehicle miles of travel in hour h on link l for vehicle mode k (auto, truck)

$$VMT_{h,truck,l} = d_l * V_l^{daily,veh} * \%Hf^{h}{}_{at(l),\ fc(l)} / 100 * Truck\%_{at(l),fc(l)}$$

$$VMT_{h,auto,l} = d_l * V_l^{daily,veh} * \%Hf^{h}{}_{at(l),\ fc(l)} / 100 * (1\text{-}Truck\%_{at(l),fc(l)})$$

$Unit\ Cost_{(oper),k}$ is the vehicle operation cost per mile for vehicle type k, see Table 2.9.4

$CostAdjust_{k,s}$ is the adjustment of vehicle operation cost per mile for driving at speed s for vehicle type k, see Table 2.9.5

$s(h,l) = s_l^h$ is the loaded speed in hour h for link l (mph)

$s(o,l) = {}_o s_l$ is the freeflow speed for link l (mph)

k is for vehicle mode (auto and truck)

h is hour of the day

l is link in the network

RCI^{urban} and RCI^{rural} are urban and rural roadway congestion indices. The equations are suggested by Texas Transportation Institute. The costants of 13,000 and 5,000 are the threshold for approaching congestion for freeway and principal arterial respectively according to TTI. Separate RCI values have to be calculated for urban and rural areas as congestion is more prominent in the urban areas than the rural areas. If both urban and rural areas are cobined together, then the high congestion levels in the urban areas will be nullified by the low congestion levels in the rural areas

$LM^{\text{urban Freeway}}$ is the lane miles for urban freeways in the highway network.

$LM^{\text{urban non-Freeway}}$ is the lane miles for urban non-freeways in the highway network.

$LM^{\text{rural Freeway}}$ is the lane miles for rural freeways in the highway network.

$LM^{\text{rural non-freeway}}$ is the lane miles for rural non-freeways in the highway network.

Table 2.9.4 – Vehicle Unit Operating Cost

Vehicle Type, k	$UnitCost_{(oper),k}$ (1990 $/mile)
Auto	0.084
Truck	0.785

Table 2.9.5 – Vehicle Unit Operating Cost Adjustment Factors by Speed Range

$CostAdjust_{k,s}$								
	Speed (mph), s							
Vehicle Type, k	<=20	<=30	<=40	<=50	<=55	<=60	<=70	>70
Auto	1.25	1.00	0.94	0.90	0.94	1.00	1.04	1.16
Truck	1.40	0.92	0.91	0.93	0.96	1.00	1.04	1.13

2.9.5 Economic Impacts

This section describes the equations for calculating the construction, operation, maintenance and users costs. All the costs are calculated in 1990 dollars.

2.9.5.1 Annual Operation & Maintenance Costs

Transit operation & maintenance cost is the annual cost to operate and maintain the transit system in the region, which provides fixed route/ schedule service. There are four transit operators in the region: Metro, TANK, Hamilton and Middletown. Individual operating characteristics of each one of these companies are different, which caused a significant variation in the unit value for the operation and maintenance cost. It might look reasonable under such circumstances to consider different unit costs in the operation and maintenance cost calculations. The other alternative (used in this analysis) is to use a single unit cost for the whole region.

Highway maintenance cost is an estimate for the annual maintenance expenditure which will be required to maintain the road network in the region.

$$Cost_{Hwy(m)}^{annual} = \Sigma_{fc}^{all, fc \neq 7} \Sigma_{at}^{all} \Sigma_{l}^{all\ \varepsilon\ at\ \&\ fc} [d_l * Lanes_l * UnitCost_{Hwy(m),at(l),fc(l)}]$$

$$Cost_{TR(o\&m)}^{annual} = VMT_{TR} * Tf * TRNYR * UnitCost_{TR(o\&m)}$$

$$Cost_{Hwy(m)+TR(o\&m)}^{annual} = Cost_{Hwy(m)}^{annual} + Cost_{TR(o\&m)}^{annual}$$

$$CostPerTrip_{TR(o\&m)} = Cost_{TR(o\&m)}^{annual} / T_{TR} * TRNYR)$$

$$CostPerPmile_{TR(o\&m)} = Cost_{TR(o\&m)}^{annual} / PMT_{TR} * TRNYR)$$

Where

$Cost_{Hwy(m)}^{annual}$ is the annual highway-maintenance cost in $/year (in 1990 $).

d_l is the distance of highway link l in miles.

$Lanes_l$ is the number of lanes for highway link l.

$UnitCost_{Hwy(m),at(l),fc(l)}$ is the unit highway maintenance cost in $/lane mile (in 1995 $) for roadway class "fc" in area type "at" of highway link l. See Table 2.9.6.

$Cost_{TR(o\ \&\ m)}^{annual}$ is the annual transit operation and maintenance cost in $/year (in 1990 $).

VMT_{TR} is the transit vehicle miles of travel for the 12 hrs. transit service modeled.

Tf is the transit conversion factor used to account the un-simulated transit operation beyond 12 hrs., 1.26.

TRNYR is a factor to convert transit daily transit trip, PMT_{TR}, VMT_{TR} to annual figures, 300 days/year.

$UnitCost_{TR(o\ \&\ m)}$ is the unit transit operation and maintenance cost, $3.9/transit miles (in 1990 $).

$CostPerTrip_{TR(o\ \&\ m)}$ is the average transit operation and maintenance cost per transit trip in $/transit trip (in 1990 $).

T_{TR} are regional daily person transit trips in a typical weekday.

PMT_{TR} is the regional daily transit passenger miles of travel in a typical weekday.

$CostPerPMile_{TR(o\ \&\ m)}$ is the average transit operation and maintenance cost per transit passenger mile in dollars/mile (in 1990 $).

$Cost_{Hwy(m)+TR(o\ \&\ m)}^{annual}$ is total annual operation and maintenance cost in dollars for the highway and transit (in 1990 $).

fc = 7 is the functional class for centroid connectors.

Table 2.9.3 – Roadway Maintenance Unit Cost by Roadway Type & by Area Type

Area type at	Road type rt	Roadway Maintenance Cost* $UnitCost_{Hwy(m),at,rt}$ ($/lane mile/year)
Urban (at=1,2,3)	Freeway (fc=1,9)	36000
Urban (at=1,2,3)	Surface streets (fc=2,3,4,5,6,8)	24000
Rural (at=4)	Freeway (fc=1,9)	34200
Rural (at-4)	Surface streets (fc=2,3,4,5,6,8)	22400

*Cost is in 1990 $
fc = 7 is for centroid connectors, which are not included in cost calculations.

2.9.5.2 Total and Annual Capital Costs

The equations for calculating highway construction, transit capital costs and right of way costs are derived in this section. The equations provide both total costs and annualized costs.

$$Cost_{Hwy(cap)} = \Sigma_{at}^{all} \Sigma_{fc}^{all,fc\neq7} \Sigma_{l}^{all\varepsilon at\ \&\ fc} [d_{(c),add,l} * (UnitCost_{(c),at(l),fc(l)} + UnitCost_{(r.o.w),at(l),fc(l)}]$$

$$Cost_{TR(cap)} = Cost_{TR(bus)} + Cost_{TR(rail)} + Cost_{TR(c)} + Cost_{TR(r.o.w)}$$

Where $Cost_{TR(bus)} = Units_{(bus)} * UnitCost_{(bus)}$

$Cost_{TR(rail)} = Units_{(rail)} * UnitCost_{(rail)}$

$Cost_{TR(c)} = Cost_{TR(rail\ c)} + Cost_{Tr(rail\ misc)}$

Where $Cost_{TR(rail\ c)} = \Sigma_{line}^{all\ rail\ lines} [\Sigma_{g=1}^{6} UnitCost_{(c),g} * d_{g,line}]$

$Cost_{Tr(rail\ misc)} = \Sigma_{line}^{all\ rail\ lines} [UnitCost_{TR(rail\ misc)} * d_{line}]$

$Cost_{TR(r.o.w.)} = \Sigma_{line}^{all\ rail\ lines} [UnitCost_{TR(rail\ r.o.w)} * d_{(rail,r.o.w),line}]$

$$Cost^{annual}_{TR(cap)} = \Sigma_{component}^{all} CapRecFact_{irate,n} * Cost_{TR(component)}$$

where component ε bus, rail, c, r.o.w

N depends on component

$$Cost_{Hwy(cap)}^{annual} = CapRecFact_{irate,n} * Cost_{Hwy(cap)}$$

where $CapRecFact_{irate,n} = irate*(1+irate)^n/[(1+irate)^n-1]$

$$Cost_{Hwy(cap)+TR(cap)} = Cost_{Hwy(cap)} + Cost_{TR(cap)}$$

$$Cost_{Hwy(cap)+TR(cap)}^{annual} = Cost_{Hwy(cap)}^{annual} + Cost_{TR(cap)}^{annual}$$

Where

$Cost_{Hwy(cap)}$ is the total highway capital cost (including construction and right of way acquisition cost) in dollars (in 1990 $).

$d_{(c),l}$ is the total of new construction and major widening in lane miles along roadway link l.

$UnitCost_{(c),at(l),fc(l)}$ is the cost in $/lane mile (in 1990 $) for the new construction and/or major widening of the roadway, which depends on area type "at" and functional class "fc" of highway link l. See Table 2.9.7.

$UnitCost_{(r.o.w),at(l),fc(l)}$ is the cost in $/lane mile (in 1990 $) for the highway right of way acquisition, which depends on area type "at" and functional class "fc" of highway link l. See 72.9.4.

$Cost_{TR(cap)}$ is the total capital cost in dollars (in 1990 $) to provide the transit service.

$Cost_{TR(bus)}$ is the total capital spending on purchasing additional buses.

$Units_{(bus)}$ is the number of additional buses required to be purchased for the transit network.

$UnitCost_{(bus)}$ is the cost of purchasing one bus in dollars (in 1990 $). Refer to Table 2.9.8.

$Cost_{TR(rail)}$ is the total capital spending on purchasing light rail units in dollars (in 1990 $). $Units_{(rail)}$ is the number of additional light rail units required to be purchased for the transit network.

$UnitCost_{(rail)}$ is the cost of purchasing one light rail vehicle unit in dollars (in 1990 $). See Table 2.9.8.

$Cost_{TR(c)}$ is the total construction cost for the transit system in dollars (in 1990 $). The transit construction cost is mainly due to construction of light rail.

$Cost_{TR(rail\ misc)}$ is the miscellaneous cost associated with the light rail in dollars (in 1990 $). Miscellaneous cost is summation of shop cost, system cost, special condition cost, soft cost, which is estimated to $ 11.30 million (in 1990 $).

$Cost_{TR(rail\ c)}$ is the cost of construction for the light rail exclusive guideways in dollars (in 1990 $).

$UnitCost_{TR(rail\ misc)}$ is the miscellaneous unit cost associated with the constructing of a mile of exclusive guideway in $/mile (in 1990 $). Refer to Table 2.9.8.

$UnitCost_{(c),g}$ is the cost of constructing a mile of exclusive guideway element of type "g" in $/mile (in 1990 $). Refer to Table 2.9.8 for definition of exclusive guideway element types and values for $UnitCost_{(c),g}$.

$d_{g,line}$ is the length of segment of transit line "line" that is of "g" type which is used mainly for the light rail exclusive guideway element. The sections of the overlapping lines are not counted more than once.

d_{line} is the length of transit line "line" in miles.

$Cost_{TR(r.o.w)}$ is the transit right of way acquisition cost in dollars (in 1990 $).

$UnitCost_{TR(r.o.w)}$ is the unit cost associated with the acquisition of the right-of-way for the light rail transit line in $/mile (in 1990 $). See Table 2.9.8

$d_{(r.o.w),line}$ is the segment of transit line "line" which needs to be acquired for exclusive right of way in miles. This is used mainly in conjunction with light rail transit lines.

$CapRecFact_{irate,n}$ is the capital recovery factor, which is used to derive the annualized cost, where "irate" is the interest rate per year (assumed 10%) and "n" is the service life time in years (which depends upon the type of construction or the vehicle). Refer to Table 2.9.8 for more information on "n".

$Cost_{TR(component)}$ is the total cost associated with the transit components, where component (bus, light rail, construction, right of way) in dollars (in 1990 $).

$Cost_{TR(cap)}^{annual}$ is the annualized transit capital cost in $/year (in 1990 $).

$Cost_{Hwy(cap)}^{annual}$ is the annualized highway capital cost in $/year (in 1990 $).

$Cost_{Hwy(cap)+TR(cap)}$ is the total of highway and transit capital costs in dollars (in 1990 $).

$Cost_{Hwy(cap)+TR(cap)}^{annual}$ is the annualized highway and transit capital cost in $/year (in 1990 $).

Table 2.9.7– Roadway Right of Way and Construction Unit Costs by Area Type and Roadway Type

Area Type at	Road Type fc	Right of way* $UnitCost_{(r.o.w.),at,fc}$ ($/lane mile#)	New Construction* $UnitCost_{(c),at,fc}$ ($/lane mile#)	Major Widening* $UnitCost_{(c),at,fc}$ ($/lane mile#)
Urban (at=1,2,3)	Freeway (fc=1,9)	48,400	234,200	115,800
Urban (at+1,2,3)	Surface streets (fc=2,3,4,5,6,8)	41,500	187,500	93,700
Rural (at=4)	Freeway (fc=1,9)	19,300	193,600	92,900
Rural (at=4)	Surface streets (fc=2,3,4,5,6,8)	16,800	155,700	75,300

* Cost is in 1990 $ assuming life span (n) of 20 years for additional lane construction or major widening and 100 years for r.o.w.
# lane width of 12 ft. assumed.

Table 2.9.8 – Transit Capital Unit Costs by Transit Elements

Transit Components	Life Span (yr) n	UnitCost* $UnitCost_g$ ($/route mile)
Light Rail Transit Construction Elements (g)		
Ground Level	30	3,500,000
Ground Level- Special Construction	30	8,800,000
Subway	30	37,000,000
Subway- Already Constructed	30	3,600,000
Aerial Structure	30	9,300,000
Aerial Structure- Already Constructed	30	3,600,000
Other Light Rail Transit Elements		
Light Rail Transit Right-of-way, $UnitCost_{TR(rail\ r.o.w)}$, $/route mile #	100	1,500,000
Light Rail Misc. Unit Cost, $UnitCost_{TR(rail\ misc)}$, $/route mile @	30	11,300,000
Light Rail Vehicle Unit, $UnitCost_{(rail)}$, $/vehicle	15	1,500,000
Bus Transit Elements		
Bus Vehicle Unit, $UnitCost_{(bus)}$, $/vehicle	12	225,100

* Cost is in 1990 $.
# double track route.
@ rail misc. cost includes shop, system, special condition and soft cost

2.9.5.3 Annual Transit Operation Subsidies

The income of a transit system collected from the fare box is often not sufficient to cover the expense of operating the system. Subsidy from other resources is often required. The following equations show the calculation of the needed subsidy for the transit system.

$$Subsidy_{TR}^{annual} = Cost_{TR(o\&m)} - Revenues_{TR}^{annual}$$

$$\text{where } Revenues_{TR}^{annual} = (Fare_{TR}^{daily} * D78TO90/100) * T_{TR} * TRNYR$$

Where

$Subsidy_{TR}^{annual}$ is the annual subsidy needed to maintain the transit operations in dollars (in 1990 $).

$Cost_{TR(o\ \&\ m)}^{annual}$ is the annual transit operation and maintenance cost in dollars/year.

$Revenues_{TR}^{annual}$ is the annual transit fare income in dollars (in 1990 $).
$Fare_{TR}^{daily}$ is the daily average transit fare per transit trip in cents (in 1978 $).

D78TO90 is the dollar conversion from 1978 dollars to 1990 dollars, 1.949.
T_{TR} is the daily transit trips in the transit system for a typical weekday.

TRNYR is the transit year, which is a factor to convert daily transit trips to annual figures, 300 days/year.

2.9.5.4 Overall Annual Transportation System Costs

$$Cost_{Hwy+TR}^{annual} = Cost_{Hwy(m)+TR(o\&m)}^{annual} + Cost_{Hwy(cap)+Tr(cap)}^{annual}$$

$$CostPerHH^{annual} = Cost_{Hwy+TR}^{annual} / HH$$

$$CostPerPop^{annual} = Cost_{Hwy+TR}^{annual} / POP$$

$$CostPerPersonMile^{annual}=Cost_{Hwy+TR}^{annual}/(PMT_{auto}^{matrix}*HWYYR+PMT_{TR}*TRNYR)$$

Where

$Cost_{Hwy+TR}^{annual}$ is the total annual transportation system cost in $/year (in 1990 $).

$Cost_{Hwy(m)+TR(o\ \&\ m)}^{annual}$ is annual highway maintenance and transit operation & maintenance cost in dollar/year (in 1990 $).

$Cost_{Hwy(cap)+TR(cap)}^{annual}$ is annualized highway and transit capital cost in dollar/year (in 1990 $).

HH is the number of households in region.

POP is the regional population.

$CostPerHH^{annual}$ is the annual system cost per household in $/HH/year (in 1990 $).

$CostPerPop^{annual}$ is the annual system cost per person in $/person/year (in 1990 $).

$CostPerPersonMile^{annual}$ is the annual average system cost per person miles traveled in $/person mile/year (in 1990 $).

PMT_{auto}^{matrix} is the daily person miles travelled by auto mode.

PMT_{TR} is the daily transit person miles of travel.

HWYYR is a factor to convert daily VMT, PMT to annual figures, 340. TRNYR is a factor to convert daily transit VMT, PMT, ridership, trips to annual figures, 300.

2.9.5.5 Annual System User's Cost

The system user's cost includes vehicle operating cost (fuel, tire, parts, repairs and maintenance), fixed cost and accident cost. The insurance companies determine the auto insurance premium based on the payment they pay out for car accidents. In this calculation car accident cost is used to represent the insurance cost paid by auto users.
Where

$$Cost_{Hwy(user\ cost)}^{annual} = (Cost_{Hwy(oper)}^{daily} + Cost_{Hwy(fixed)} + Cost_{Hwy(acc)}^{daily}) * HWYYR$$

where

$$Cost_{Hwy(oper)}^{daily} = \Sigma_k^{all} \Sigma_l^{all} VMT_{k,l} * (UnitCost_{(oper),k} * CostAdjust_{k.s.l})$$

$$Cost_{Hwy(fixed)} = \Sigma_k^{all} \Sigma_l^{all} VMT_{k,l} * UnitCost_{(fixed),k}$$

$$Cost_{Hwy(acc)}^{daily} = \Sigma_k^{all} \Sigma_{acctyp}^{all} Accidents_{acctyp,k}^{daily} * UnitCost_{acctyp}$$

where

k= auto, truck

acctyp = fatality, injury, property damage

$VMT_{truck,l} = d_l * V_l * Truck\%_{at(l),fc(l)}$

$VMT_{auto,l} = d_l * V_l * (1-Truck\%_{at(l),fc(l)})$

$Accident_{acctyp,k}^{daily} = \Sigma_l^{all} VMT_{k.l} * 10^{-6} * Af_{acctyp,at(l),fc(l)} * Cf_{v,cf,fc(l)}$

$Cost_{Hwy(user\ cost)}^{annual}$ is the annual highway users cost in $/year (in 1990 $) which includes operation, fixed and accident cost a user has to pay each year.

$Cost_{Hwy(oper)}^{daily}$ is the daily highway users vehicle operation cost in $/day (in 1990 $).

$CostHwy_{(fixed)}^{daily}$ is the daily highway users auto fixed cost in $/day (in 1990 $).

$Cost_{Hwy(acc)}^{annual}$ is the daily highway users auto insurance cost in $/day (in 1990 $).

HWYYR is the highway year, a factor to convert daily VMT, PMT to annual figures, 340.

$VMT_{k,l}$ is the daily vehicle miles traveled by vehicle of type "k" along link l ($k_{.}$ truck, auto).

d_l is the distance for link l in the highway network in miles.

V_l is the daily volume for link l in the highway network in vehicles per day.

$Truck\%_{at(l),fc(l)}$ is the percentage of trucks among the total vehicles traveling on highway link l which belong to roadway class "fc" in area type "at". Refer to Table 2.9.9. The values are derived from classified traffic count data.

$UnitCost_{(oper),k}$ is the operating cost of vehicle type k, in $/vehicle mile (in 1990 $). It includes fuel, maintenance and tires. Refer to Table 2.9.10.

$CostAdjust_{k,s(l)}$ is the cost adjustment factor which depends on the vehicle type (k) and the speed (s(l)) at which the vehicle is traveling on link l. Refer to Table 2.9.11.

$UnitCost_{fixed(k)}$ is the average fixed cost of vehicle type k, in $/vehicle mile (in 1990 $). It includes depreciation, license, interest and insurance. Refer to Table 2.9.10.

$Accidents_{acctyp,k}^{daily}$ are the daily number of accidents by accident type "acctyp" for the vehicle type "k" (where $acctyp_{.}$ (fatal, injury, property damage)).

$Af_{acctyp,at(l),fc(l)}$ is the accident rate per million miles of travel for accident type "acctype" for highway link l, which is of functional class "fc" and in area of type "at". Refer to Table 2.9.12. These rates represent the accident frequencies for roadways with level of service C (i.e traffic volume/capacity˜ 0.7).

$Cf_{vcf,fc(l)}$ is the accident rate adjustment factor for highway link l of type "fc" with a traffic volume/capacity ratio (V_l/C_l) in group "vcf". Refer to Table 2.9.13 for $Cf_{vcf,fc(l)}$.

$UnitCost_{acctyp}$ is the unit accident cost for the accident type "acctyp" in dollars/accident (in 1990 $). Refer to Table 2.9.12.

Table 2.9.9 – Truck Percentages by Roadway Type and Area Type

Area type at	Road Type Fc	Truck% $_{at,fc}$
Urban (at=1,2,3)	Freeway (fc=1,9)	0.085
Urban (at=1,2,3)	Surface streets (fc=2,3,4,5,6,8)	0.040
Rural (at=4)	Freeway (fc=1,9)	0.220
Rural (at=4)	Surface streets (fc =2,3,45,6,8)	0.060

Table 2.9.10 – Vehicle Operating & Fixed Unit Costs by Vehicle Type

Vehicle type k	Operation Cost* $UnitCost_{oper(k)}$ ($/VMT)	Fixed Cost* $UnitCost_{fixed(k)}$ ($/VMT)
Car	0.084	0.278
Truck	0.785	0.157

* in 1990 dollars

Table 2.9.11 – Vehicle Unit Operating Cost Adjustment Factors by Speed Ranges

s (mph)	$CostAdjust_{k,s}$		s (mph)	$CostAdjust_{k,s}$	
	Auto	Truck		Auto	Truck
10	1.25	1.40	50	0.94	0.96
20	1.00	0.92	55	1.00	1.00
30	0.94	0.91	60	1.04	1.04
40	0.90	0.93	70	1.16	1.13

Table 2.9.12 – Unit Accident Costs & Accident Rates by Roadway Type and Area Type

Area Type at	Roadway Type	$Af_{acctyp,at,rt}$			
		Accident Type (acctyp)			
		fatality		injury	property damage
		year			
		1990	2020	1990 & 2020	1990 & 2020
Urban (at=1,2,3)	Freeway (fc=1,9)	0.006	0.004	0.493	0.744
Urban (At=1,2,3)	Surface streets (fc=2,3,4,5,6,8)	0.011	0.007	1.608	4.096
Rural (at=4)	Freeway	0.016	0.011	0.603	3.19
Rural (at=4)	Surface streets	0.048	0.032	3.058	7.335

	Accident Type acctyp		
	Fatality	Injury	Prop. Damage
*UnitCostacctyp	$1700000	$14000	$3000

* in 1990 dollars

Table 2.9.13 – Accident Rate adjustment Factors by Level-of-Service and Road Type

V/C Group vcf	Level Of Service	Traffic Volume/Road Capacity Ratio V/C	Adjustment Factor $Cf_{vcf,fc}$	
			Freeway (fc=1,9)	Surface street (fc=2,3,4,5,6,8)
1	A	≤ 0.4	0.42	0.22
2	B	≤ 0.6	0.67	0.53
3	C	≤ 0.8	1.00	1.00
4	D	≤ 0.9	1.43	1.71
5	E	< 1.0	1.80	2.65
6	F	> 1.0	2.62	4.15

2.9.6 Energy and Environmental Impacts

2.9.6.1 Emission

MOBILE6.2 is a software program designed by the U.S. Environmental Protection Agency to estimate emission rates for the highway motor vehicle fleet under a range of conditions. MOBILE6.2 calculates emission rates for HC, CO, and NOx. The emission rates are affected by altitude/temperature/humidity, vehicle fleet characteristics (age distribution, annual mileage accumulation rates, diesel fractions), vehicle activity (vehicle miles traveled fraction by vehicle class, vehicle miles of traveled fraction by highway functional system, vehicle miles traveled fractions by hour of the day, vehicle miles traveled fraction by average speed, vehicle engine starts per day and by hour of the day, vehicle soak time between engine starts, vehicle hot soak time after engine shut down, vehicle diurnal soak time, vehicle trip length distributions),vehicle gasoline properties (volatility, reformulated, oxygen content, sulfur content), inspection and maintenance programs and anti-tampering programs. In Mobile6.2 operation the input data used for emission rates calculation are specified in “flag files”. Since the emission control strategies implemented are different for different time periods, three sets are developed for years before 1999, years between 1999 and 2003 and years after 2003. In addition, since the emission control strategies implemented in Ohio and Kentucky states are different, in each set there are two subsets, one for Ohio and the other for Kentucky. The input flag data to MOBILE6.2 program are listed in Table 2.9.16 - Table 2.9.18

Mobile6.2 default values for fleet characteristics and vehicle activity are used except vehicle age distribution and VMT fractions. The vehicle age distribution data for LDV (light duty vehicle) and LDT1 (light duty truck) are derived for year 2000 e-check testing information, see Table 2.9.14 and Table 2.9.15. The default distributions are used for the other 14 vehicle classes.

Table 2.9.14 – Vehicle Age (1-25) Distribution for LDV and LDT1 for Ohio

* LDV
0.0810 0.0751 0.0816 0.0789 0.0713 0.0808 0.0685 0.0686 0.0571 0.0580
0.0485 0.0514 0.0411 0.0380 0.0284 0.0238 0.0144 0.0087 0.0044 0.0039
0.0031 0.0060 0.0042 0.0028 0.0004
* LDT1
0.0810 0.0751 0.0816 0.0789 0.0713 0.0808 0.0685 0.0686 0.0571 0.0580
0.0485 0.0514 0.0411 0.0380 0.0284 0.0238 0.0144 0.0087 0.0044 0.0039
0.0031 0.0060 0.0042 0.0028 0.0004

Table 2.9.15 – Vehicle Age (1-25) Distribution for LDV and LDT1 for Kentucky

* LDV
0.0429 0.0881 0.0779 0.0831 0.0763 0.0784 0.0760 0.0679 0.0622 0.0528
0.0552 0.0468 0.0493 0.0328 0.0344 0.0192 0.0166 0.0064 0.0051 0.0029
0.0037 0.0050 0.0056 0.0025 0.0089
* LDT1
0.0429 0.0881 0.0779 0.0831 0.0763 0.0784 0.0760 0.0679 0.0622 0.0528
0.0552 0.0468 0.0493 0.0328 0.0344 0.0192 0.0166 0.0064 0.0051 0.0029
0.0037 0.0050 0.0056 0.0025 0.0089

VMT fractions are calculated using the data in the loaded highway network from the travel demand model. The flow of the emission calculation is shown in Figure 2.9.1. The calculations of VMT fractions and emission are described below.

(A) Calculate VMT% by speed bin and hour of the day, VMT% by hour of the day and VMT% by roadway functional class needed for EPA's MOBILE 6.2 program

$V_{l,h}^{veh} = V_l^{daily,veh} * \%Hf^{h}_{at(l), fc(l)} / 100$ for link l ε facility class "fc" and area type "at"

$s_{l,h} = {}_o s_l / (1+ a(r) (V_l^h / C_l)^{b(r)})$ for link l ε roadway group r

$VMT_{l,h}^{veh} = V_{l,h}^{veh} * d_l$

$VMT_{b,h}^{freeway} = \Sigma_{l\ \varepsilon\ f=1,2} \Sigma_{k \text{ with } s(l,h)\ \varepsilon\ b} VMT_{l,h}^{veh}$

$VMT_{b,h}^{non-freeway} = \Sigma_{l\ \varepsilon\ f=3,4,5,6} \Sigma_{k \text{ with } s(l,h)\ \varepsilon\ b} VMT_{l,h}^{veh}$

$VMT\%_{b,h}^{freeway} = VMT_{b,h}^{freeway} / \Sigma_b VMT_{b,h}^{freeway}$

$VMT\%_{b,h}^{non-freeway} = VMT_{b,h}^{non-freeway} / \Sigma_b VMT_{b,h}^{non-freeway}$

$VMT_h^{veh} = \Sigma_{l\ \varepsilon \text{ all } f} VMT_{l,h}^{veh}$

$VMT\%_h^{veh} = VMT_h^{veh} / \Sigma_h VMT_h^{veh}$

$VMT_{fc,h}^{veh} = \Sigma_{l\ \varepsilon\ fc} VMT_{l,h}^{veh}$

$VMT\%_{fc,h}^{veh} = VMT_{fc,h}^{veh} / \Sigma_{fc} VMT_{fc,h}^{veh}$

f = (1, 2, 3, 4, 5, 6) for roadway facility type : urban freeway, rural freeway, urban arterial, rural arterial, urban collector, rural collector
fc = (1, 2, 3, 4) for roadway functional class : freeway, ramp, arterial and others)

r = (1, 2, 3, 4, 5) for roadway group code for speed-capacity relationship equations
b = (1, 2, 3, …14) for speed bins : <5, 5-10, 10-15, 15-20, 20-25, 25-30,30-35, 35-40, 40-45, 45-50, 50-55, 55-60, 60-65, >65)
h = (1, 2, 3, …, 24) for hours of the day
l = link in the highway network
ε = belong
Σ = summation

$V_{l,h}^{veh}$ = Loaded traffic volume (auto and truck) on link l in hour h (in vehicles)
V_l^{daily} = Loaded traffic volume (auto and truck) on link l for 24 hours (in vehicles)
$\%Hf^h_{at(l),\, fc(l)}$ is hourly traffic distribution for hour "h" of the day which depends on area type "at" and roadway functional class "fc" of highway link l. for roadway facility type f (see Table 2.9.2)
$s_{l,h}$ = Loaded speed for link l in hour h (in miles per hour)
d_l = Length of link l (in miles)
$(1+ a(r)\,(V^h_l / C_l)^{b(r)})$ = Speed-volume relationship equation for group r:

$1 + 0.2 * (V/C)^{8}$	for group 1 (freeways, ramps controlled expressways)
$1 + 0.195 * (V/C)^{8.16}$	for group 2 (expressways, freeway-to-freeway ramps, on-ramps, rural arterials)
$1 + 0.198 * (V/C)^{4.67}$	for group 3 (arterials with four-way stop)
$1 + 0.196 * (V/C)^{7.18}$	for group 4 (urban major roads, off-ramps)
$1 + 0.259 * (V/C)^{6.12}$	for group 5 (minor roads)

C_l is the hourly capacity of the highway link l (in vehicles/hour).
${}_o s_l$ is the freeflow speed for highway link l (in miles per hour)
$VMT_{l,h}^{veh}$ = Vehicle miles of travel on link l during hour h
$VMT_{b,h}^{freeway}$ = Vehicle miles of travel during hour h for freeways with loaded speed in the speed range of bin b
$VMT_{b,h}^{non\text{-}freeway}$ = Vehicle miles of travel during hour h for non-freeways with loaded speed in the speed range of bin b
$VMT\%_{b,h}^{freeway}$ = Vehicle miles of travel % for hour h and speed bin b for freeways
$VMT\%_{b,h}^{non\text{-}freeway}$ = Vehicle miles of travel % for hour h and speed bin b for non-freeways
VMT_h^{veh}= Vehicle miles of travel for hour h
$VMT\%_h^{veh}$ = Vehicle miles of travel % for hour h
$VMT_{fc,h}^{veh}$ = Vehicle miles of travel for roadway class fc and hour h
$VMT\%_{fc,h}^{veh}$ = Vehicle miles of travel % by roadway class fc for hour h (assume the same for all 28 vehicle types)

(B) Apply EPA's MOBILE 6.2 to Obtain Emission Factors

MOBILE 6.2 produces a set of emission factors: one for HC, one for CO and one for NOX (Ef_{hc}, Ef_{co} and Efnox)

(C) Apply Emission Factors to VMT to Obtain Emission

$Em_{chem}^{daily} = Em_{veh,chem}^{daily} + Em_{bus,chem}^{daily}$

Where

Veh = auto +truck

Chem = CO, HC, NOX

$Em_{veh,,chem}^{daily}. = VMT_{veh}^{daily} * Ef_{chem.}$

$Em_{bus, chem}^{daily}. = VMT_{bus}^{daily} * Ef_{bus,chem.,20mph}$

Where

$VMT_{veh}^{daily} = \Sigma_{l}^{all} VMT_{l}^{veh}$

$VMT_{bus}^{daily} = \Sigma_{line}^{all\ bus\ lines} [\Sigma^{all}_{period} (Run_{line}^{period})*Tf * d_{line}]$

Where

Em_{chem}^{daily} is the regional daily emissions for chemical "chem" ("chem". CO, HC, NOX) in tons/day.

$Em_{veh,chem}^{daily}$ is the daily emissions for chemical "chem" in tons/day for veh (auto + truck).

$Em_{bus,chem}^{daily}$ is the daily bus emissions for chemical "chem" in tons/day.

$Ef_{chem,}$ is the composite emission factor in grams/mile for chemical "chem". The composite emission factors are obtained using the MOBILE6.2 and input flag files to MOBILE6.2 run are shown in Table 2.9.16 – Table 2.9.18.

$Ef_{bus,chem,20mph}$ is the bus composite emission factor for chemical "chem" at average speed of 20 mph.

$VMT_{l}^{daily,veh}$ is the daily vehicle miles traveled on highway link l calculated as $V_{l}*d_{l}$.

$V_{l}^{daily,veh}$ is daily link volume in vehicles per day on highway link l.

d_{l} is link distance in miles for highway link l.

VMT_{bus}^{daily} is the daily bus vehicle miles traveled

$Runs_{line}^{period}$ is the total number of one way runs on transit line "line" during the time period "period" (where period. AM, MIDDAY, PM). Operation for PM peak period is assumed to be the same as AM peak period.

Tf is the transit conversion factor to account for operation in night period, 1.26.

d_{line} is the length of transit line "line" in miles calculated as sum of distance of transit links (d_{l}) along line "line".

Figure 1: Emission Calculation

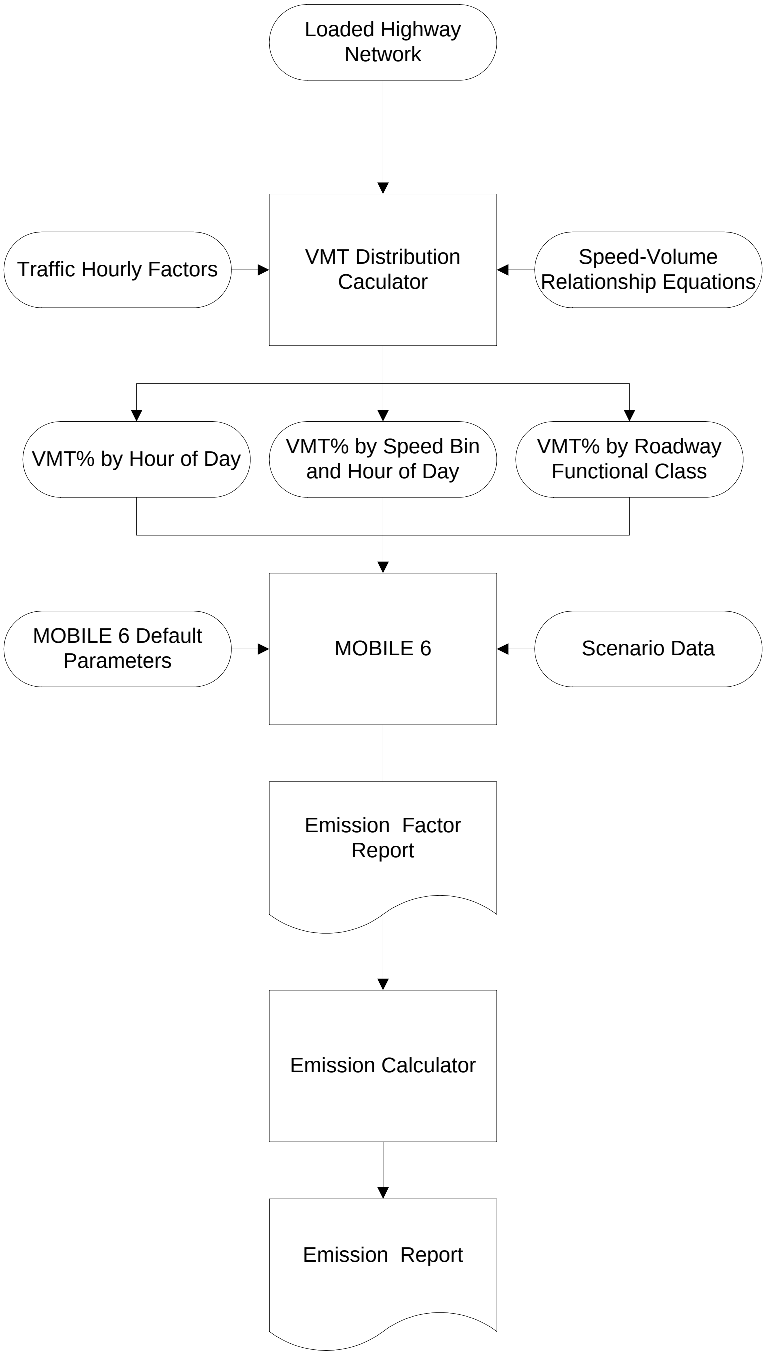


Table 2.9.16 – Mobile 62 Flag Data File (for years before 1999)

```
* Filename: 95oh.in
* M6 run for OKI model
******************* Header Section ************************
MOBILE6 INPUT FILE
> Analysis Year 1995-1999, OH counties of Butler, Clermont, Hamilton, and Warren
POLLUTANTS        : HC NOx CO                         generate factors for HC,NOx, and CO
REPORT FILE       : OH.RPT
DATABASE OUTPUT   :
WITH FIELDNAMES   :
DATABASE EMISSIONS : 2211 1111                        include exhaust running and start emissions in database
DAILY OUTPUT      :
EMISSIONS TABLE   : 1995oh.tb1

RUN DATA
******************* Run Section ***************************
FUEL RVP          : 9.0
VMT BY HOUR       : OHHVMT.D                          VMT% by Hour of Day from TDM
SPEED VMT         : OHSVMT.D                          VMT% by Speed Bin & Hour from TDM
VMT BY FACILITY   : OHFVMT.D                          VMT% by Roadway Functional Class from TDM
EXPRESS HC AS VOC :
I/M PROGRAM       : 1 1996 2050 2 T/O ASM 2525 FINAL  ASM program
I/M MODEL YEARS   : 1 1971 2050                       model years subject to OBD I/M program
I/M VEHICLES      : 1 22222 21111111 1                gasoline vehicles under 10000 lbs. GVWR subject to test
I/M STRINGENCY    : 1 15.0                            exhaust failure rate for pre'81 model year vehicles
I/M COMPLIANCE    : 1 96.0                            expected compliance with I/M program
I/M WAIVER RATES  : 1 01.0 01.0                       % of compliant vehicles that fail initial test and retest
FUEL PROGRAM      : 1                                 conventional gasoline east fuel program
OXYGENATED FUELS  : .035 .197 .027 .031 2             MTBE use, gasohol use, O2 % MTBE,02% gasohol
STAGE II REFUELING :
93 3 86. 86.                                          1993 start w/ 3-yr phase-in,86% efficiency
ANTI-TAMP PROGR   :
96 71 50 22222 21111111 2 12 096. 12111112            96% compliance,check for catalyst removal and gas cap
EXPAND BUS EFS    :                                   emission factors for urban transit buses calculated
MIN/MAX TEMP      : 65.0 95.0                                 avg.min/max temp for high ozone days
ABSOLUTE HUMIDITY : 75.0                              default humidity value

******************* Scenario Section **********************
*SCENARIO RECORD  : Ohio Emissions - CY1995            scenario section read from OKI program
*CALENDAR YEAR    : 1995
*EVALUATION MONTH : 7
*SEASON           : 1
******************* End of Run ****************************
END OF RUN
```

Table 2.9.16 – Mobile 62 Flag Data File (for years before 1999) (Continue)

```
MOBILE6 INPUT FILE :
*created 07/01/02,ajr
************************ Header Section *****************
> Analysis Year 1995-1999, KY counties of Boone, Campbell and Kenton
POLLUTANTS        : HC NOx CO
REPORT FILE       : KY.RPT
DATABASE OUTPUT   :
WITH FIELDNAMES   :
DATABASE EMISSIONS : 2211 1111
DAILY OUTPUT      :
EMISSIONS TABLE   : 1995ky.tb1

RUN DATA
************************ Run Section *******************
> Analysis Year 1995, KY counties of Boone, Campbell and Kenton
FUEL RVP         : 7.8                        Reid Vapor Pressure, US EPA Standards March 2000
REG DIST         : KYREG.D                    NKY VET age distribution For LDGV
VMT BY HOUR      : KYHVMT.D                   MT% by Hour of Day from TDM
SPEED VMT        : KYSVMT.D                   VMT% by Speed Bin & Hour from TDM
VMT BY FACILITY  : KYFVMT.D                   VMT% by Roadway Functional Class from TDM
EXPRESS HC AS VOC :
I/M PROGRAM      : 1 1999 2050 2 T/O IDLE     No I/M or ATP before 1999
I/M MODEL YEARS  : 1 1968 1995
I/M VEHICLES     : 1 22222 22221111 1
I/M STRINGENCY   : 1 20.0
I/M COMPLIANCE   : 1 99.0
I/M WAIVER RATES : 1 18.0 10.0
I/M PROGRAM      : 2 1999 2050 2 T/O FP & GC
I/M MODEL YEARS  : 2 1981 1995
I/M VEHICLES     : 2 22222 11111111 1
I/M STRINGENCY   : 2 20.0
I/M COMPLIANCE   : 2 99.0
I/M WAIVER RATES : 2 18.0 10.0
I/M PROGRAM      : 3 1999 2050 2 T/O OBD I/M
I/M MODEL YEARS  : 3 1996 2050
I/M VEHICLES     : 3 22222 22221111 1
I/M STRINGENCY   : 3 20.0
I/M COMPLIANCE   : 3 99.0
I/M WAIVER RATES : 3 18.0 10.0
I/M PROGRAM      : 4 1999 2050 2 T/O EVAP OBD
I/M MODEL YEARS  : 4 1996 2050
I/M VEHICLES     : 4 22222 11111111 1
I/M STRINGENCY   : 4 20.0
I/M COMPLIANCE   : 4 99.0
I/M WAIVER RATES : 4 18.0 10.0
FUEL PROGRAM     : 2 N
STAGE II REFUELING :
99 2 86. 86.
ANTI-TAMP PROGR  :
99 75 50 22222 22222222 2 12 099. 22222222
EXPAND BUS EFS   :
MIN/MAX TEMP     : 65.0 95.0                  average min/max temperature
ABSOLUTE HUMIDITY : 75.0                      average humidity default value

******************** Scenario Section ****************
*SCENARIO RECORD : KY EMISSIONS - CY1995      scenario section read from OKI program
*CALENDAR YEAR   : 1995
*EVALUATION MONTH : 7
*SEASON          : 1
*********************************** END OF RUN *****************
END OF RUN
```

Table 2.9.17 – Mobile 62 Flag Data File (for years between 1999-2003)

* Mobile6 file for Butler, Clermont, Hamilton and Warren counties, post 1999	
* created 05/22/03, ajr	
******************* Header Section ************************	
MOBILE6 INPUT FILE :	
POLLUTANTS : HC NOx CO	*generate factors for HC,NOx, and CO*
REPORT FILE : oh.rpt	
DATABASE OUTPUT :	
WITH FIELDNAMES :	
DATABASE EMISSIONS : 2211 1111	*include exhaust running and start emissions in database*
DAILY OUTPUT :	
EMISSIONS TABLE : ohemiss.tb1	
RUN DATA	
******************* Run Section ***************************	
VMT BY HOUR : OHHVMT.D	*VMT% by Hour of Day from TDM*
SPEED VMT : OHSVMT.D	*VMT% by Speed Bin & Hour from TDM*
VMT BY FACILITY : OHFVMT.D	*VMT% by Roadway Functional Class from TDM*
FUEL RVP : 9.0	*Reid Vapor Pressure, US EPA Standards March 2000*
EXPRESS HC AS VOC :	
I/M PROGRAM : 1 2001 2050 2 T/O ASM 2525 PHASE-IN	*ASM program began January '01*
I/M MODEL YEARS : 1 1977 2050	*model years subject to OBD I/M program*
I/M VEHICLES : 1 22222 21111111 1	*gasoline vehicles under 10000 lbs. GVWR subject to test*
I/M STRINGENCY : 1 27.0	*exhaust failure rate for pre'81 model year vehicles*
I/M COMPLIANCE : 1 96.0	*expected compliance with I/M program*
I/M WAIVER RATES : 1 3.0 3.0	*% of compliant vehicles that fail initial test and retest*
I/M EXEMPTION AGE : 1 25	*vehicles 25 years old and older are exempt from test*
I/M GRACE PERIOD : 1 2	*new vehicles have 2 years before first testing*
* EVAP PROGRAM	
I/M PROGRAM : 2 1996 2050 2 T/O GC	*biennial evaporative gas cap test*
I/M MODEL YEARS : 2 1971 2050	*model years subject gas cap test*
I/M VEHICLES : 2 22222 21111111 1	*LDGV, LDGT and HDGV subject to test*
I/M STRINGENCY : 2 27.0	*exhaust failure rate for pre'81 model year vehicles*
I/M COMPLIANCE : 2 96.0	*expected compliance with I/M program*
I/M WAIVER RATES : 2 3.0 3.0	*% of compliant vehicles that fail initial test and retest*
I/M EXEMPTION AGE : 2 25	*vehicles 25 years old and older are exempt from test*
I/M GRACE PERIOD : 2 2	*new vehicles have 2 years before first testing*
FUEL PROGRAM : 1	*conventional gasoline east fuel program*
OXYGENATED FUELS : .001 .419 .027 .035 2	*MTBE use, gasohol use, O_2 % MTBE,0_2% gasohol*
STAGE II REFUELING :	
93 3 86. 86.	*1993 start w/ 3-yr phase-in,86% efficiency*
ANTI-TAMP PROGR :	*1996 start, covers same vehicle as I/M programs,*
96 71 50 22222 21111111 1 12 096. 12111112	*96% compliance,check for catalyst removal and gas cap*
EXPAND BUS EFS :	*emission factors for urban transit buses calculated*
MIN/MAX TEMP : 63.9 87.7	*avg.min/max temp,10-highest ozone days '99-'02*
ABSOLUTE HUMIDITY : 75.0	*default humidity value*
******************* Scenario Section **********************	
*SCENARIO RECORD : Ohio Emissions - CY20xx	*scenario section read from OKI program*
*CALENDAR YEAR : 200x	
*EVALUATION MONTH : 7	
*SEASON : 1	
******************* End of Run ****************************	

Table 2.9.17 – Mobile 62 Flag Data File (for years between 1999-2003) (Continue)

*********** MOBILE6 file for Kentucky **************	
*Mobile6 file for Boone, Campbell and Kenton counties, post 1999 analysis years,	
*created 8/7/03,ajr	
************************ Header Section *****************	
MOBILE6 INPUT FILE :	
POLLUTANTS : HC NOx CO	*generate factors for HC,NOx, and CO*
REPORT FILE : KY.RPT	
DATABASE OUTPUT :	
WITH FIELDNAMES :	
DATABASE EMISSIONS : 2211 1111	*include exhaust running and start emissions in database*
DAILY OUTPUT :	
EMISSIONS TABLE : kyemdata.tb1	
RUN DATA	
************************ Run Section *******************	
REG DIST : KYREG.D	*NKY VET age distribution For LDGV*
VMT BY HOUR : KYHVMT.D	*VMT% by Hour of Day from TDM*
SPEED VMT : KYSVMT.D	*VMT% by Speed Bin & Hour from TDM*
VMT BY FACILITY : KYFVMT.D	*VMT% by Roadway Functional Class from TDM*
FUEL RVP : 7.8	*Reid Vapor Pressure, US EPA Standards March 2000*
EXPRESS HC AS VOC :	
I/M PROGRAM : 1 1999 2050 2 T/O IDLE	*biennial test-only idle test began in 1999*
I/M MODEL YEARS : 1 1968 2050	*model years subject to I/M program*
I/M VEHICLES : 1 22222 22211111 1	*vehicles under 19500 lbs. GVWR subject to program*
I/M STRINGENCY : 1 20.0	*exhaust failure rate for pre'81 model year vehicles*
I/M COMPLIANCE : 1 99.0	*expected compliance with I/M program*
I/M WAIVER RATES : 1 18.0 10.0	*% of compliant vehicles that fail initial test and retest*
I/M PROGRAM : 2 1999 2050 2 T/O FP & GC	*biennial test-only evaporative pressure and gas cap test*
I/M MODEL YEARS : 2 1981 2050	*model years subject to this I/M program*
I/M VEHICLES : 2 22222 11111111 1	*light-duty vehicles are subject to this program*
I/M COMPLIANCE : 2 99.0	
I/M WAIVER RATES : 2 18.0 10.0	
FUEL PROGRAM : 2 N	*RFG fuel program for the northern region*
STAGE II REFUELING :	*1999 start w/ 2-yr phase-in,86% efficiency*
99 2 86. 86.	
ANTI-TAMP PROGR :	*1999 start year for anti-tampering program*
99 75 50 22222 22222222 2 12 099. 22222222	*all vehicle types covered, all checks performed*
EXPAND BUS EFS :	*emission factors for urban transit buses calculated*
**** MOBILE6 file for KY continued ***********	
MIN/MAX TEMP : 66.0 89.0	*average min/max temperature as provided byKDAQ* ABSOLUTE
HUMIDITY : 75.0	*average humidity default value*
******************** Scenario Section ****************	
*SCENARIO RECORD : KY EMISSIONS - CY20xx	*scenario section read from OKI program*
*CALENDAR YEAR : 20xx	*calendar year value read from OKI program*
*EVALUATION MONTH : 7	
*MIN/MAX TEMP : 66.0 89.0	
*ABSOLUTE HUMIDITY : 75.0	
*SEASON : 1	
********************************** END OF RUN *****************	
END OF RUN	

Table 2.9.18 – Mobile 62 Flag Data File (for Years after 2003)

* Mobile6 file for Butler, Clermont, Hamilton and Warren counties, post 2003	
* OBD program initiated on 1/5/04	
* created 01/12/04, ajr	
******************* Header Section ************************	
MOBILE6 INPUT FILE :	
POLLUTANTS : HC NOx CO	*generate factors for HC,NOx, and CO*
REPORT FILE : oh.rpt	
DATABASE OUTPUT :	
WITH FIELDNAMES :	
DATABASE EMISSIONS : 2211 1111	*include exhaust running and start emissions in database*
DAILY OUTPUT :	
EMISSIONS TABLE : ohemiss.tb1	
RUN DATA	
******************* Run Section ***************************	
VMT BY HOUR : OHHVMT.D	*VMT% by Hour of Day from TDM*
SPEED VMT : OHSVMT.D	*VMT% by Speed Bin & Hour from TDM*
VMT BY FACILITY : OHFVMT.D	*VMT% by Roadway Functional Class from TDM*
REG DIST : OHREG.D	*LDGV age distribution from local E-Check data*
FUEL RVP : 9.0	*Reid Vapor Pressure, US EPA Standards March 2000*
EXPRESS HC AS VOC :	
* ANTI-TAMPERING PROGRAM	
ANTI-TAMP PROG :	*1996 start, covers same vehicle as I/M programs,*
96 82 50 22222 21111111 1 12 096. 12111112	*96% compliance,check for catalyst removal and gas cap*
* I/M PROGRAM(S)	
* OBD	
I/M PROGRAM : 1 2004 2050 2 T/O OBD I/M	*OBD program began January '04*
I/M MODEL YEARS : 1 1996 2050	*model years subject to OBD I/M program*
I/M VEHICLES : 1 22222 21111111 1	*gasoline vehicles under 10000 lbs. GVWR subject to test*
I/M STRINGENCY : 1 27.0	*exhaust failure rate for pre'81 model year vehicles*
I/M COMPLIANCE : 1 96.0	*expected compliance with I/M program*
I/M WAIVER RATES : 1 10 10	*% of compliant vehicles that fail initial test and retest*
I/M GRACE PERIOD : 1 2	*new vehicles have 2 years before first testing*
* EVAP OBD with no post '07 HDGV	
I/M PROGRAM : 2 2004 2050 2 T/O EVAP OBD & GC	*biennial evaporative gas cap/OBD evap test, no HDGV*
I/M MODEL YEARS : 2 1996 2007	*model years subject to OBD evap program*
I/M VEHICLES : 2 22222 11111111 1	*LDGV and LDGT subject to test*
I/M COMPLIANCE : 2 96.0	*expected compliance with evap program*
I/M WAIVER RATES : 2 10 10	*% of compliant vehicles that fail initial test and retest*
I/M EXEMPTION AGE : 2 25	*vehicles 25 years old and older are exempt from test*
I/M GRACE PERIOD : 2 2	*new vehicles have 2 years before first testing*
* EVAP OBD with post '07 HDGV	
I/M PROGRAM : 3 2004 2050 2 T/O EVAP OBD & GC	*biennial evaporative gas cap and OBD evap test*
I/M MODEL YEARS : 3 2008 2050	*model years subject to OBD evap program*
I/M VEHICLES : 3 22222 21111111 1	*LDGV, LDGT and HDGV subject to test*
I/M COMPLIANCE : 3 96.0	*expected compliance with evap program*
I/M WAIVER RATES : 3 10 10	*% of compliant vehicles that fail initial test and retest*
I/M EXEMPTION AGE : 3 25	*vehicles 25 years old and older are exempt from test*
**** MOBILE6 files for Ohio continued *****************	
I/M GRACE PERIOD : 3 2	*new vehicles have 2 years before first testing*
* ASM 2525	
I/M PROGRAM : 4 2001 2050 2 T/O ASM 2525 PHASE-IN	*biennial test-only program, ASM 2525 began in 2001*
I/M MODEL YEARS : 4 1982 1995	*Pre'96 model years only subject to this I/M program*
I/M VEHICLES : 4 22222 21111111 1	*gasoline vehicles under 10000 lbs. GVWR subject to test*
I/M COMPLIANCE : 4 96.0	*expected compliance with I/M program*
I/M WAIVER RATES : 4 10 10	*% of compliant vehicles that fail initial test and retest*
I/M EXEMPTION AGE : 4 25	*vehicles 25 years old and older are exempt from test*
I/M GRACE PERIOD : 4 2	*new vehicles had 2 years before first testing*
* IDLE	
I/M PROGRAM : 5 1998 2000 2 T/O IDLE	*biennial Idle test-only program,ended in 2000*
I/M MODEL YEARS : 5 1973 1996	*model years subjected to I/M program*
I/M VEHICLES : 5 22222 21111111 1	*gasoline vehicles under 10000 lbs. GVWR subject to test*
I/M STRINGENCY : 5 20.0	*exhaust failure rate for pre'81 model year vehicles*
I/M COMPLIANCE : 5 96.0	*expected compliance with I/M program*
I/M WAIVER RATES : 5 10 10	*% of compliant vehicles that fail initial test and retest*
I/M EXEMPTION AGE : 5 25	*vehicles 25 years old and older are exempt from test*
I/M GRACE PERIOD : 5 2	*new vehicles had 2 years before first testing*
* IM 240	

I/M PROGRAM : 6 1996 1997 2 T/O IM240	*biennial IM240 test-only program, ended in 1997*
I/M MODEL YEARS : 6 1971 1994	*model years subjected to I/M program*
I/M VEHICLES : 6 22222 21111111 1	*gasoline vehicles under 10000 lbs. GVWR subject to test*
I/M STRINGENCY : 6 20.0	*exhaust failure rate for pre'81 model year vehicles*
I/M COMPLIANCE : 6 96.0	*expected compliance with I/M program*
I/M WAIVER RATES : 6 10 10	*% of compliant vehicles that fail initial test and retest*
I/M EXEMPTION AGE : 6 25	*vehicles 25 years old and older are exempt from test*
I/M CUTPOINTs : 6 CUTPOINT.D	*specifies emission level cutpoints*
I/M GRACE PERIOD : 6 2	*new vehicles had 2 years before first testing*
* GC	
I/M PROGRAM : 7 1996 2050 2 T/O GC	*biennial evaporative gas cap test for pre '96 vehicles*
I/M MODEL YEARS : 7 1982 1995	*model years subjected to evap program*
I/M VEHICLES : 7 22222 21111111 1	*gasoline vehicles under 10000 lbs. GVWR subject to test*
I/M COMPLIANCE : 7 96.0	*expected compliance with evap program*
I/M WAIVER RATES : 7 10 10	*% of compliant vehicles that fail initial test and retest*
I/M EXEMPTION AGE : 7 25	*vehicles 25 years old and older are exempt from test*
I/M GRACE PERIOD : 7 2	*new vehicles had 2 years before first testing*
FUEL PROGRAM : 1	*conventional gasoline east fuel program*
OXYGENATED FUELS : .001 .419 .027 .035 2	*MTBE use, gasohol use, O_2 % MTBE,0_2% gasohol*
STAGE II REFUELING :	
93 3 86. 86.	*1993 start w/ 3-yr phase-in,86% efficiency*
EXPAND BUS EFS :	*emission factors for urban transit buses calculated*
MIN/MAX TEMP : 63.9 87.7	*avg.min/max temp,10-highest ozone days '99-'02*

********* MOBILE6 file for Ohio continued *************	
ABSOLUTE HUMIDITY : 75.0	*default humidity value*
******************* Scenario Section **********************	
*SCENARIO RECORD : Ohio Emissions - CY20xx	*scenario section read from OKI program*
*CALENDAR YEAR : 20xx	
*EVALUATION MONTH : 7	
*MIN/MAX TEMP	
*SEASON : 1	
******************* End of Run ****************************	
END OF RUN	

Table 2.9.18 – Mobile 62 Flag Data File (for Years after 2003) (continue)

```
*********** MOBILE6 file for Kentucky **************
*Mobile6 file for Boone, Campbell and Kenton counties, post 2003 analysis years,
*created 8/7/03,ajr
************************ Header Section *****************
MOBILE6 INPUT FILE :
POLLUTANTS        : HC NOx CO                      generate factors for HC,NOx, and CO
REPORT FILE       : KY.RPT
DATABASE OUTPUT   :
WITH FIELDNAMES   :
DATABASE EMISSIONS : 2211 1111                     include exhaust running and start emissions in database
DAILY OUTPUT      :
EMISSIONS TABLE   : kyemdata.tb1
RUN DATA
************************ Run Section *******************
REG DIST          : KYREG.D                        NKY VET age distribution For LDGV
VMT BY HOUR       : KYHVMT.D                       VMT% by Hour of Day from TDM
SPEED VMT         : KYSVMT.D                       VMT% by Speed Bin & Hour from TDM
VMT BY FACILITY   : KYFVMT.D                       VMT% by Roadway Functional Class from TDM
FUEL RVP          : 7.8                            Reid Vapor Pressure, US EPA Standards March 2000
EXPRESS HC AS VOC :
I/M PROGRAM       : 1 1999 2050 2 T/O IDLE         biennial test-only idle test began in 1999
I/M MODEL YEARS   : 1 1968 2050                    model years subject to I/M program
I/M VEHICLES      : 1 22222 22211111 1             vehicles under 19500 lbs. GVWR subject to program
I/M STRINGENCY    : 1 20.0                         exhaust failure rate for pre'81 model year vehicles
I/M COMPLIANCE    : 1 99.0                         expected compliance with I/M program
I/M WAIVER RATES  : 1 18.0 10.0                    % of compliant vehicles that fail initial test and retest
I/M PROGRAM       : 2 1999 2050 2 T/O FP & GC      biennial test-only evaporative pressure and gas cap test
I/M MODEL YEARS   : 2 1981 2050                    model years subject to this I/M program
I/M VEHICLES      : 2 22222 11111111 1             light-duty vehicles are subject to this program
I/M COMPLIANCE    : 2 99.0
I/M WAIVER RATES  : 2 18.0 10.0
FUEL PROGRAM      : 2 N                            RFG fuel program for the northern region
STAGE II REFUELING :                               1999 start w/ 2-yr phase-in,86% efficiency
99 2 86. 86.
ANTI-TAMP PROGR   :                                1999 start year for anti-tampering program
99 75 50 22222 22222222 2 12 099. 22222222         all vehicle types covered, all checks performed
EXPAND BUS EFS    :                                emission factors for urban transit buses calculated

MIN/MAX TEMP      : 66.0 89.0                          average min/max temperature as provided byKDAQ ABSOLUTE
HUMIDITY  : 75.0                                   average humidity default value

******************** Scenario Section ****************
*SCENARIO RECORD   : KY EMISSIONS - CY20xx         scenario section read from OKI program
*CALENDAR YEAR     : 20xx                          calendar year value read from OKI program
*EVALUATION MONTH  : 7
*MIN/MAX TEMP      : 66.0 89.0
*ABSOLUTE HUMIDITY : 75.0
*SEASON            : 1
*********************************** END OF RUN *****************
END OF RUN
```

2.9.6.2 Energy

$$Fuel^{daily} = Fuel_{auto}^{daily} + Fuel_{truck}^{daily} + Fuel_{bus}^{daily}$$

where

$$Fuel_k^{daily} = \Sigma_l^{all}\ \Sigma_{h=1}^{24}\ [VMT_{k,l,h} * Ff_{k,spf(s(l,h))}] * Adj_{k,fc(l)}$$

where k ε auto, truck

$$Fuel_{bus}^{daily} = (\Sigma_{line}^{all\ bus\ line}\Sigma_{period}^{all}\ (Runs_{line}^{period} * Tf)*(\Sigma_{l}^{all\ l\ \varepsilon\ line}\ d_l*Ff_{bus,spf(s(l,h))})* Adj_{bus,fc(l)}$$

Where period ε AM Peak, MIDDAY, PM Peak

Where

$VMT_{k,l,h}$ is the daily vehicle miles traveled on highway link l for vehicle type k, in hour h, calculated as $V_{k,l,h}*d_l$.

$V_{k.l,h}$ is traffic volume for vehicle type k (auto, truck) on highway link l in hour h.

d_l is link distance in miles for highway link l.

$s_{l,h}$ is the average travel speed in mph for hour "h" of the day along the highway link l. $s_{l,h} = {}_o s_l / (1+ a(r) (V_l^h / C_l)^{b(r)})$ for link l ε roadway group r

$Runs_{line}^{period}$ is the total number of one way runs on transit line "line" during the period "period" (where period. AM, MIDDAY, PM). Operation for PM peak period is assumed to be the same as AM peak period.

Tf is the transit conversion factor to account for night period operation, 1.26.

d_{line} is the length of transit line "line" in miles calculated as sum of distance of transit links (d_l) along line "line".

$Fuel_k^{daily}$ is the daily fuel consumption in gallons/day for each vehicle type k. Where k. (auto,truck)

$Adj_{k,fc(l)}$ is the adjustment factor for the fuel consumption rate for vehicle type "k" for roadway functional class "fc" of highway link l. Refer to Table 2.9.21.

$Adj_{bus,fc(l)}$ is the adjustment factor for the fuel consumption rate for bus for roadway functional class "fc" of highway link l. Refer to Table 2.9.21.

spf is the speed group index for the speed ranges of the highway link speed.

$Ff_{k,spf(s(l,h)}$ is the fuel consumption rate in gallons/mile for vehicle type "k" for speed range "spf" in which vehicle speed falls. Refer to Table 2.9.19 (for 1990) or Table 2.9.20 (for 2030).

$Ff_{bus,spf(s(l,h)}$ is the fuel consumption rate in gallons/mile for bus for speed range "spf" in which bus speed falls. Refer to Table 2.9.19 (for 1990) or Table 2.9.20 (for 2030).

Table 2.9.19 – Fuel Consumption Rates (1990)

Speed group Index spf	Speed Groups (mph)	Fuel Consumption Rate (gallons/mile) $Ff_{k,spf}$			Speed group spf	Speeds (mph)	Fuel Consumption Rate (gallons/mile) $Ff_{k,spf}$		
		Vehicle Type, k					Vehicle Type, k		
		Car	Truck	Bus			Car	Truck	Bus
0	< 5	--	--	.344	8	< 45	0.041	0.143	0.131
1	< 10	0.057	0.290	0.205					
2	< 15	0.048	0.222	0.169	9	< 50	0.043	0.160	
3	< 20	0.039	0.169	0.155	10	< 55	0.047	0.185	
4	< 25	0.037	0.145	0.152	11	< 60	0.050	0.208	
5	< 30	0.035	0.133	0.128	12	< 65	0.052		
6	< 35	0.037	0.129	0.110	13	. 65	0.0541		
7	< 40	0.0385	0.133	0.118					

Source: OKI Staff research (CUTS 1985, 1992, NTS Annual Report 1993)

Table 2.9.20 – Fuel Consumption Rates (2030)

Speed group Index spf	Speed Groups (mph)	Fuel Consumption Rate (gallons/mile) $Ff_{k,spf}$			Speed group spf	Speeds (mph)	Fuel Consumption Rate (gallons/mile) $Ff_{k,spf}$		
		Vehicle Type, k					Vehicle Type, k		
		Car	Truck	Bus			Car	Truck	Bus
0	< 5	--	--	.341	8	< 45	0.023	0.152	0.128
1	< 10	0.040	0.284	0.202					
2	< 15	0.031	0.222	0.166	9	< 50	0.025	0.166	
3	< 20	0.022	0.175	0.152	10	< 55	0.030	0.189	
4	< 25	0.020	0.153	0.149	11	< 60	0.033	0.210	
5	< 30	0.018	0.143	0.125	12	< 65	0.035		
6	< 35	0.020	0.139	0.107	13	. 65	0.037		
7	< 40	0.022	0.143	0.115					

Table 2.9.21 – Adjustment Factor For Fuel Consumption Rates

Vehicle Type k	$Adj_{k,fc}$	
	freeway (fc=0,1)	surface street (fc=2,3,4,5,6,8,9)
Auto	0.94	1.085
Truck	0.94	1.130
Bus	0.94	1.130

2.9.7 Environmental Justice Impact Measures

For EJ impact analysis, additional measures are identified and developed. The measures allow for assessing the impacts to EJ population groups relative to the general population. In accordance with the data available from OKI Travel Demand Model, the measures considered for EJ impact analysis fall into three categories: average travel time, job / service opportunity and congested vehicle mile of travel (VMT).   The specific measures identified for each category are summarized in Table 2.9.22.

Table 2.9.22 – EJ Measures for Transportation Plan / Program Alternative Analysis

- Travel time (in minutes)
  - For work trips by auto (for peak / off-peak periods and daily average)
  - For work trips by transit (for peak / off-peak periods and daily average)
  - For non-work trips by auto (for peak / off-peak periods and daily average)
  - For non-work trips by transit (for peak / off-peak periods and daily average)
  - For trips to hospital (for off-peak period only)
  - For trips to university (for off-peak period only)
  - For trips to CBD (for off-peak period only)
  - For trips to regional Shopping Center (for off-peak period only)

- Job / service opportunity (in terms of employment or population)
  - Employment within 20 minutes peak auto time (for EJ target zones only)
  - Percentage of population within 20 minutes off-peak auto time from a hospital
  - Percentage of population within 20 minutes off-peak auto time from a university
  - Percentage of population within 20 minutes off-peak auto time from CBD
  - Percentage of population within 10 minutes off-peak auto time from a regional shopping center
  - Job opportunity within 40 minutes peak transit time (for EJ target zones only)
  - Percentage of population within 40 minutes off-peak transit time from a hospital
  - Percentage of population within 40 minutes off-peak transit time from a university
  - Percentage of population within 40 minutes off-peak transit time from CBD
  - Percentage of population within 20 minutes off-peak transit time from a regional shopping center

- Congested VMT
  - Percentage of VMT congested in the peak hour (for EJ target zones only)
  - Percentage of VMT congested in a day (for EJ target zones only)

The measures are calculated for the following population groups unless otherwise specified in Table 2.9.22:

- All population in the region
- Minority population in the region
- Non-minority population in the region
- Low-income population in the region
- Non-low-income population in the region
- Elderly population in the region
- Non-elderly population in the region
- Disabled population in the region
- Non-disabled population in the region
- Zero-car household population in the region
- Non-zero-car household population in the region
- All population in minority target zones
- All population in non-minority target zones
- All population in low-income target zones
- All population in non-low-income target zones
- All population in elderly target zones
- All population in non-elderly target zones
- All population in disabled target zones
- All population in non-disabled target zones
- All households in zero-car household target zones
- All households in non-zero-car household target zones

The target zones for various EJ population groups are defined as the zones with zonal EJ (i.e. minority, low-income, elderly, disabled and zero-car household) population % higher than its regional percentage. This definition is recommended by OKI's EJ Committee. The definition of target zones is based on 2000 census population and household data. For example, a traffic zone with a minority population % more than 15.9% is defined as a minority target zone. 15.9% of the population in OKI region is minority. The regional population percentages for low-income, elderly, and disabled population groups are 9.40%, 15.4% and 17.4%. The regional household percentage for zero-car household group is 9.80%. Figures 2.9.1 - 2.9.5 show the target zones for the five EJ categories.

Figure 2.9.1 – Year 2000 EJ Target Zones for Minority Population

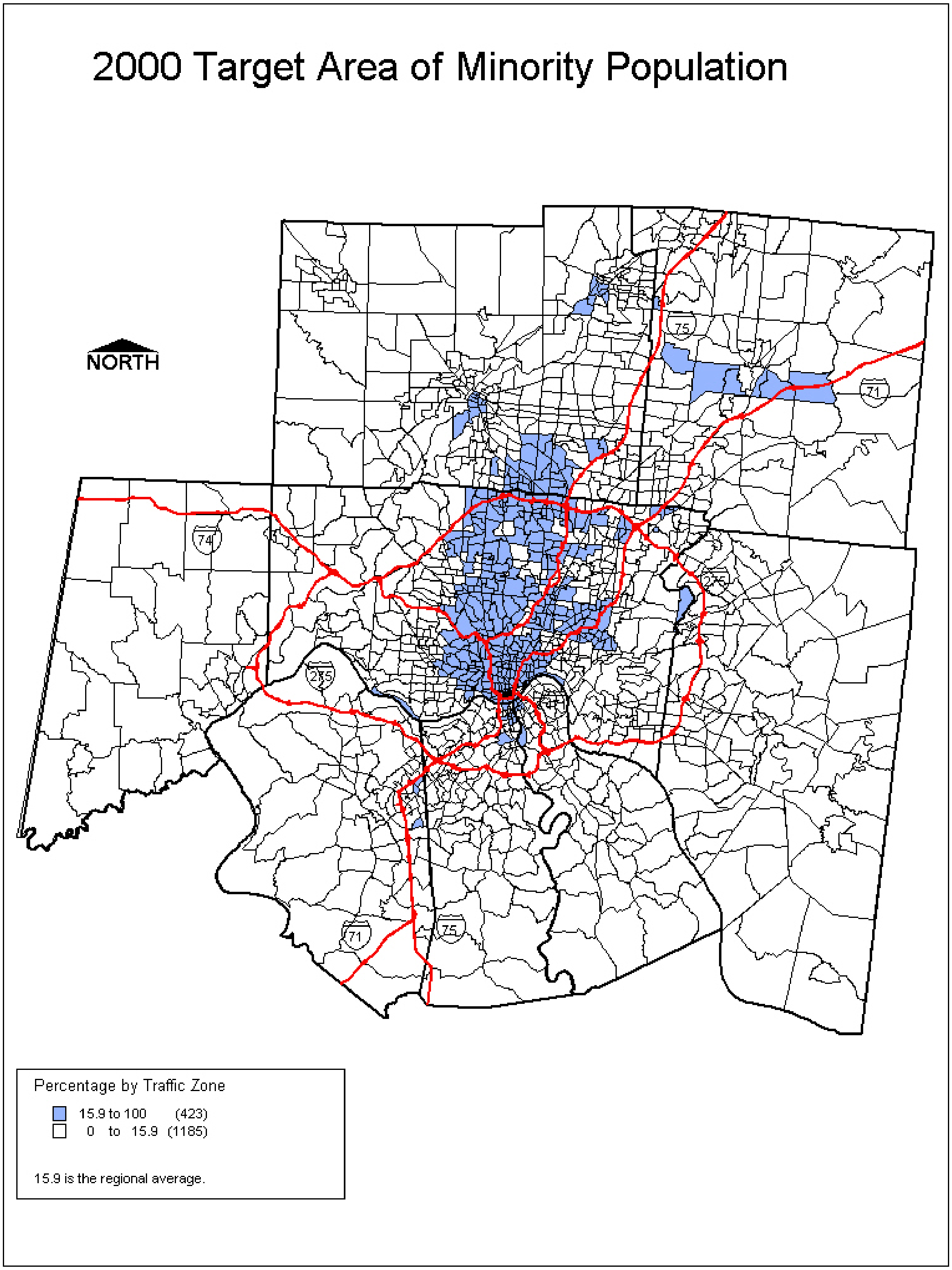


Figure 2.9.2 – Year 2000 EJ Target Zones for Poverty Population

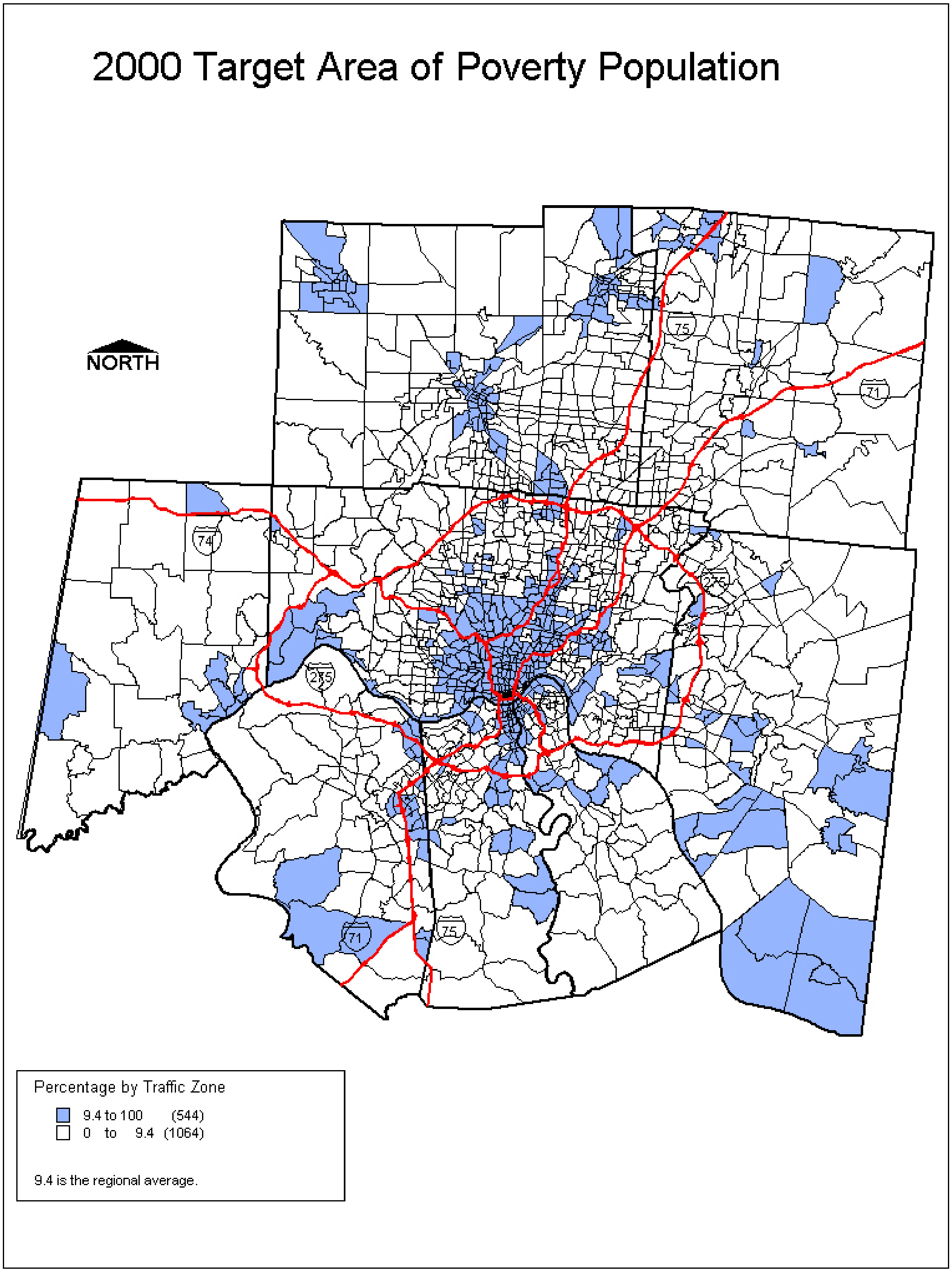


Figure 2.9.3 – Year 2000 EJ Target Zones for Disabled Population

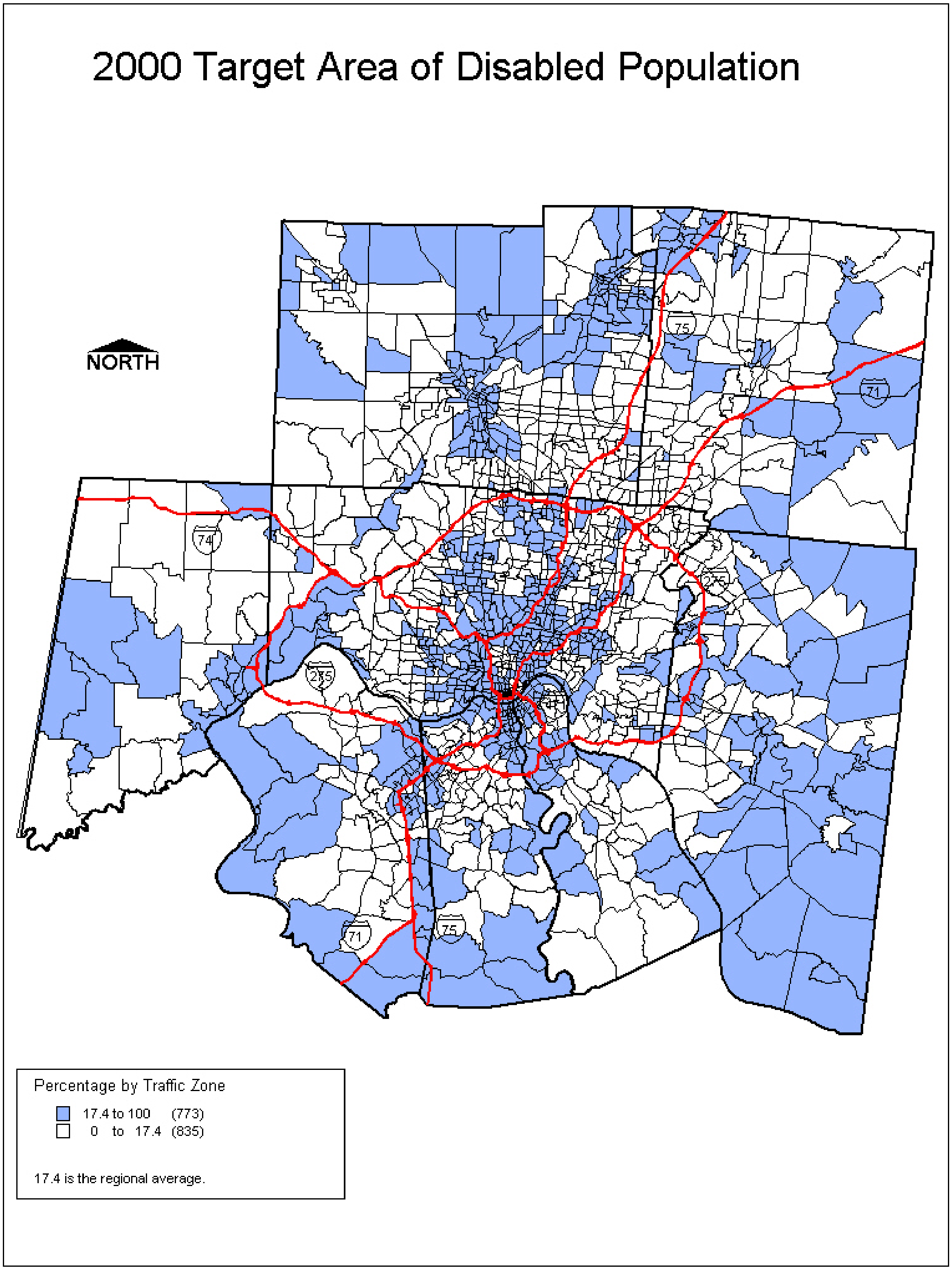


Figure 2.9.4 – Year 2000 EJ Target Zones for Elderly Population

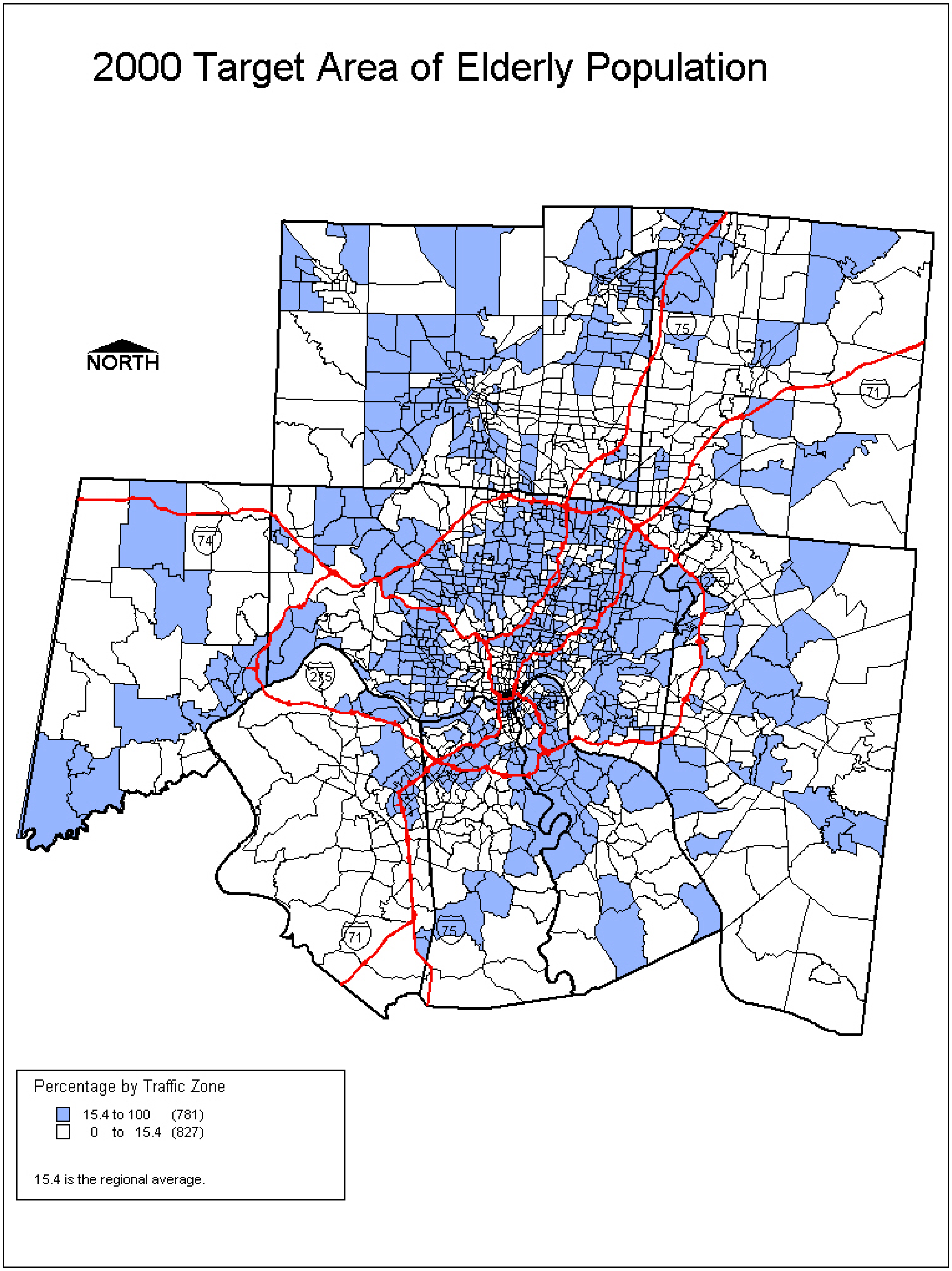
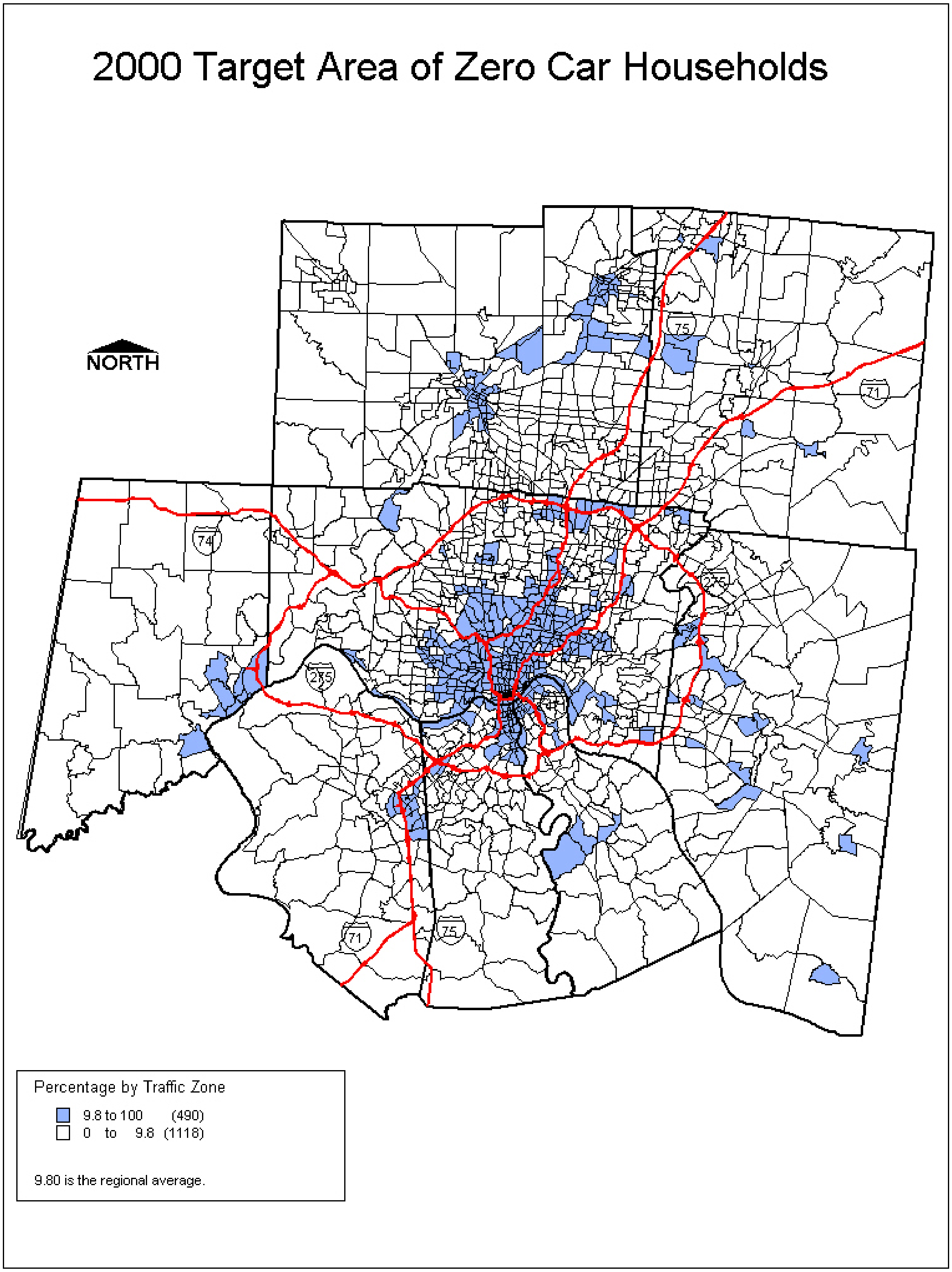


Figure 2.9.5 – Year 2000 EJ Target Zones for Zero-Car Households



The data needed for calculating these selected measures include: work trip table, non-work trip table, auto travel times, transit travel times and zonal population and employment data.

The trip tables provide the number of trips made from a traffic analysis zone to the other for all zone pairs. Two trip tables are needed, one for peak period and the other for off-peak period.

The zone-to-zone travel times are used to calculate the average travel time for EJ population groups. The zone-to-zone travel time is the travel time along the minimum time path between the zones in the highway network or the transit network. Peak travel times are derived from the peak highway and transit networks and off-peak times are derived from off-peak highway and transit networks. For each alternative to be evaluated, peak highway / transit networks and off-peak highway / transit networks with travel time information are coded to represent the alternative. Zone-to-zone transit times are derived for each transit mode. There are eight transit modes: local bus transit with walk access, local bus transit with drive access, express bus transit with walk access, express bus transit with drive access, LRT with walk access, LRT with drive access, CRT with walk access and CRT with drive access. The shortest zone-to-zone travel time among these eight modes is used in this calculation. Auto travel time includes driving time and parking time. Transit time includes driving time, walking time, waiting time and riding time.

The travel time to a service generator (i.e. hospital, University, CBD, and regional shopping center) from a traffic analysis zone is defined slightly different. Since, in general, there are multiple locations for a type of service generator, it is assumed people will go to the nearest one. The travel time from a traffic analysis zone to a service generator is defined as the shortest of the zone-to-zone travel times from the zone to the zones where service generators are located. The service generators considered in this work include:

General Hospitals: McCullough-Hyde Memorial Hospital of Oxford, Mercy Hospital of Hamilton, Mercy Hospital of Fairfield, Middletown Regional Hospital, Clermont County Mercy Hospital, Bethesda North Hospital, Bethesda Oak Hospital (not used, it was closed in late 1990's), Children Hospital Medical Center, Christ Hospital, Franciscan Hospital of Mt. Airy, Franciscan Hospital of Western Hills, Good Samaritan Hospital, Jewish Hospital Medical Center of Reading, Jewish Hospital Medical Center (used, it was moved to Kenwood in early 2000's), Mercy Hospital of Anderson, University of Cincinnati Hospital, V.A. Medical Center, St. Elizabeth (north) Medical Center, St. Elizabeth (south) Medical Center, St. Luck (west) Hospital, St. Luck (east) Hospital, Dearborn County Hospital.

Regional Shopping Centers: East-gate Mall, Forest Fair Mall, Kenwood Towne Center, Northgate Mall, Tri-County Mall, Western Hill Plaza, Florence Mall.

General Universities: University of Cincinnati, Xavier University, Northern Kentucky University, Miami University (Oxford), Miami University (Middletown), Miami University (Hamilton), Cincinnati Technical College, Thomas More College, Clermont

College, Raymond Walters College, OMI College of Applied Science, Mt. Saint Joseph College

CBD: Cincinnati central business district.

(A) Travel Time

Regionwide Average Trip Time by Mode m, for Trip Purpose p:
Average Trip Time^{p,m} = $\{\Sigma_t \ \Sigma_{i,j}^{all}$ [(Travel Time$_{i,j}^{m,t}$ * Trip$_{i,j}^{p,m,t}$]} / $\{\Sigma_t \ \Sigma_{i,j}^{all}$ Trip$_{i,j}^{p,m,t}$)}
Where m : auto mode or transit sub modes (local bus transit with walk access, local bus transit with drive access, express bus transit with walk access, express bus transit with drive access, LRT with walk access, LRT with drive access, CRT with walk access and CRT with drive access), t : peak and off-peak, and p : work or non-work, i or j : 1-1608

Regionwide Average Trip Time by Mode m, for Time Period t, for Trip Purpose p:
Average Trip Time^{p,m,t} = $\{\Sigma_{i,j}^{all}$ [(Travel time$_{i,j}^{m,t}$ * Trip$_{i,j}^{p,m,t}$] / $\Sigma_{i,j}^{all}$ Trip$_{i,j}^{p,m,t}$}

Zonal Average Trip Time by Mode m, for Time Period t, for Trip Purpose p for Zone i:
Average Trip Time$_i^{p,m,t}$ = $\{\Sigma_j^{all}$ [(Travel Time$_{i,j}^{m,t}$ * Trip$_{i,j}^{p,m,t}$] / Σ_j^{all} Trip$_{i,j}^{p,m,t}$}

Zonal Average Trip Time by Mode m, for Trip Purpose p for Zone i:
Average Trip Time$_i^{p,m}$ = $\{\Sigma_t \ \Sigma_j^{all}$ [(Travel Time$_{i,j}^{m,t}$ * Trip$_{i,j}^{p,m,t}$]} / { $\Sigma_t \ \Sigma_j^{all}$ Trip$_{i,j}^{p,m,t}$}

Regionwide Average Trip Time for Population Group n by Mode m, for Trip Purpose p
Average Trip Time$_n^{p,m}$ = {[Σ_i^{all} Zonal Average Trip Time by Mode m, for Trip Purpose p (i) * EJ Group n Population (i)] / [Σ_i^{all} Group n Population (i)]

Regionwide Average Trip Time for Household Group n by Mode m, for Trip Purpose p (for zero-car households):
Average Trip Time$_n^{p,m}$ = {[Σ_i^{all} Zonal Average Trip Time by Mode m, for Trip Purpose p (i) * EJ Group n Household (i)] / [Σ_i^{all} Group n Household (i)]

EJ Group n Target Zone by Mode m, for Trip Purpose p:
Average Trip Time$_{ntz}^{p,m}$ = {$\Sigma_{\text{i belong to target zones}}$ [Zonal Average Trip Time by Mode m, for Trip Purpose p (i) * Zonal Total Population (i)]} / {[$\Sigma_{\text{i belong to target zones}}$ [Zonal Total Population (i)]}

(To special generator group q) Regionwide Average Trip Time by Mode m:

Average Trip Time^{m} = {Σ_i^{all} [Zonal Minimum Trip Time by Mode m, to special generator group q (i) * Zonal Total Population (i)]} / {[Σ_i^{all} [Zonal Total Population (i)]}

(To special generator group q) Regionwide Average Trip Time for Population Group n by Mode m:
Average Trip Time$_q^{m}$ = {[Σ_i^{all} Zonal Minimum Trip Time by Mode m, to special generator group q (i) * EJ Group n Population (i)] / [Σ_i^{all} EJ Group n Population (i)]

(To special generator group q) Average Trip Time for Group n Target Zones by Mode m:
Average Trip Time$_{ntz}^{m}$ = {[$\Sigma_{i \text{ belong to group n target zones}}$ Zonal Minimum Trip Time by Mode m, to special generator group q (i) * Population (i)] / [$\Sigma_{i \text{ belong to group n target zones}}$ Population (i)]

Note : Not all special generators are accessible form every zone by transit

Zonal minimum Trip Time by mode m to special generator group q(i) =
$\text{Min}_{j \text{ belong to special group q zones}}$ Trip Time$_{i,j}$

Group n Population (i) = Population (i) * Year 2000 EJ Group n Population% (i)

EJ Group n Population% (i) are derived from 2000 census data and used for all analysis years.

Target zones for group n = Zones with Year 2000 EJ Group n Population% (i) greater than Year 2000 Target Threshold Value.

Year 2000 Target Threshold Value = 1.25 * Year 2000 Regional EJ Group n Population%

Year 2000 Regional EJ Group n Population% = Σ_i^{all} [Year 2000 Group n Population (i)] / Σ_i^{all} [Year 2000 Population (i)]

Household (i) = household in zone i

Population (i) = Household(i) * Pop/HH(i)

Employment (i) = Employment in zone i

Year 2000 EJ Group n population % (i) = Minority, Non-minority, Poverty, Non-Poverty, Elderly (over age 64), Non-elderly, Disabled, Non-Disabled, Zero-car household, Non-zero-car household, all.

Year 2000 minority population includes Black, American Indian, Asian, Pacific Island, multiple-race with the above, non-white Spanish (not include Others)
Year 2000 non-minority population = Total population – minority population

Travel $Time_{i,j}^{auto, peak}$ = peak period highway travel time matrix,
Travel $Time_{i,j}^{auto,off\text{-}peak}$ = off peak period highway travel time matrix
Travel $Time_{i,j}^{transit, peak}$ = peak period transit travel time matrix, minimum time among (Transit time by local bus transit with walk access, local bus transit with drive access, express bus transit with walk access, express bus transit with drive access, LRT with walk access, LRT with drive access, CRT with walk access and CRT with drive access) (Zones without transit service are ignored)
Travel $Time_{i,j}^{transit,off\text{-}peak}$ = off peak period transit travel time matrix, minimum time among (Transit time by local bus transit with walk access, local bus transit with drive access, express bus transit with walk access, express bus transit with drive access, LRT with walk access, LRT with drive access, CRT with walk access and CRT with drive access) (Zones without transit service are ignored)

$Trip_{i,j}^{work, auto, peak}$ = HBW auto peak person trips form zone i to zone j
$Trip_{i,j}^{work, auto, off\text{-}peak}$ = HBW auto off-peak person trips form zone i to zone j
$Trip_{i,j}^{non\text{-}work, auto, peak}$ = HBO auto peak person trips form zone i to zone j
$Trip_{i,j}^{non\text{-}work, auto, off\text{-}peak}$ = HBO auto off-peak person trips form zone i to zone j
$Trip_{i,j}^{work, transit, peak}$ = HBW transit peak person trips form zone i to zone j
$Trip_{i,j}^{work, transit, off\text{-}peak}$ = HBW transit off-peak person trips form zone i to zone j
$Trip_{i,j}^{non\text{-}work, transit, peak}$ = HBO transit peak person trips form zone i to zone j
$Trip_{i,j}^{non\text{-}work, transit, off\text{-}peak}$ = HBO transit off-peak person trips form zone i to zone j

Note 1 : Zone to Zone transit time includes walk time (home to transit stop + park and ride lot to transit stop + transit stop to transit stop + transit stop to final destination), auto driving time to park & ride lot, initial waiting time, transfer waiting time, in-vehicle time (local + premium modes)

Assumptions :

- Trip making behavior of all groups of population is assumed the same (trip rates, destination, mode and route choices). (Of course, this assumption does not reflect the reality. For example, the trip making behavior for elderly population is very different from the non-elderly population.)
- Treat home-based-work trips as work trips
- Treat home-based-other trips as non-work trips

- Spanish population is treated as all white except in the zone where Spanish population is greater than white population.
- The year 2000 % target group population in a zone is assumed remain the same for all years.

(B) Job Opportunity

Job Opportunity within 20 min. in peak by Auto Mode for Group n Target Zones:
$\text{Job Opportunity}_{ntz}^{auto} = \Sigma_{\text{j belongs to Travel Time}^{\text{auto, peak}}\text{(i,j) <20 min. from i belongs to group n target zones}}$ Employment (j)

Job Opportunity with 40 min. in peak by Transit Mode for Group n Target Zones:
$\text{Job Opportunity}_{ntz}^{transit} = \Sigma_{\text{j belongs to Travel Time}^{\text{min transit, peak}}\text{(i,j) <40 min. from i belongs to group n target zones}}$ Employment (j)

$\text{Travel Time}_{i,j}^{\text{min transit, peak}} = \text{Minimize}_{\text{m belong to transit sub modes}}\ \text{Travel Time}_{i,j}^{\text{m, peak}}$

(C) Accessibility to Essential Service

Regionwide Percentage of Population within 20 min. in off peak by Auto Mode from a Hospital:
$\text{Accessibility}_{hospital}^{auto} = \{\Sigma_{\text{i belong to minimum auto off peak time to a hospital (i) <20 min.}}\ \text{Population (i)}\} / \{\Sigma_i^{all}\ \text{Population (i)}\}$

Where
Minimum Auto Off Peak Time to a Hospital (i) = $\text{Minimize}_{\text{j belong to hospital zones}}\ [\text{Travel Time}_{i,j}^{\text{auto, off-peak}}]$

Regionwide Percentage of Population within 40 min. in off peak by Transit Mode from a Hospital:
$\text{Accessibility}_{hospital}^{transit} = \{\Sigma_{\text{i belong to minimum transit off peak time to a hospital (i) <40 min.}}\ \text{Population (i)}\} / \{\Sigma_i^{all}\ \text{Population (i)}\}$

Where
Minimum Transit Off Peak Time to a Hospital (i) = $\text{Minimize}_{\text{j belong to hospital zones}}\ [\text{Minimize}_{\text{m belong to transit sub modes}}\ \text{Travel Time}_{i,j}^{\text{m,off -peak}}]$

Regionwide Percentage of Population within 20 min. in off peak by Auto Mode from a Hospital for Population Group n:
$\text{Accessibility}_{hospital,n}^{auto} = \{\Sigma_{\text{i belong to minimum auto off peak time to a hospital (i) <20 min.}}\ \text{Group n Population (i)}\} / \{\Sigma_i^{all}\ \text{Group n Population (i)}\}$

Regionwide Percentage of Population within 40 min. in off peak by Transit Mode from a Hospital for Population Group n:

$Accessibility_{hospital,n}^{transit} = \{\Sigma_{\text{i belong to minimum transit off peak time to a hospital (i) <40 min.}}$ Group n Population (i)$\}$ / $\{\Sigma_i^{all}$ Group n Population (i)$\}$

Percentage of Population within 20 min. in off peak by Auto Mode from a Hospital for Group n Target Zones:
$Accessibility_{hospital,ntz}^{auto} = \{\Sigma_{\text{i belong to group n target zone and belong to minimum auto off peak time to a hospital (i) <20 min.}}$ Population (i)$\}$ / $\{\Sigma_{\text{i belong to group n target zone}}$ Population (i)$\}$
Percentage of Population within 40 min. in off peak by Transit Mode from a Hospital for Group n Target Zones:
$Accessibility_{hospital,ntz}^{transit} = \{\Sigma_{\text{i belong to group n target zone and belong to minimum transit off peak time to a hospital (i) <40 min.}}$ Population (i)$\}$ / $\{\Sigma_{\text{i belong to group n target zone}}$ Population (i)$\}$
The same formula is used for CBD zones, shopping zone and university zones.

(D) Congested VMT

% of VMT in Level of Service D,E or F in peak hour:
$Congested\ VMT\%^{peak\ hour} = \Sigma_{\text{l belong to LOS(l) = D,E,F}} [10\% * Volume_l * Length_l] / \Sigma_l^{all} [10\% * Volume_l * Length_l]$

% of VMT in Level of Service D,E or F for Group n Target Zones in peak hour:
$Congested\ VMT\%_{ntz}^{peak\ hour} = \Sigma_{\text{l belong to group n target zone and belong to LOS(l) = D,E,F}} [10\% * Volume_l * Length_l] / \Sigma_{\text{l belong to group n target zone}} [10\% * Volume_l * Length_l]$

% of VMT in Level of Service D,E or F in a day:
$Congested\ VMT\%^{daily} = \Sigma_{\text{l belong to LOS(l) = D,E,F}}$
$\Sigma_{h=1}^{24} [Hour_h * Volume_l * Length_l] / \Sigma_l^{all} [Volume_l * Length_l]$

% of VMT in Level of Service D,E or F for Group n Target Zones in a day:
$Congested\ VMT\%_{ntz}^{daily} = \Sigma_{\text{l belong to group n target zone and belong to LOS(l) = D,E,F}} [\Sigma_{h=1,24} [Hour_h * Volume_l * Length_l] / \Sigma_{\text{l belong to group n target zone}} [Volume_l * Length_l]$

Where

$Volume_l$ = the assigned daily traffic volume for highway link l

$Length_l$ = the length in mile for highway link l

$HOUR_h$ = Traffic hourly distribution factor for hour h

LOS_l = the level of service for highway link l

LOS_l = D, if $10\%*Volume_l$ or $Hour_h*Volume_l / Capacity_l > V/C^{z,c}$ for l belong to facility type z

LOS_l = E, if 10%*$Volume_l$ or $Hour_{h*}Volume_l$ / $Capacity_l$ > $V/C^{z,d}$ for l belong to facility type z

LOS_l = F, if 10%*$Volume_l$ or $Hour_h$*$Volume_l$ / $Capacity_l$ > $V/C^{z,e}$ for l belong to facility type z

$V/C^{z,los}$ = volume-capacity ratio for level of service los for facility type z

Chapter 3 Model Input

The modeling process described in Chapter 2 requires information from three data files in order to quantify the number of trips and distribute them over the regional transportation system. The data files include socioeconomic data, highway network data and transit network data.

3.1 Development of Zonal Socioeconomic Data

The travel generated by the model is a function of social and economic characteristics assigned to the individual traffic analysis zones. These characteristics are used to represent the trip generation and attraction potentials of each zone in terms of the residential population and place of work. The social and economic characteristics include:

- Household population
- Group quarters populations (institutionalized, dormitory, non-institutionalized other)
- Households
- Population per household
- Employed household labor force (zone of residence)
- Employed group quarters labor force (zone of residence)
- Workers per household
- Household vehicles
- Vehicles per household
- Dormitory vehicles
- Total employment (zone of work)
- Employment by industry (ten categories)
- University enrollment
- Area type
- Area (acres)

Demographic data files are prepared for a base year (typically a decennial census year) and a long range analysis year which is specified in the federal guidelines to be at least twenty years in the future. The primary use of the base year data file is for validating the travel demand model by testing its ability to estimate actual traffic counts and observed ridership volumes given known existing socioeconomic conditions. Once the model is able to reproduce known traffic and ridership volumes, it may be applied to the future database to forecast the volume of traffic and ridership that can be expected for different scenarios of change.

Occasionally, intermediate year databases are needed for various reasons. These are produced by calculating county level households, labor force and employment and then factoring the base year zonal figures to reflect county level changes for the intermediate analysis year.

The base year for demographics is 2000 to coincide with the decennial census. The base year database was prepared for the decennial census year to take advantage of the wide range of geographically detailed and consistent information collected in the U.S. Census of Population and Housing. Although the Census is taken April 1 of the census year, processing the data into the needed products by the Census Bureau takes years so that the 2000 OKI zonal data file wasn't completed until February 2004.

The Census Bureau products used for the socioeconomic database include the SF1 block statistics for population and households and the SF3 block group statistics for employed labor force and household vehicles. Base year employment is derived primarily from ES202 (unemployment coverage) data.

OKI's long range projections for the year 2030 are based on population projections for the region's counties made by the respective state designated agencies for Ohio, Kentucky and Indiana. Each state uses a version of a cohort-component projection model which is based on the most recent census year demographic characteristics. The distribution of the population to the sub-county traffic analysis zones is done by the OKI staff with a traditional manual allocation procedure assisted by local jurisdiction planning staff. This procedure is undertaken once new projections are produced following the decennial census and when the state produced population projections are updated during the decade. The Kentucky State Data Center issued three series -- High, Middle, Low Growth -- in early August 2003; the Middle Series was utilized for the OKI work.

3.1.1 Population and household data

Base Year

Household population and households for the traffic analysis zones for year 2000 were based on block data from Census 2000. Utilizing ArcGIS, zone data was derived through the area proportion allocation of block level data. Automated zonal allocations were reviewed and manual adjustments made where necessary to more accurately reflect distribution of population and households. This review was facilitated by the superimposition of zone boundaries over aerial photography in ArcGIS.

From the household population and household totals for each zone, the population per household was calculated (household population/number of households).

A similar procedure was used to develop year 2000 group quarters populations (institutionalized, dormitory, non-institutionalized other) for each zone.

Future Year

County population projections drive the analysis year zonal projections; however, the sub-county allocation is more easily accomplished using households because households (occupied housing units) are more easily related to land use and the use of GIS-based resources. Moreover, population is more dynamic than households in respect to the number of people per household. This ratio has been dropping for several decades with the result that zones which appear to be stable in terms of households may actually be declining in population.

The projected number of households per county was developed using the "householder methodology." The principle of the householder projection methodology is that the likelihood of a person to be the head of a household (householder) varies with the different components of the population. For example, persons under the age of 16 are unlikely to be the head of a household and are generally excluded from the calculations. Similarly the ratio of householders for persons 16 to 25 is relatively low (10% - 20%) as people complete their education and remain part of their parents' households. Rates jump to 50% - 60% for persons in the 25 to 65 age groups as people leave home, marry, and establish families. Among the elderly, 65 and over, the proportion of householders increases again to 70% - 80% as people divorce, and is widowed with more people living alone.

From the respective state data centers, the 2030 county population projections provide the future five-year age cohorts. Because the number of households must be calculated using only the household population, an estimated group quartered population was removed from the target year total population in each age cohort based on the distribution of the total population in those age cohorts in Census 2000 for ages 25 and older. The dormitory population was removed from the 18-24 age cohort in Butler, Campbell and Hamilton counties. The 2000 group quartered population was chosen for consistency with the existing zonal group quartered projections, and the uncertainty in allocating changes in group quartered population at the zonal level so far in the future.

For each county, the OKI household projections for 2030 were developed by applying the Census 2000 householder rate for each age group to the projected household population. The householder rate was calculated by dividing the number of householders in each age cohort by the total household population in that same age cohort.

The manual allocation process involved a review of each zone regarding its potential for change during the forecast period. Consideration was given to the direction and magnitude of change between 1990 and 2000, the type of existing land use and that recommended in local land use plans, the amount of vacant developable land (not steep slope or flood plain), and its location in relationship to regional areas of growth and transportation accessibility. Based on these considerations, a portion of the county's household growth was allocated to the zone.

Once households were allocated to the zones, the population for each zone was calculated. This was achieved by applying a factor to the year 2000 population per household in each zone and multiplying that adjusted population per household by the zone's number of households. The applied factor resulted in the sum of the zonal populations equaling the county control total.

See Table 3.1.1 and Table 3.1.2 for a summary of population and household by county.

Table 3.1.1 – Household Summary

	2000	2010	2020	2030
Butler	123,082	139,823	156,185	170,523
Clermont	66,013	78,409	89,434	98,140
Hamilton	346,790	340,413	333,390	320,254
Warren	55,966	77,886	102,326	126,716
Boone	31,258	43,662	59,696	79,886
Campbell	34,742	37,394	39,464	40,650
Kenton	59,444	64,735	69,776	70,313
Dearborn	16,832	19,694	21,653	22,879
OKI Region	734,127	802,017	871,925	929,361

Table 3.1.2 – Population Summary

	2000	2010	2020	2030
Butler	332,807	367,660	403,860	439,740
Clermont	177,977	202,830	225,340	245,000
Hamilton	845,303	807,560	771,540	730,570
Warren	158,383	215,020	276,250	338,350
Boone	85,991	116,181	154,885	204,591
Campbell	88,616	92,315	94,962	95,862
Kenton	151,464	158,304	163,311	165,443
Dearborn	46,109	50,855	53,305	54,339
OKI Region	1,886,650	2,010,725	2,143,453	2,273,895

3.1.2 Labor force and vehicle data

Base Year

The OKI travel demand model uses zonal labor force (workers by place of residence) for determining a portion of the trips generated by a given zone that will be using the transportation network.

The OKI labor force is a function of the population as determined by a labor force participation rate (the number of employed persons aged 16 and older). The household labor force in a zone was derived from a ratio of employed labor force, including armed forces, calculated for the corresponding census block groups. (Unemployed members of the labor force are excluded as they are not making work trips). The ratio was calculated by dividing the employed labor force by the total population in each block group.

The assignment of census block group labor force ratio for each zone was accomplished using ArcGIS. The employed labor force ratio in the block group which occupied the greatest area of each zone was assigned to that zone.

The zone's labor force ratio was then multiplied by the household population in the zone to determine the labor force in that zone.

The labor force among non-institutionalized group quarters residents was developed using the same ratio applied to the household population. Since all employed persons were included in the calculation of the ratio, the non-institutionalized population carried some weight in the determination of the labor force ratio. The dormitory and non-institutionalized populations were totaled and then that sum was multiplied by the labor force ratio in each zone.

The model also uses the number of automobiles per household in a zone to apportion trips for several purposes to an appropriate mode of travel. The number of vehicles in a zone is derived from a ratio of vehicles per household calculated for the corresponding census block groups. The census data used is the housing table for occupied housing units by number of vehicles (vehicles include automobiles, vans, and trucks of one ton capacity or less kept at home for use by household members). The table reports occupied housing units with 0 vehicles, 1, 2, 3, 4, and 5 or more vehicles. For each block group, the number of households was multiplied by the corresponding number of vehicles (5.1 for 5 or more) to estimate the total number of vehicles available in that block group. The vehicles were then divided by the number of households to get a ratio of "autos" per household for the block group. That value was assigned to zones based on which block group occupied the greatest area of each zone. This factor, applied to the zonal households, provided an estimate of the number of vehicles available for the zone.

The number of dormitory vehicles was determined by contacting area universities with dormitory populations for counts.

Future Year

For the future year, the OKI labor force is a function of the population as determined by a labor force participation ratio (the number of persons in the labor force per persons 16 years and over). For OKI's purpose, unemployed members of the labor force are subtracted as they would not be making work trips. Therefore, the labor force figure represents employed labor force, or the number of workers living in a given zone. The 2030 labor force projections are based on the 2030 county population projections by age and sex and projections of age and sex specific labor force participation rates for the year 2030 by the U.S. Bureau of Labor Statistics.

For horizon year 2030, the year 2000 vehicles per household were retained. According to the National Household Travel Survey conducted in 2001/2002, the number of vehicles per household now exceeds the number of licensed drivers. Therefore, any inflation of the vehicles per household figure would produce inflated trips in the model.

The year 2000 dormitory vehicle counts were retained for 2030.

See Table 3.1.3 and Table 3.1.4 for a summary of labor force and vehicle by county.

Table 3.1.3 – Labor Force Summary

	2000	2010	2020	2030
Butler	163,681	191,729	205,515	222,966
Clermont	90,035	111,423	121,035	130,905
Hamilton	405,418	416,175	391,091	374,738
Warren	77,837	116,045	148,853	180,705
Boone	45,338	69,466	92,262	121,788
Campbell	43,430	48,967	49,459	50,055
Kenton	77,273	88,170	88,670	90,466
Dearborn	23,119	27,038	27,454	27,564
OKI Region	**926,131**	**1,069,013**	**1,124,339**	**1,199,188**

Table 3.1.4 – Vehicles Summary

	2000	2010	2020	2030
Butler	231,453	266,446	300,690	330,830
Clermont	131,758	156,312	178,127	195,347
Hamilton	551,528	544,742	537,248	518,668
Warren	114,501	161,295	213,427	265,451
Boone	60,769	88,417	123,981	168,845
Campbell	58,823	64,131	68,357	70,869
Kenton	101,266	111,951	122,119	123,291
Dearborn	34,985	41,036	45,262	47,845
OKI Region	**1,285,083**	**1,434,331**	**1,589,211**	**1,721,147**

3.1.3 Employment

Base Year

Employment is prepared by zone of work to determine the number of work trip attractions for each zone. For base year 2000, employment was derived primarily from ES202 (unemployment coverage) data provided by the Ohio Department of Transportation and Kentucky Transportation Cabinet. Individual business records containing physical location, number of employees and SIC code were geocoded through ArcGIS and aggregated to zones. ES202 employment which could not be linked to a physical location was distributed proportionally by industry across all zones in a county. This data set was supplemented by other sources, including information directly from employers, Census Transportation Planning Package zonal estimates of employment, and published employment data, to complete the employment picture in the OKI region. Each zone's employment was divided according to the SIC code into ten industries (agriculture, construction, FIRE, manufacturing, mining, public, retail service, transportation and wholesale).

Individual record ES202 data were not available for Dearborn County at the time the work was undertaken. A data set was purchased from InfoUSA containing a list of all businesses in Dearborn County, with SIC codes, number of employees and latitude/longitude coordinates. The data were imported into ArcGIS where they were converted into point data and aggregated to TAZs.

Future Year

The first step in the future year distribution of employment by zone of work is to calculate a regional employment control total for the analysis year. The projected number of workers in the region is defined as the projected resident employed labor force (previously determined) minus those workers projected to commute out of the region to work, plus workers projected to commute into the region to work from outside. For decades, there has been a net gain of workers from external commuting for the OKI region. Furthermore, in 2002, the U.S. Office of Management and Budget expanded the Cincinnati CBSA by two counties based on the number of workers commuting into the region to work. The projected gain from net commuting is determined from historical trends.

The second step for the employment projections is to allocate the regional control total among the eight counties. The county distribution of employment by place of work is independent of the place of residence of the labor force. While all eight counties have continued to experience employment growth, the distribution of that growth has changed as employers and services have followed population to the suburbs. Also, structural changes in the regional economy from manufacturing to services have resulted in declining employment in some of the older urban manufacturing centers. Historic trends of county employment and their percent share of the regional total are projected to the analysis year and controlled to the regional control total.

The third step is to allocate the projected change in county employment among the component zones. The procedure and resources used are similar to those described previously for allocating households. As a rule, employment is not lowered for a zone unless the staff is aware of changes that have occurred causing a loss of employment since the last projections or that will occur before the analysis year. Once the projected increment of growth has been distributed for the county, the zones are summed and adjusted so that the county control total is obtained.

The distribution of future year employment by industry type was adjusted to reflect anticipated broad shifts in economic conditions. Existing (year 2000) and projected (year 2025) distribution of employment by industry type for each county is available from Woods & Poole Economics. A factor based on the directional change for each industry for each county as indicated in the Woods & Poole data was applied to the year 2000 distribution of employment to create the year 2030 zonal distribution by type.

See Table 3.1.5 for a summary of employment by county.

Table 3.1.5 – Employment Summary

	2000	2010	2020	2030
Butler	134,879	156,702	172,186	191,260
Clermont	53,021	62,901	72,132	81,968
Hamilton	565,124	603,633	610,794	624,699
Warren	66,469	77,247	86,093	95,630
Boone	72,957	86,076	95,400	108,049
Campbell	26,609	30,899	32,576	36,016
Kenton	60,015	69,523	75,622	84,452
Dearborn	15,207	16,553	18,615	19,871
OKI Region	**994,281**	**1,103,533**	**1,163,418**	**1,241,946**

3.1.4 Special Generators

Current and Future Year

College and university enrollment is examined to account for the special trip making characteristics of students. There are several major recreational facilities in the region such as Paramount's Kings Island, US Bank Arena, and the Argosy Casino in southeastern Indiana, for which add-on factors are used based on event attendance. In 2002, the OKI staff reviewed these listings and contacted the respective sources to obtain the necessary figures.

The future characteristics of special generator activities, including universities, recreational centers, and airport operations, are held constant to the year 2000 counts.

3.1.5 Area Type

Current and Future Year

Each zone is assigned an area type designation as CBD, Urban, Suburban or Rural. This designation was established during the 1978 update of the regional transportation plan to determine and stratify trip generation rates for home-based work and home-based other trips using the survey data collected. Since that time the urban boundary has moved outward from the center of the region. The area type designations have been modified through the use of the 2000 demographic database and staff knowledge of the area. The goal was to group traffic zones based on general trip making patterns using quantifiable measures if possible. The criteria for each of the four area types, primarily based on population and employment densities, are as follows.

CBD:
CBD area type is the same as was used in the 1978 model. CBD areas will remain as determined at that time. Zones 252-295 are classified as CBD. This represents the Cincinnati CBD.

Urban:
1) within the City of Cincinnati or
2) population per acre. 10 or
3) population per acre. 6 and employment per acre. 2.5 or
4) employment per acre. 10
<u>and</u>
5) zones are in or adjacent to the CBD's of Covington, Newport, Hamilton, or Middletown.

Zones meeting any of these criteria were designated urban.

Suburban zones are zones not meeting the criteria for urban but have population densities. 1.56 persons per acre. In some cases pockets of "suburbanization" have developed outside the primary central urban boundary or those of Hamilton or Middletown. Where two or more contiguous zones meeting urban criteria occur, the zones are designated suburban.

Rural zones are those which do not meet the criteria for CBD, urban or suburban as described above.

Where a zone which is surrounded by zones of a certain area type but do not meet criteria of the surrounding zones, the zone may be designated the same as the surrounding zones for reasons of homogeneity.

Revisions to the zonal area type classifications of suburban and rural are made once the analysis year residential and employment projections are complete. A zonal change from one classification to another is based on the analysis year demographics.

Separate designations for year 2000 and 2030 are made.

3.1.6 Area Acreage

Base and Future Years

The area, in acres, of each zone was determined by utilization of the area measurement feature in ArcGIS. This measurement is carried over through all future years.

3.1.7 Local Review

Once the staff has completed the previously described work for the population, household and employment allocations and projections, each county's figures are provided to the planning commission staffs of the counties and major cities for review. This is an important step as the local planning staffs have a better awareness of potential growth locations and conditions which may have changed since the last comprehensive plan update. Revisions to the distributions are welcomed, however the county control totals for population, households and employment must be maintained. Consequently, increases allocated to some zones must be balanced by compensating reductions to others. Once the local review adjustments have been incorporated into the forecasted database, and control totals are attained, it may be used for planning purposes.

Once this version of the socioeconomic database was completed, the data in the Excel spreadsheet was converted into a database file and modified for use by the travel demand model. The ten industry types were converted into high, medium and low trip generation categories as follows:

Trip Generation	Industry Type
High	Retail
Medium	FIRE
	Public
	Services
	Wholesale
Low	Manufacturing
	Transportation
	Agriculture
	Construction
	Mining

For truck model, the ten industry types were converted into four groups as follows:

Tuck Model Group	Industry Type
RET	Retail
OFF	FIRE
	Public
	Services
MFG	Wholesale
	Manufacturing
	Transportation
AMC	Agriculture
	Construction
	Mining

3.1.8 Maps of zonal social economic data and projected growth

Following thematic maps depict year 2000 zonal population, employment, household, automobile ownership, labor force and their projected growths from year 2000 to year 2010, and from year 2000 to year 2030. It seems that all the growth maps from 2000 to 2010 show the suburbanization trends: declining in urban core, and flourishing in fringe areas. The growth maps from 2000 to 2030 demonstrate that the trend intensified.

Figure 3.1.1 Year 2000 Zonal Total Population

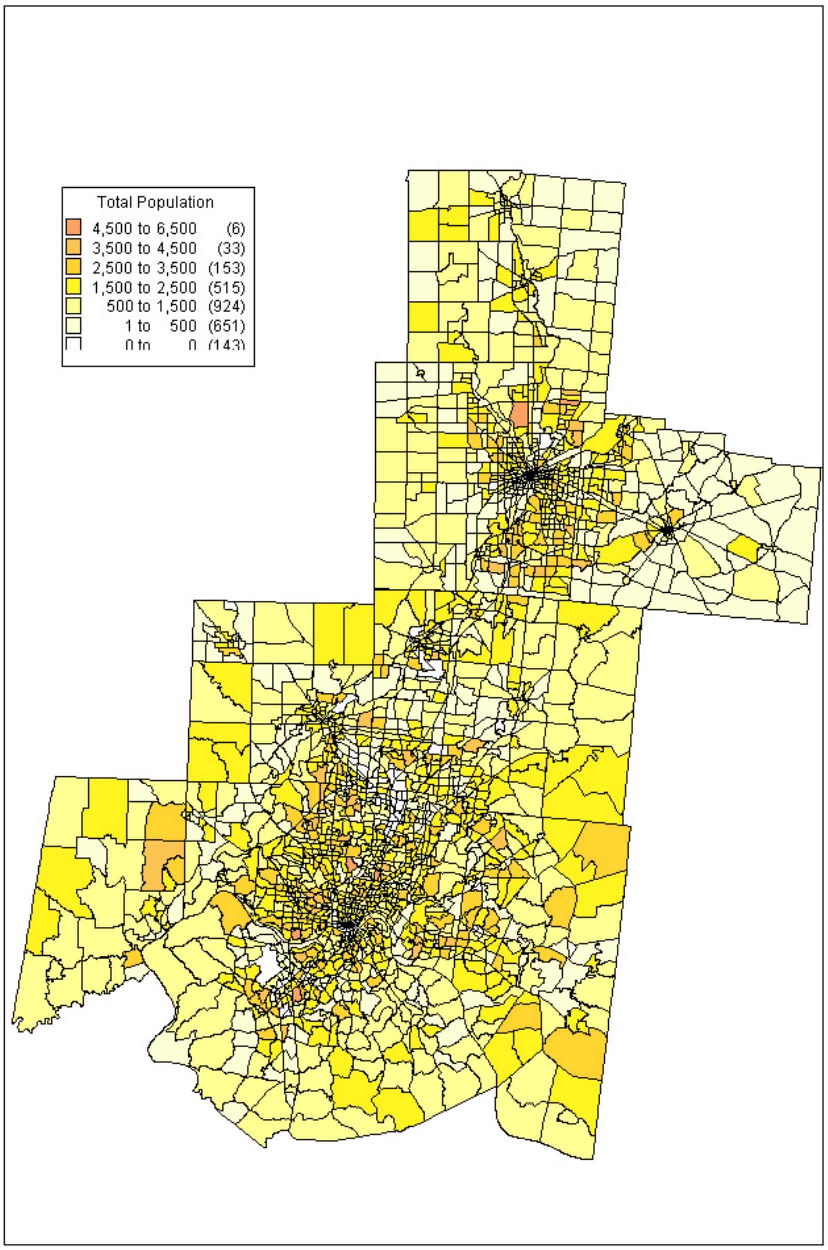


Figure 3.1.2 Year 2000 Zonal Total Employment

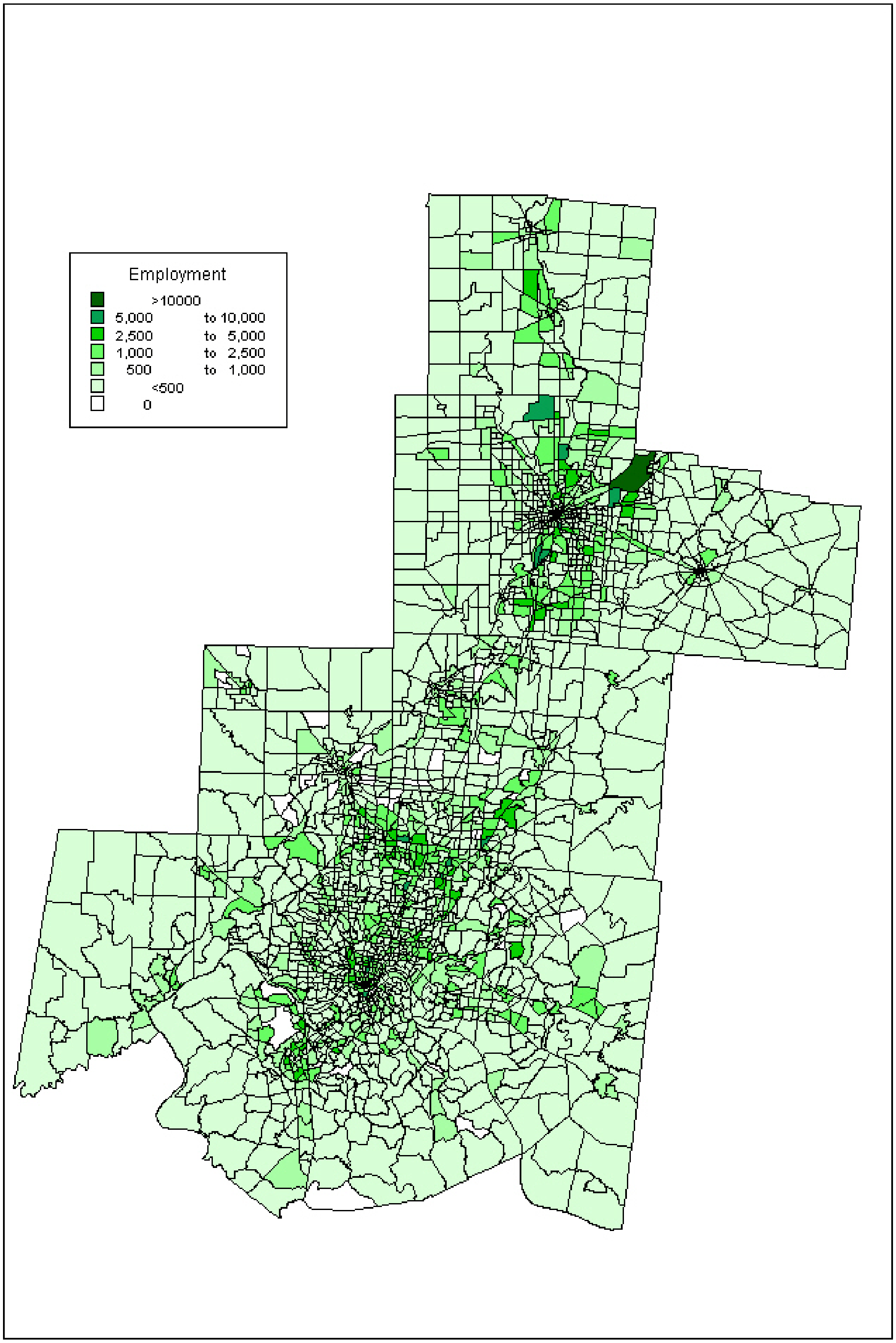


Figure 3.1.3 Year 2000 Zonal Total Households

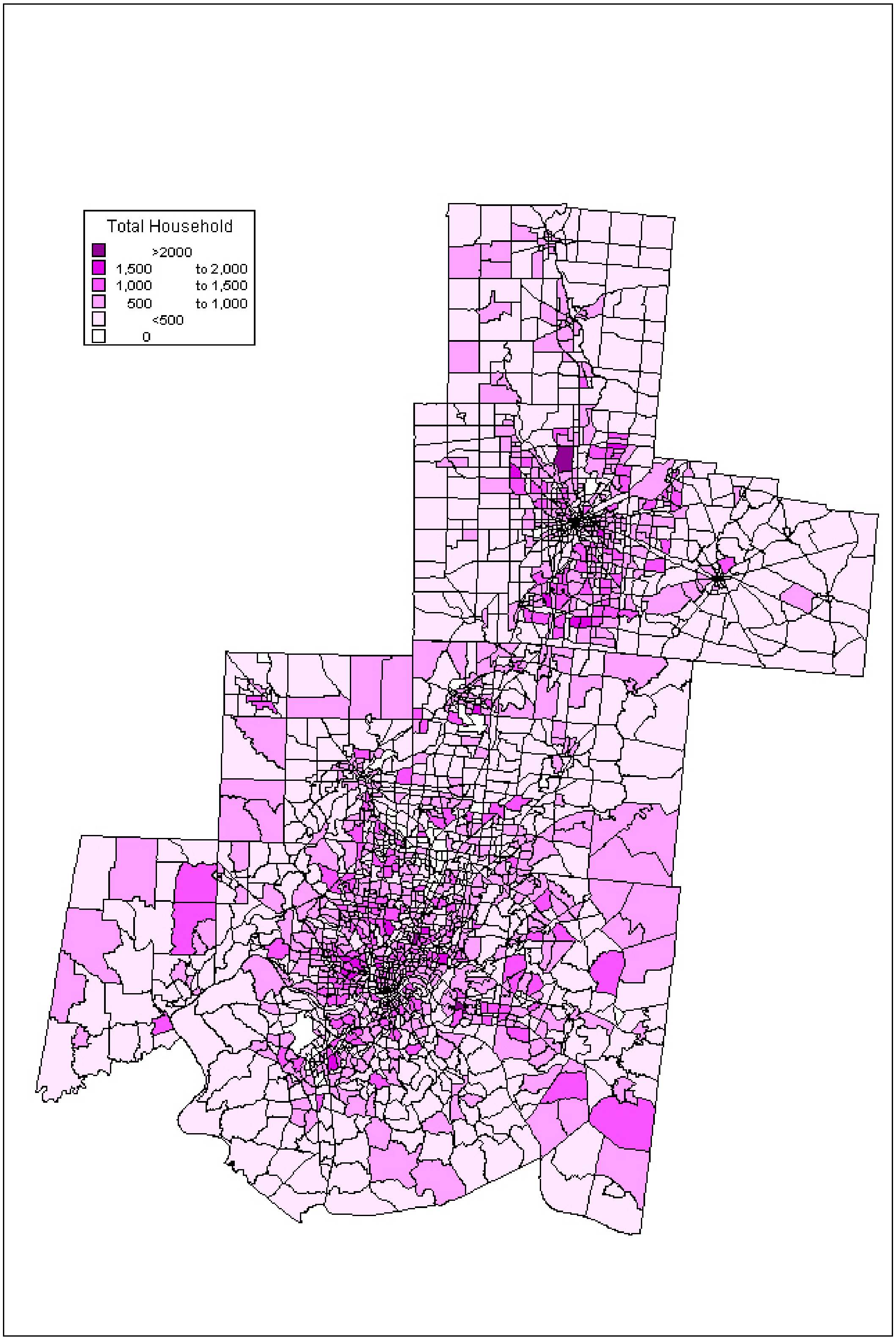


Figure 3.1.4 Year 2000 Total Automobile Ownership

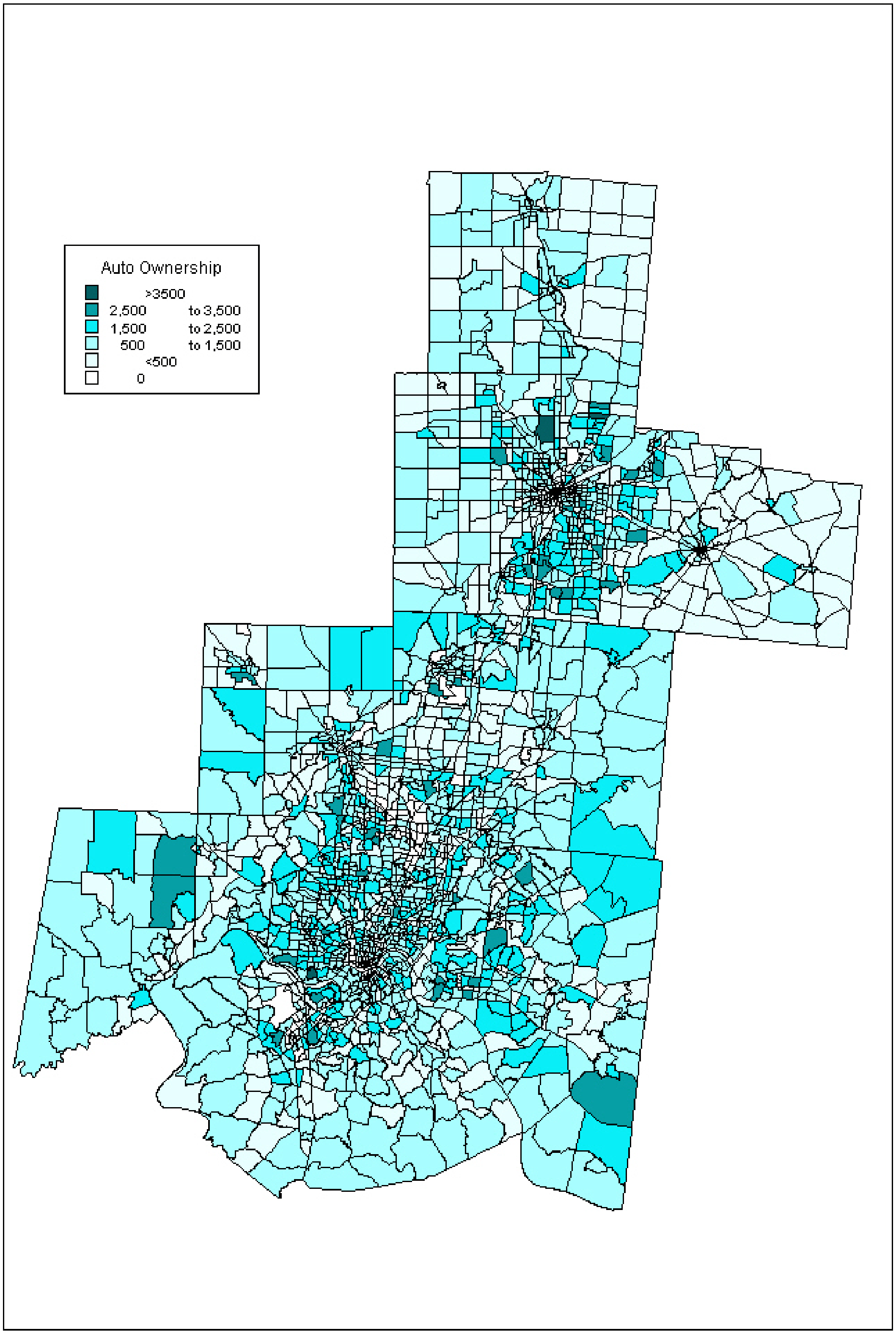


Figure 3.1.5 Year 2000 Zonal Labor Force

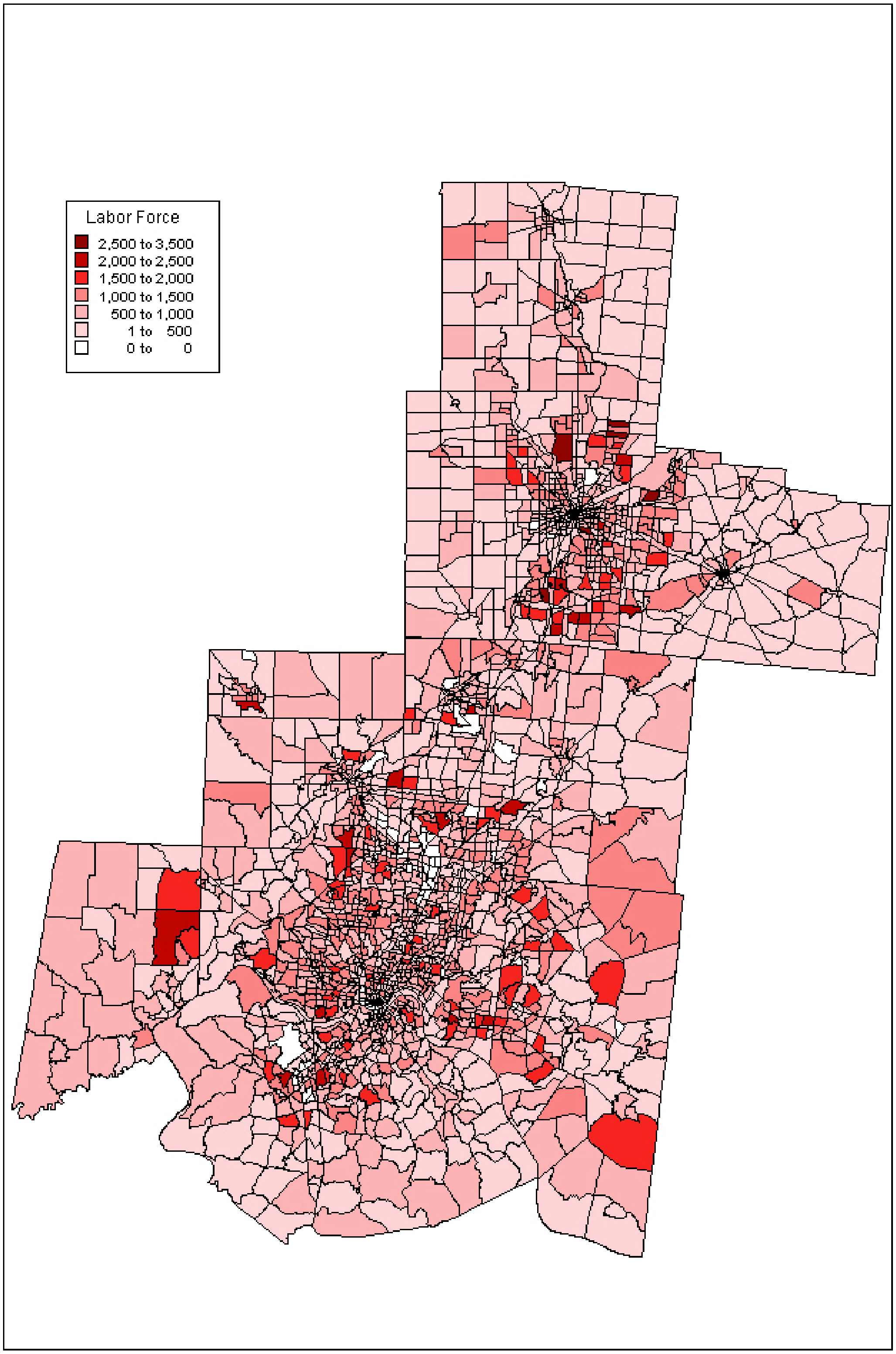


Figure 3.1.6 Year 2000 – 2010 Population Growth in Percentage

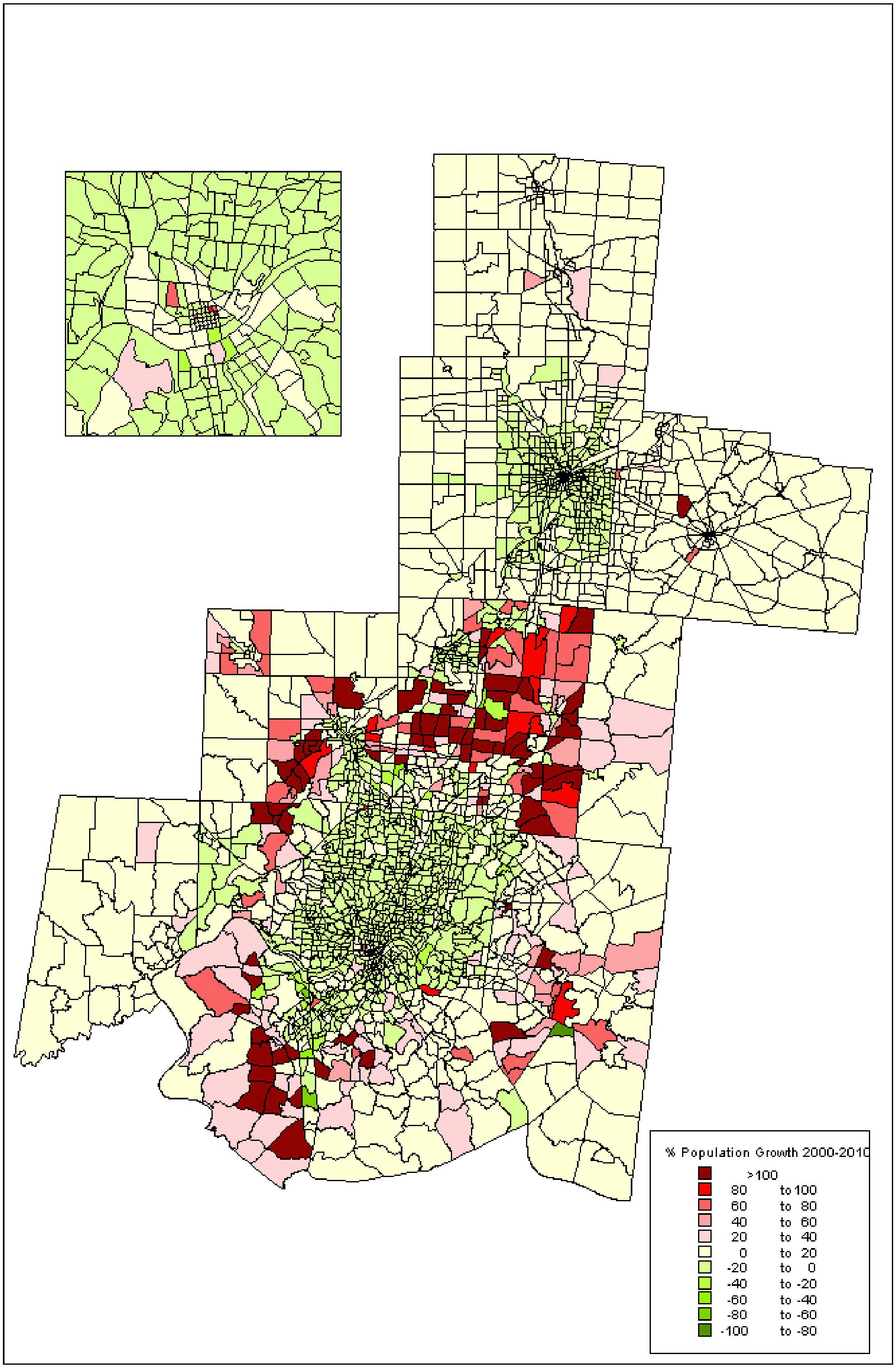


Figure 3.1.7 Year 2000 - 2030 Population Growth in Percentage

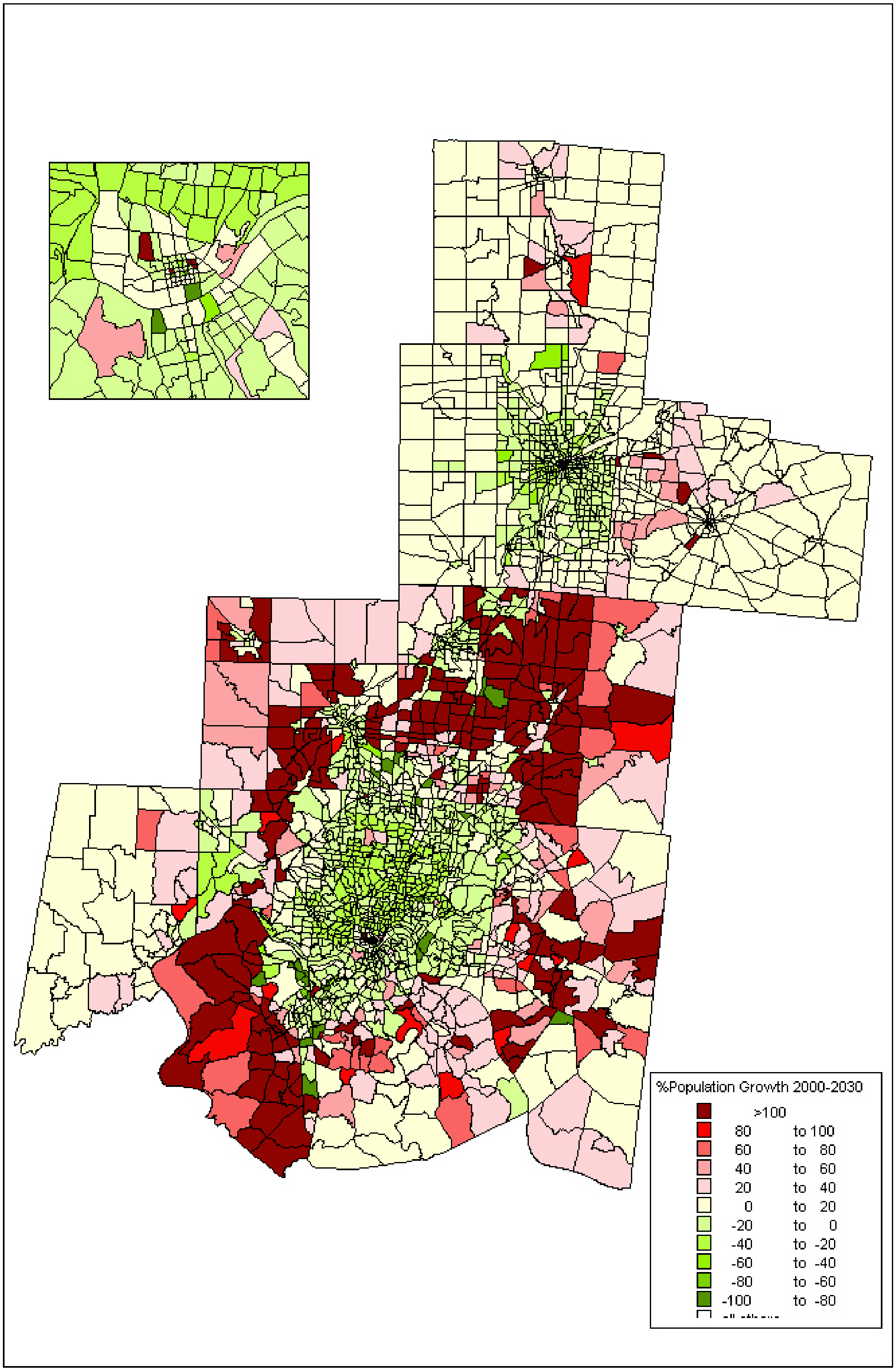


Figure 3.1.8 Year 2000 – 2010 Employment Growth in Percentage

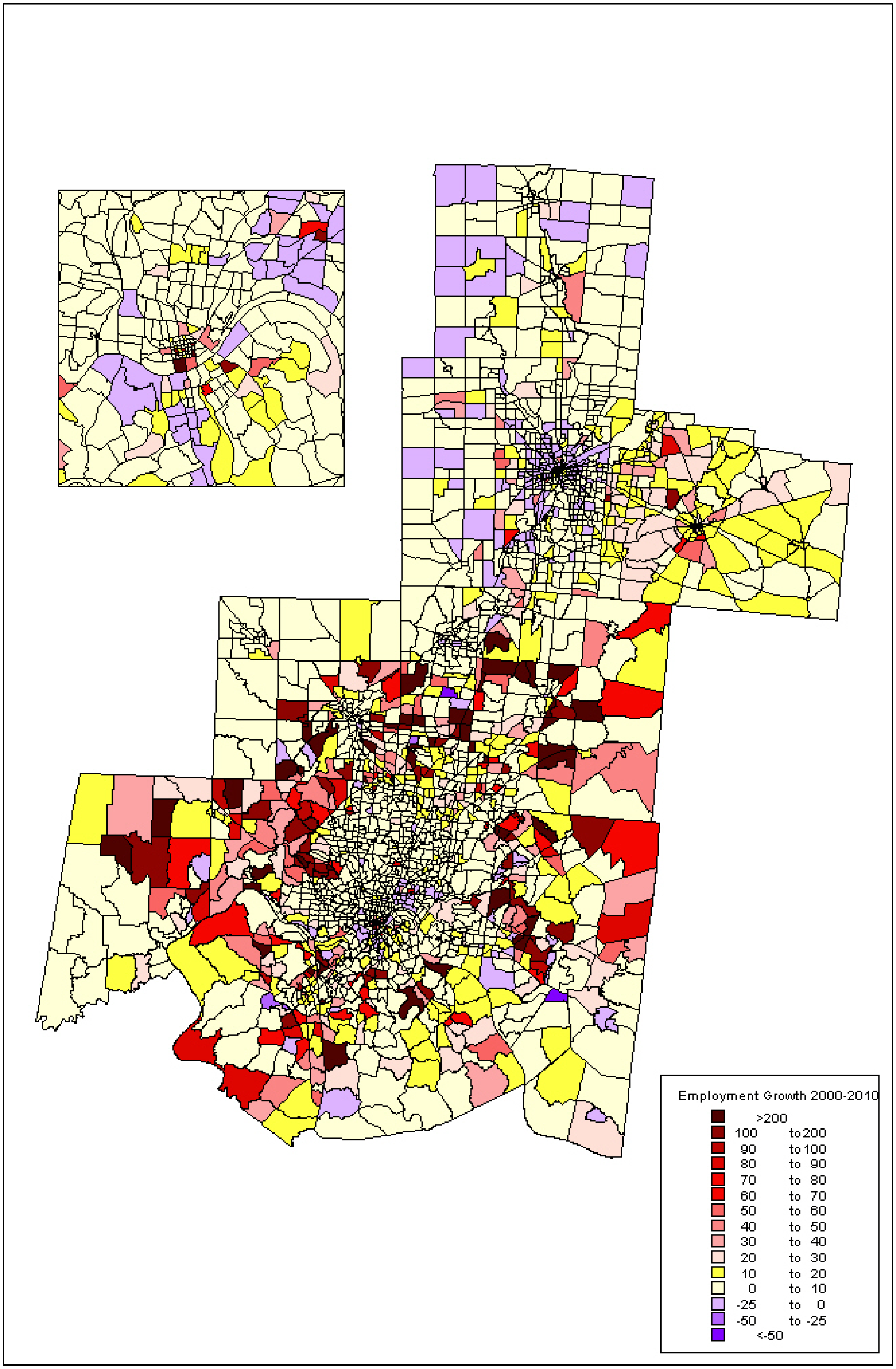


Figure 3.1.9 Year 2000 – 2030 Employment Growth in Percentage

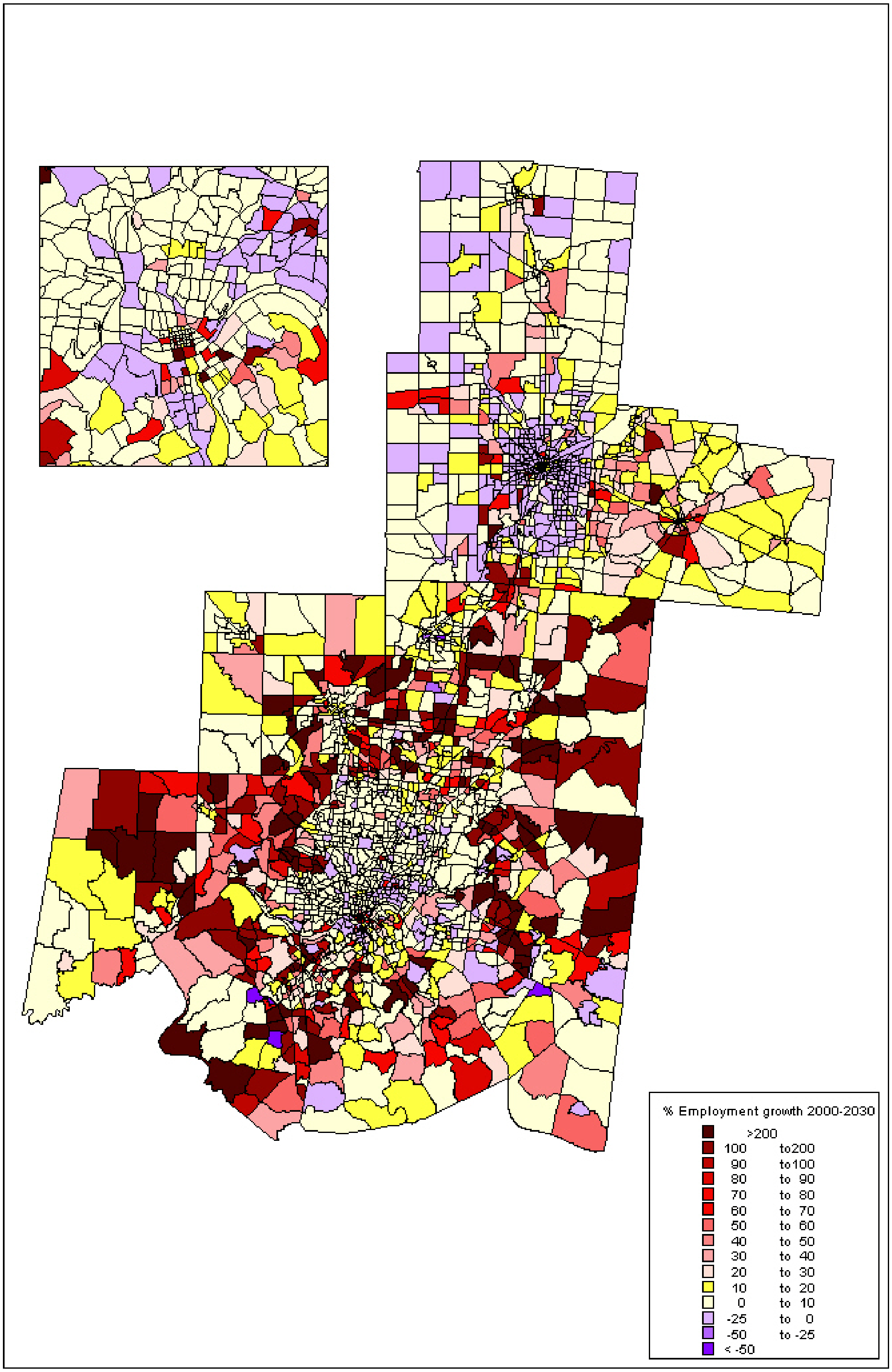


Figure 3.1.10 Year 2000 – 2010 Household growth in percentage

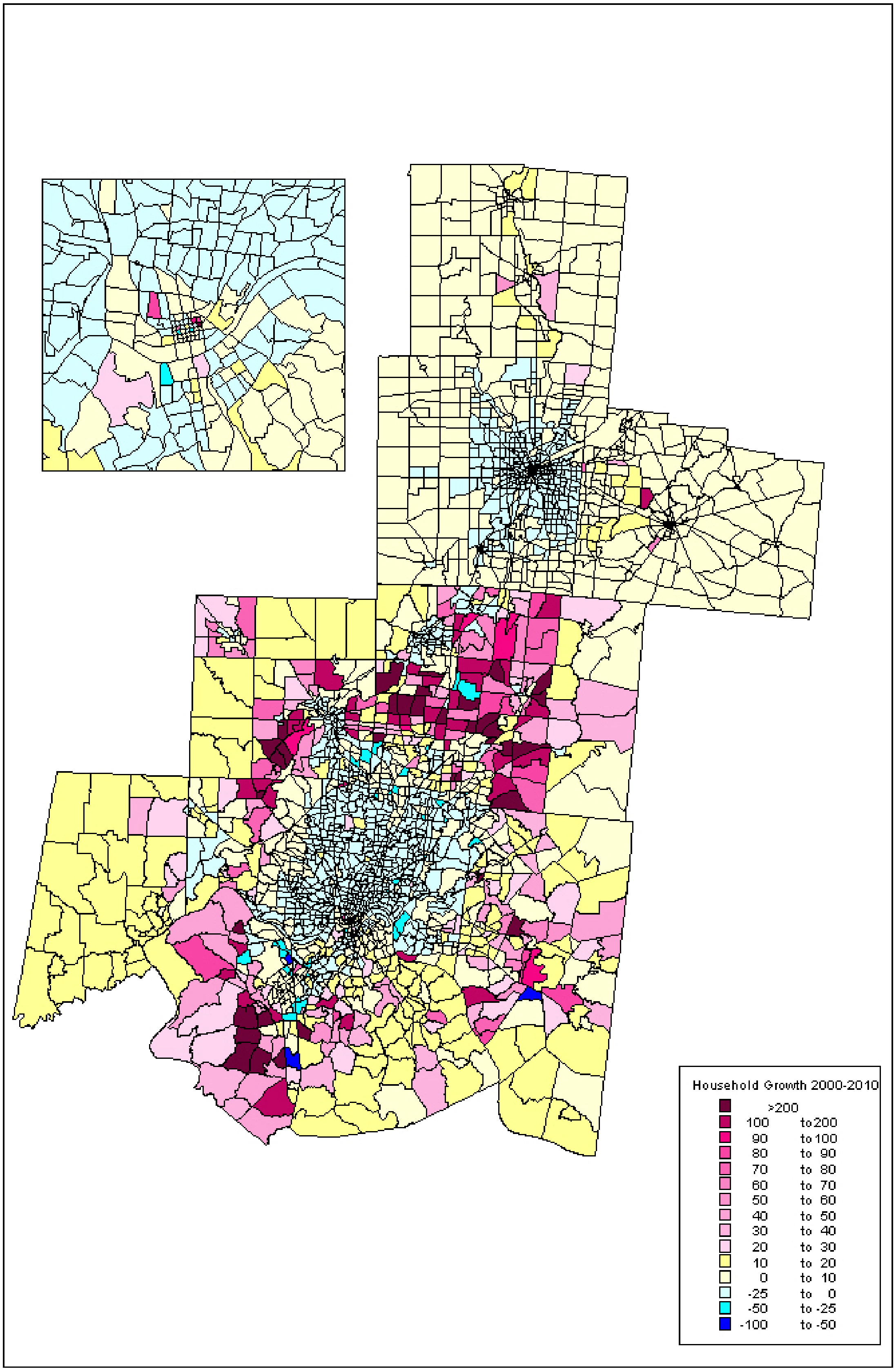


Figure 3.1.11 Year 2000 – 2030 household growth in percentage

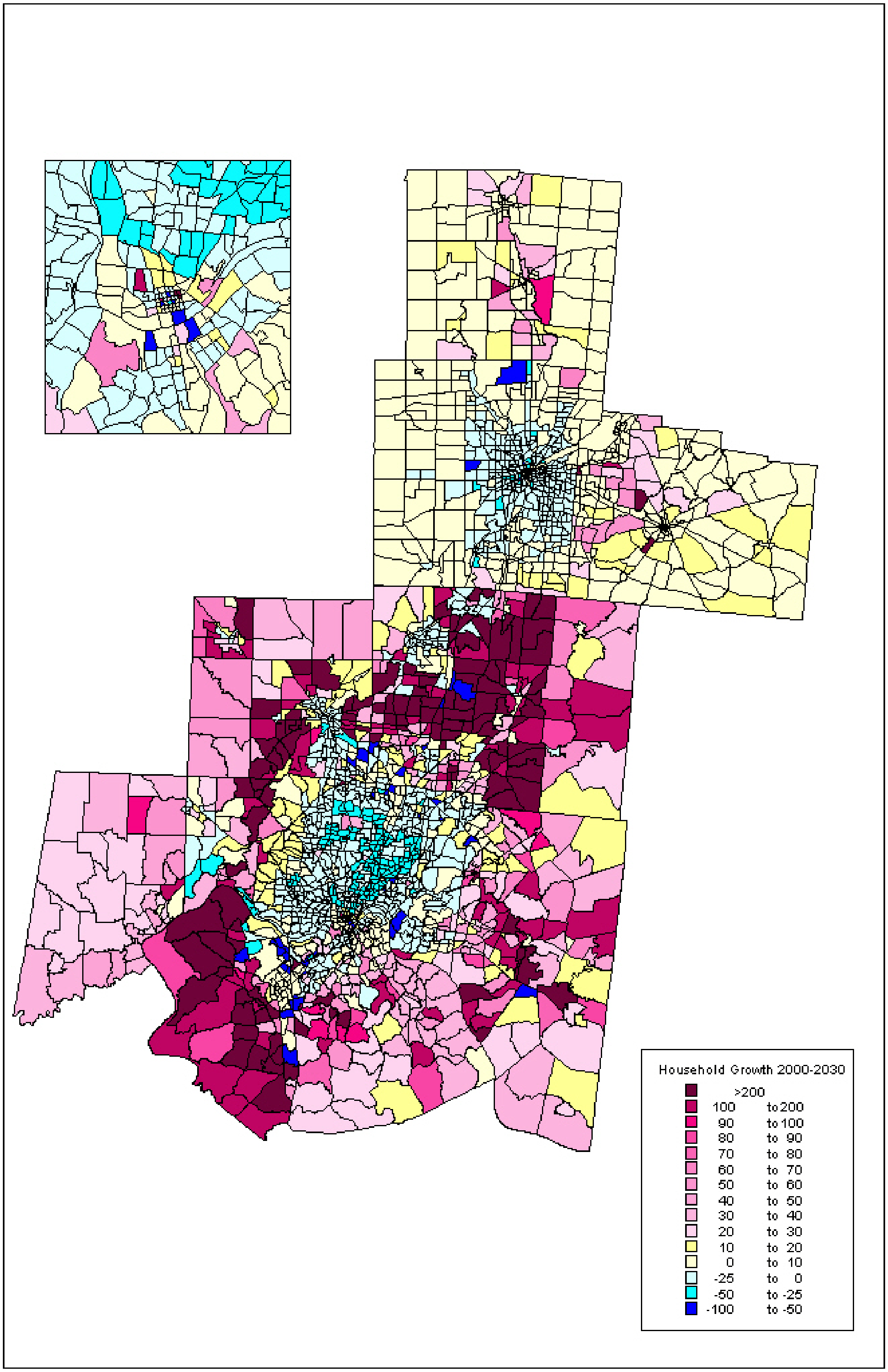


Figure 3.1.12 Year 2000 - 2010 Automobile ownership growth in percentage

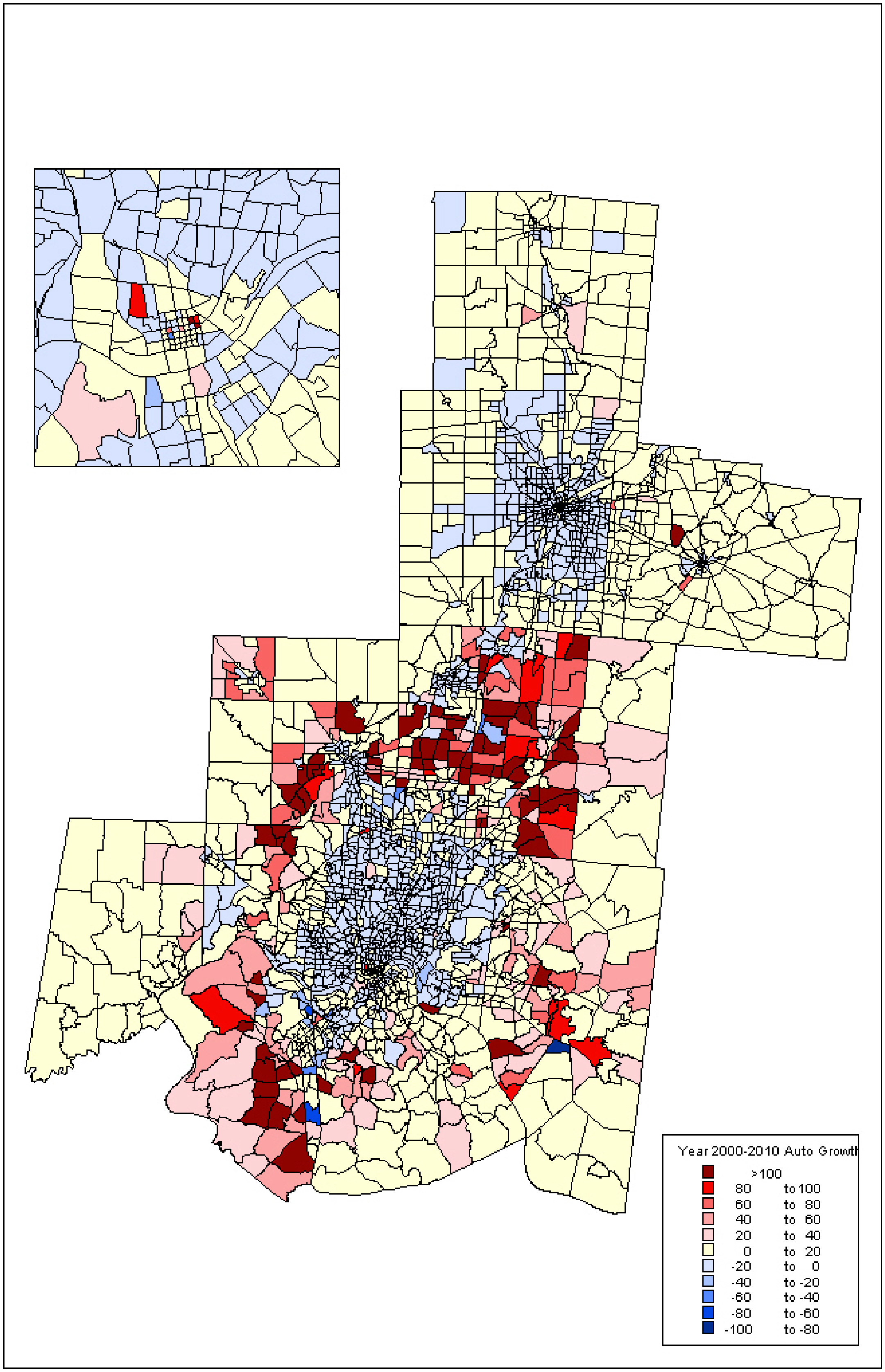
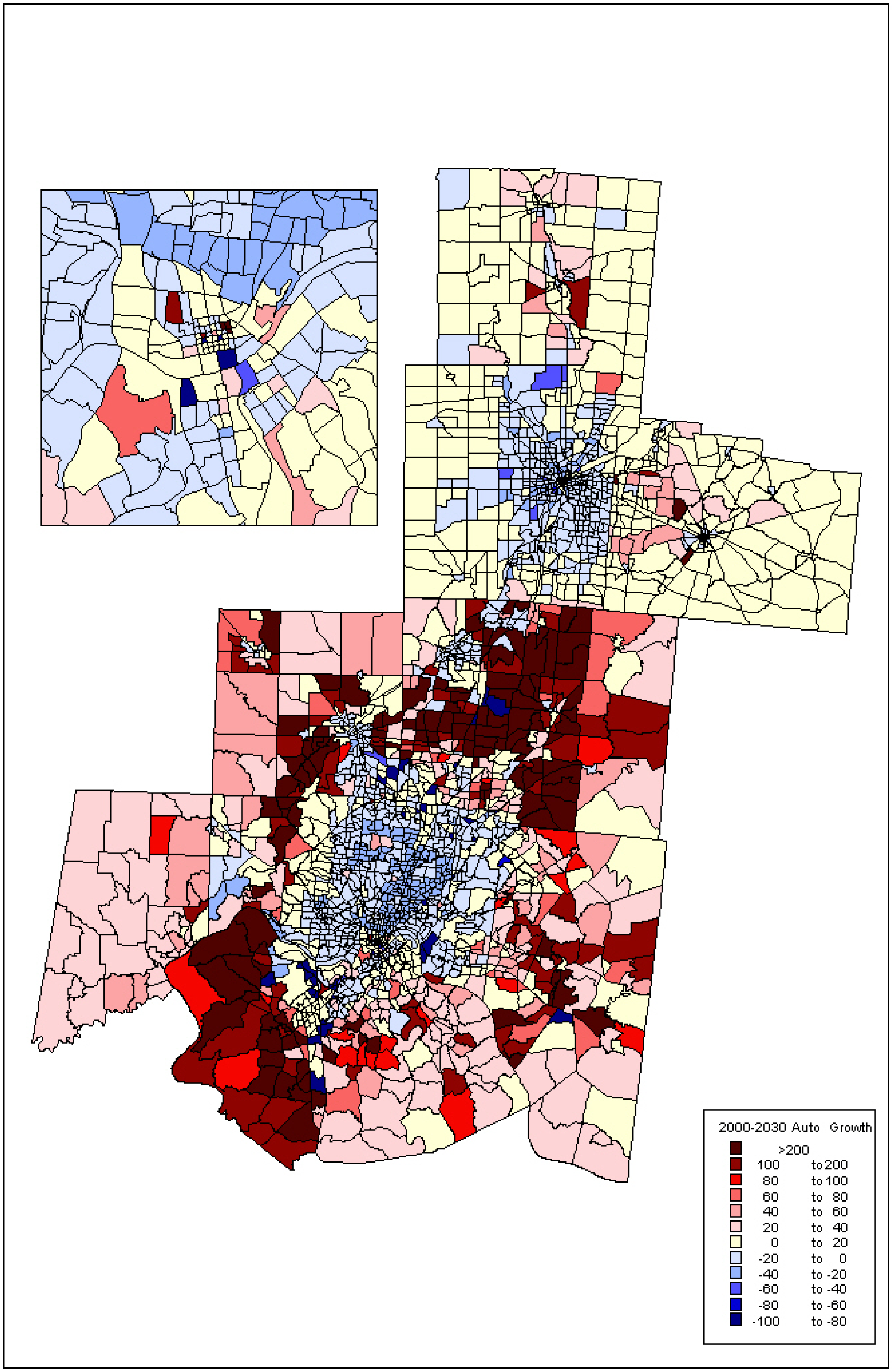


Figure 3.1.13 Year 2000 – 2030 Automobile Ownership Growth in Percentage



3.2 Development of Highway Network Data

3.2.1 Procedure/Process

A vital input in the travel demand model is a highway network. The network is an abstraction of the actual roadway system, and it is comprised of links and nodes with attributes describing the roadway characteristics such as lanes, functional classification, distance, speed, capacity, etc. The highway network of the OKI/MVRPC model has over 14,000 nodes, and over 19, 000 one way or two-way links, and is in PLANPAC ASCII format, and can be easily converted to GIS format for presentation and editing using an OKI developed program.

Networks by Time of Day

Five highway networks are developed for the model to represent different conditions: daily off-peak, daily peak, AM peak period, Midday period and PM peak period (Table 3.2.1). These networks have different usages. The daily peak and daily off-peak networks are used to skim travel times and distances for the trip distribution and modal choice phases first, then, the AM peak period network is used for trip assignment in the initial loop and for from distribution to assignment in feedback loops. The Midday period and PM peak period networks are applied together with the AM peak period network for the time of day trip assignments. The Midday period network is also used for night period trip assignment. The speeds coded for all network are free-flow speed except the daily peak network. The loaded speeds for the daily peak network are calculated using speed-volume relationship equations with traffic counts coded. For the links without a count, ratio loaded speeds are coded. The capacities coded represent the number of the lanes for the time period. For the daily off-peak network, the "number of lanes" represents midday conditions and for the daily peak network the "number of lanes" represents the higher of AM peak or PM peak periods.

Table 3.2.1 – Highway Networks by Time Periods

NAME	SPEEDS	CAPACITY	NUMBER OF LANES	USED BY
Daily Off-Peak	Free-flow	Hourly	Off peak traffic	Trip Distribution, INET, Mode Choice (all loops)
Daily Peak	Loaded speeds	Hourly	Heaviest traffic period of the day	Trip Distribution, INET, Mode Choice (initial loop)
AM Peak Period	Free-flow	Hourly	AM Peak period	Trip Distribution, INET, Mode Choice (feedback loops) Highway Assignment (all loops)
Midday Period (assignment only)	Free-flow	Hourly	Midday period	Highway Assignment (final loop)
PM Peak Period (assignment only)	Free-flow	Hourly	PM Peak period	Highway Assignment (final loop)

Base year network and future year networks

For travel demand model calibration and validation, the model needs a base year highway network to replicate current condition. The calibrated and validated model is then used with future analysis year networks and estimates of future socioeconomic data to predict future traffic. So it is important to update the base year network and keep it current as possible, and also necessary to code and update traffic counts for validation.

The current base year network is coded to represent year 2000 highway conditions. In recent updating process, all the network attributes were checked using GIS technology. Sets of criteria were established to flag out the “out of bounds” values for each attribute first, then, thematic maps were created showing attributes with colored “out of bounds” values for checking and editing. Maps in section 3.2.5 show the updated highway network attributes. In addition to the link data, the network alignments also were checked, updated, errors were corrected based on GIS street maps, aerial photos, and field surveys.

Traffic counts on the base year network are used for peak speed calculation at initial loop of model run, and also used for model validation as observed data comparing with model assigned volumes. The traffic counts were updated recently. The counts on the base year network represent 2000 volumes even though that include 1998, 1999 and 2001 counts and estimations. More details about traffic counts will be discussed at Chapter 4.

3.2.1.1 Roadways Included in the Network

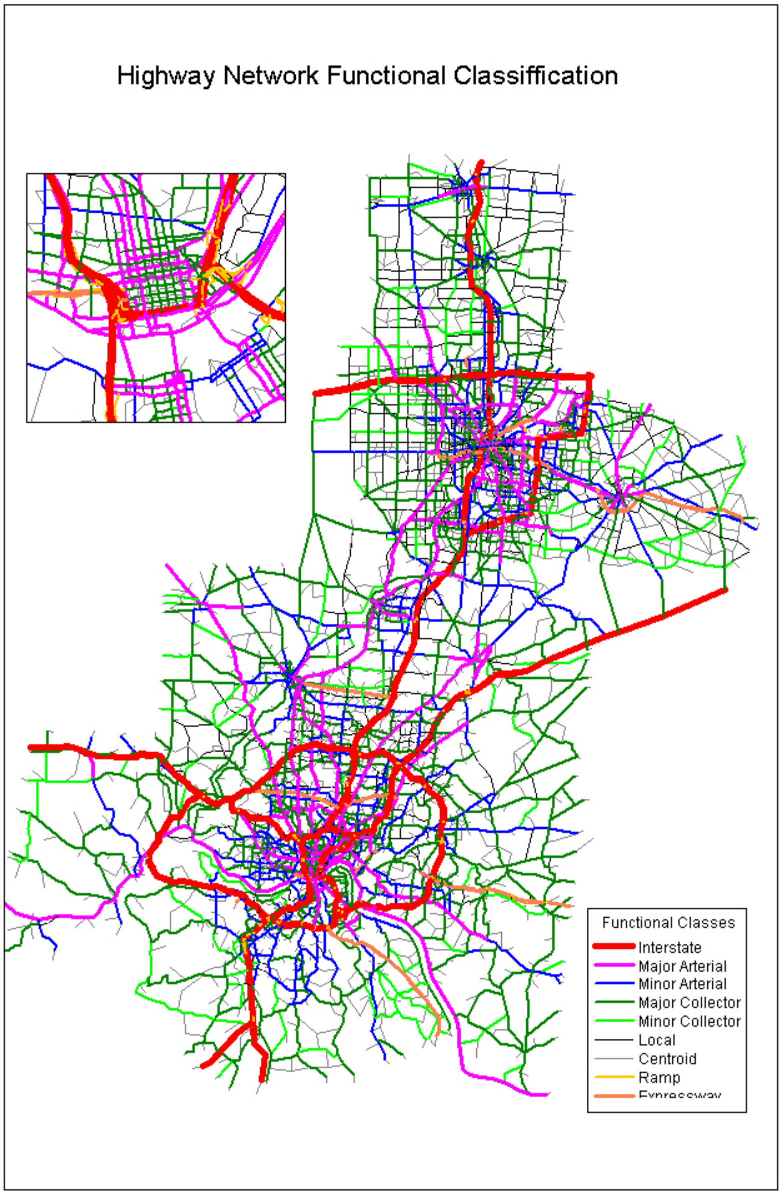
The complexity of the network is determined by the aim of the analysis and limitation of the computer and software development. The network should be designed to be detailed enough to get good modeling results yet simplified enough to remain manageable. For travel demand modeling at the regional level of detail, only roadways with regional importance are on the highway network. The current highway functional classification system is used to determine the roadways of regional importance that should be included in the network. At early days, the network is quite simplified, now become more and more detailed, and more and more match with the actual roadway alignments due to the requirements for better modeling results, and due to the development of computer and software technology.

All roadways classified as collector or higher are included in the highway network. The functional classes coded on the highway network are:

- Interstates
- Expressway
- Major Arterial
- Minor Arterial
- Major Collector
- Minor Collector
- Local road
- Centroid Connector
- Ramp

Figure 3.2.1 shows the functional classification of 2000 highway network. Not all the local roads are in the network. Some local roads are in the highway network because they carry significant amount of traffic and have impacts on trip assignments, and others are included to maintain an appropriate traffic zone to highway network compatibility for small zones. A few more local roads were added recently to support transit lines because transit network is built using highway links and nodes. Centroid connector is for loading the trips to the network, and usually represents several, not only one local road.

Figure 3.2.1 – Functional Classification of OKI/MVRPC Highway Network



3.2.1.2 Operational Characteristics of the Highway Network

Highway network link attributes describe roadway physical and operational characteristics. Speed, capacity and distance are critical attributes to the travel demand forecasting model. The speeds and distances are used to determine the minimum time paths and the travel time between traffic zones that, in turn are used to determine the trip destination, mode of transportation and route used. The capacities are used to determine the degree of congestion and to adjust the coded speeds to reflect the travel speeds under various congestion levels. The capacities are also used to determine the level of service on the roads, to identify the capacity deficiencies and thus to identify the improvement needs for roads.

The network links representing roadways need to be grouped by their characteristics for average speed and per-lane capacity calculation. The network uses “facility class” and “Speed-capacity code” to categorize links, and all the links were assigned into facility class, which consists of freeway, expressway, major road, minor road, ramp and centroid connector. Then, each facility class is further divided into several sub groups based on density of intersections, control conditions at intersections, lane width, pavement width, grade, curvature, truck/bus traffic, curb parking, one or two way roadway, divided or undivided roadway and the activity intensity adjacent the link. Each sub group has a speed-capacity code. The speed and capacity calculation are based on “Highway Capacity Manual”(HCM) using Level of Service (LOS) E standards, and the details of calculation are in OKI technical memorandum “Development of Classified Speed / Capacity Table and Speed-Volume Relationships”(OKI technical Memorandum), October 2001.

3.2.1.2.1 Speed and Capacity Derivations

Table 3.2.2 is a classified speed/capacity table listing the calculated free-flow speeds and per lane capacities, and on table, following road type description, first number in parentheses is facility class code, and second number is speed capacity code. The following sections will discuss more about the variables

Since the roadway groups are defined based on average conditions, and some roadways have certain conditions that may warrant a higher or lower speed and capacity than the average. A discount factor is introduced to increase or decrease speed and capacity because of special circumstances for a particular link. However, the usage of the discount factors should have empirical reasons, and should not be a tool to artificially fit the assignment. The limits of the discount factors are set at + - 15 percent.

It should be noted that the facility groups and sub groups represent highly generalized conditions. The speed and capacity values in the speed/capacity table are intend as input to the model for system wide analyses and not detailed evaluations of conditions on specific roadways or for small areas.

Table 3.2.2 – Classified Speed/Capacity Table

Roadway Type and Code	Per Lane LOS E Capacity (vph)	Free Flow Speed (mph)
Freeways, Short Upgrade, >5% Trucks (1 11)	1,400	64
Freeways, Short Upgrade, <5% Trucks (1 12)	1,600	67
Freeways, Long Upgrade, >5% Trucks (1 13)	1,250	62
Freeways, Long Upgrade, <5% Trucks (1 14)	1,500	64
Freeways, Rolling (1 21)	1,800	68
Freeway, Downhill (1 22)	1,950	69
Freeway, Level, Close Interchange Spacing (1 31)	1,875	65
Freeway, Level, Long Interchange Spacing (1 32)	1,950	70
Expressway, Ramp Controlled (2 11)	1,700	57
Expressways, Signal Controlled (2 12)	1,380	47
Freeway-Freeway Ramps (3 11)	1,200	48
On-Ramps (3 12)	1,000	41
Off-Ramps (3 13)	910	33
Major Road, Sparse Intersection, No Signal Controlled (4 11)	1,350	42
Major Road, Sparse Intersection, Signal Controlled (4 12)	1,160	41
Major Road, Sparse Intersection, 4-Way Stop Controlled (4 13)	660	37
Major Road, Dense Spaced Intersection, Residential (4 21)	840	32
Major Road, Dense Spaced Intersection, Access Control (4 22)	930	36
Major Road, Dense Spaced Intersection, Blocking Control (4 23)	880	34
Major Road, Dense Spaced Intersection, No Blocking Control (4 24)	780	29
Major Road CBD (4 31)	490	24
Minor Road, Sparse Spaced Intersection (5 11)	560	29
Minor Road, Dense Spaced Intersection (5 12)	480	26
Minor Road, Intermediate Spaced Intersection (5 13)	520	28

3.2.1.2.2 Capacity

The roadway capacity is the service flow rate (vehicle per hour) at Level Of Service E. LOS E capacities are calculated for all facility classes and their sub groups, and the procedures to calculate the capacities are primarily based on the Highway Capacity Manual.

Capacity for Freeways

The equation for freeway capacity calculation from HCM is used:

$$C = ISF * f_w * f_{HV} * f_p * PHF$$ (HCM Eq. 3-2, Eq. 3-4)

Where

C = the level of service E per lane capacity, vehicle per hour per lane
ISF =the maximum service flow rate under ideal condition, vehicle per hour per lane
f_w = the factor to adjust for the effects of restricted lane widths and lateral clearance
f_{HV} = the factor to adjust for the effect of heavy vehicles on the traffic stream
f_p = the factor to adjust for the effect of recreational or unfamiliar driver population
PHF I= the peak hour factor

Capacity for freeways is calculated on a segment-by-segment basis using a spreadsheet developed for this purpose, the calculated capacity is also subjected to slight adjustments if needed to achieve better assignments between competing routes. The spreadsheet is based on HCM, and uses a maximum Service Flow Rate of 2200 and 2300 vphpl under ideal conditions for capacity calculation of 4 and 6 or 8 lane freeways respectively. See Table 3.2.3 for a tabulation of capacity calculations for OKI area freeways. This table was updated recently, and truck percentages, number of lanes, slopes and terrain were checked and edited, as well as roadway segments.

For proposed facilities for which segment-specific information is not available, generalized capacities are calculated based on OKI freeway classifications. These capacities are tabulated in the form of Table 3.2.4. These capacities are based on an assumed truck percentage and other physical characteristics, if more information on any parameter is available, it is used in place of the assumed values.

Table 3.2.3 – Freeway / Expressway Segment-by-Segment Capacities

State& Route	Section Description	Dir.	Lanes	Truck Lanes	Design Speed	V/C_ LOS E	S_Vol	f(W)	Ter._ Type	Grade %	Grade_ Length	Truck %	PCE	PHF	f(HV)	f(P)	Cap_E	Cap_E
OH I-71	I-75 JCT - PLUM STREET OVERPASS	EB	2		70	1.00	2200	1	1			7	1.5	0.9	0.966	1	3826	1913
OH I-71	I-75 JCT - PLUM STREET OVERPASS	WB	4			1.00		1						0.9			7652	1913
OH I-71	PLUM STREET OVERPASS - BROADWAY OVERPASS	EB	2		70	1.00	2300	1	1			7	1.5	0.9	0.966	1	4000	2000
OH I-71	PLUM STREET OVERPASS - BROADWAY OVERPASS	WB	4					1						0.9			8000	2000
OH I-71	BROADWAY OVERPASS - SIXTH ST OVERPASS	NB	2		70	1.00	2300	1	1			8	1.5	0.9	0.962	1	3980	1990
OH I-71	BROADWAY OVERPASS - SIXTH ST OVERPASS	SB	3					1						0.9			5970	1990
OH I-71	SIXTH ST OVERPASS - I-471	NB	4		70	1.00	2300	1	1			8	1.5	0.9	0.962	1	7960	1990
OH I-71	SIXTH ST OVERPASS - I-471	SB	4					1						0.9			7960	1990
OH I-71	I-471 - ELSINOR OVERPASS	NB	3		70	1.00	2300	1	1			8	1.5	0.9	0.962	1	5970	1990
OH I-71	I-471 - ELSINOR OVERPASS	SB	3					1						0.9			5970	1990
OH I-71	ELSINOR OVERPASS - FLORENCE AVE	NB	5		70	1.00	2300	1	0	4.4	0.4	7	2.5	0.9	0.905	1	9365	1873
OH I-71	ELSINOR OVERPASS - FLORENCE AVE	SB	3					1					1.5	0.9	0.966		6000	2000
OH I-71	FLORENCE AVE - MCMILLAN AVE	NB	5		70	1.00	2300	1	0			7	1.5	0.9	0.966	1	10000	2000
OH I-71	FLORENCE AVE - MCMILLAN AVE	SB	4					1		4.4	0.5		3.0	0.9	0.877		7264	1816
OH I-71	MCMILLAN AVE - VICTORY PARKWAY	NB	5		70	1.00	2300	1	1			6	1.5	0.9	0.971	1	10050	2010
OH I-71	MCMILLAN AVE - VICTORY PARKWAY	SB	4				.	1						0.9			8040	2010
OH I-71	VICTORY PARKWAY- OH 562	NB	4		70	1.00	2300	1	1			6	1.5	0.9	0.971	1	8040	2010
OH I-71	VICTORY PARKWAY- OH 562	SB	4					1						0.9			8040	2010
OH I-71	OH 562 - KENNEDY AVE	NB	3		70	1.00	2300	1	1			6	1.5	0.9	0.971	1	6030	2010
OH I-71	OH562 - KENNEDY AVE	SB	3					1						0.9			6030	2010
OH I-71	KENNEDY AVE - KENWOOD RD	NB	3		70	1.00	2300	1	0	3.8	0.8	6	2.5	0.9	0.917	1	5697	1899
OH I-71	KENNEDY AVE - KENWOOD RD	SB	3					1					1.5	0.9	0.971		6030	2010
OH I-71	KENWOOD RD - FIELDS-ERTEL RD	NB	3		70	1.00	2300	1	1			8	1.5	0.9	0.962	1	5970	1990
OH I-71	KENWOOD RD - FIELDS-ERTEL RD	SB	3					1						0.9			5970	1990
OH I-71	FIELDS-ERTEL RD - CLINTON CO LINE	NB	2		70	1.00	2200	1	1			28	1.5	0.9	0.877	1	3474	1737
OH I-71	FIELDS-ERTEL RD - CLINTON CO LINE	SB	2					1						0.9			3474	1737
OH I-74	INDIANA STATE LINE- I-275 JCT (BLUE JAY)	EB	2		70	1.00	2200	1	1			16	1.5	0.9	0.926	1	3666	1833
OH I-74	INDIANA STATE LINE-I-275 JCT (BLUE JAY)	WB	2					1						0.9			3666	1833
OH I-74	I-275 JCT (TAYLOR CREEK)- NORTH BEND RD.	EB	2		70	1.00	2200	1	1			11	1.5	0.9	0.948	1	3754	1877
OH I-74	I-275 JCT (TAYLOR CREEK)- NORTH BEND RD.	WB	2					1						0.9			3754	1877

State& Route	Section Description	Dir.	Lanes	Truck Lanes	Design Speed	V/C_ LOS E	S_Vol	f(W)	Ter._ Type	Grade %	Grade_ Length	Truck %	PCE	PHF	f(HV)	f(P)	Cap_E	Cap_E
OH I-74	NORTH BEND ROAD - MONTANA AVE	EB	2		70	1.00	2200	1	0			10	1.5	0.9	0.952	1	3772	1886
OH I-74	NORTH BEND ROAD - MONTANA AVE	WB	2	1						3.0	2.8		3.0	0.9	0.833		4950	1650
OH I-74	MONTANA AVE- I-75 TERMINAL	EB	2		70	1.00	2200	1	1			6	1.5	0.9	0.971	1	3844	1922
OH I-74	MONTANA AVE- I-75 TERMINAL	WB	2					1						0.9			3844	1922
OH I-75	KY STATE LINE- I-71	NB	4		70	1.00	2300	0.95	1			10	1.5	0.9	0.952	1	7884	1971
OH I-75	KY STATE LINE- I-71	SB	4					0.95						0.9			7884	1971
OH I-75	I-71 - NINTH ST OVERPASS	NB	2		70	1.00	2200	1	1			10	1.5	0.9	0.952	1	3772	1886
OH I-75	I-71 - NINTH ST OVERPASS	SB	2					1						0.9			3772	1886
OH I-75	NINTH ST OVERPASS - I-74	NB	4		70	1.00	2300	1	1			9	1.5	0.9	0.957	1	7924	1981
OH I-75	NINTH ST OVERPASS - I-74	SB	4					1						0.9			7924	1981
OH I-75	I-74 - BUTLER CO LINE	NB	3		70	1.00	2300	1	1			11	1.5	0.9	0.948	1	5886	1962
OH I-75	I-74 - BUTLER CO LINE	SB	3					1						0.9			5886	1962
OH I-75	BUTLER CO LINE - MONTGOMERY CO LINE	NB	3		70	1.00	2300	1	1			19	1.5	0.9	0.913	1	5670	1890
OH I-75	BUTLER CO LINE - MONTGOMERY CO LINE	SB	3					1						0.9			5670	1890
OH 1-275	INDIANA STATE LINE- I-74 (BLUE JAY)	NB	2		70	1.00	2200	1	2			15	2.5	0.9	0.816	1	3232	1616
OH 1-275	INDIANA STATE LINE-I-74 (BLUE JAY)	SB	2					1						0.9			3232	1616
OH 1-275	I-74 (BLUE JAY)- I-74 (TAYLOR CREEK)	EB	3		70	1.00	2200	1	2			11	2.5	0.9	0.858	1	5100	1700
OH 1-275	I-74 (BLUE JAY)- I-74 (TAYLOR CREEK)	WB	3					1						0.9			5100	1700
OH 1-275	I-74 (TAYLOR CREEK) - BLUE ROCK ROAD	EB	3		70	1.00	2300	1	0	4.0	0.6	12	2.5	0.9	0.847	1	5262	1754
OH 1-275	I-74 (TAYLOR CREEK) - BLUE ROCK ROAD	WB	3					1					1.5	0.9	0.943		5859	1953
OH 1-275	BLUE ROCK ROAD - US 27	NB	3		70	1.00	2300	1	2			11	2.5	0.9	0.858	1	5331	1777
OH 1-275	BLUE ROCK ROAD - US 27	SB	3					1						0.9			5331	1777
OH 1-275	US 27 - OH SR 4	EB	3		70	1.00	2300	1	2			10	2.5	0.9	0.870	1	5400	1800
OH 1-275	US 27 - OH SR 4	WB	3					1						0.9			5400	1800
OH 1-275	OH SR 4 - OH SR 747	EB	4		70	1.00	2300	1	2			9	2.5	0.9	0.881	1	7296	1824
OH 1-275	OH SR 4 - OH SR 747	WB	4					1						0.9			7296	1824
OH 1-275	OH SR 747- I-75 JCT	EB	4		70	1.00	2300	1	2			11	2.5	0.9	0.858	1	7108	1777
OH 1-275	OH SR 747- I-75 JCT	WB	4					1						0.9			7108	1777
OH 1-275	I-75 JCT - US 42	EB	3		70	1.00	2300	1	2			9	2.5	0.9	0.881	1	5472	1824
OH 1-275	I-75 JCT - US 42	WB	3					1						0.9			5472	1824
OH 1-275	US 42 - HAMILTON CO LINE	EB	3		70	1.00	2300	1	2			8	2.5	0.9	0.893	1	5544	1848
OH 1-275	US 42 - HAMILTON CO LINE	WB	3					1						0.9			5544	1848

State& Route	Section Description	Dir.	Lanes	Truck Lanes	Design Speed	V/C_ LOS E	S_Vol	f(W)	Ter._ Type	Grade %	Grade_ Length	Truck %	PCE	PHF	f(HV)	f(P)	Cap_E	Cap_E
OH 1-275	HAMILTON CO LINE- OH SR 28	NB	3		70	1.00	2300	1	2			7	2.5	0.9	0.905	1	5619	1873
OH 1-275	HAMILTON CO LINE- OH SR 28	SB	3					1						0.9			5619	1873
OH 1-275	OH SR 28- US 50 RELOCATED	NB	3		70	1.00	2300	1	0	3.0	1.9	7	3.0	0.9	0.877	1	5448	1816
OH 1-275	OH SR 28- US 50 RELOCATED	SB	3					1					1.5	0.9	0.966		6000	2000
OH 1-275	US 50 RELOCATED- US 52 CONNECTOR	NB	2		70	1.00	2200	1	2			8	2.5	0.9	0.893	1	3536	1768
OH 1-275	US 50 RELOCATED- US 52 CONNECTOR	SB	2					1						0.9			3536	1768
OH 1-275	US 52 CONNECTOR - KY STATE LINE	EB	3		70	1.00	2300	1	2			9	2.5	0.9	0.881	1	5472	1824
OH 1-275	US 52 CONNECTOR - KY STATE LINE	WB	3					1						0.9			5472	1824
COL PKWY	HEW BLDG DRIVE - REDBANK RAMPS	EB	2		60	1.00	2200	1	1			3	1.5	0.9	0.985	1	3902	1951
COL PKWY	HEW BLDG DRIVE - REDBANK RAMPS	WB	2					1						0.9			3902	1951
CROSS CO	I-275 - COLERAIN AVE (US 27)	EB	2		70	1.00	2200	1	1			4	1.5	0.9	0.980	1	3882	1941
CROSS CO	I-275 - COLERAIN AVE (US 27)	WB	2					1						0.9			3882	1941
CROSS CO	I-75 - READING RD (US 42)	EB	2		70	1.00	2200	1	1			4	1.5	0.9	0.980	1	3882	1941
CROSS CO	I-75 - READING RD (US 42)	WB	2					1						0.9			3882	1941
CROSS CO	READING RD (US 42) - MONTGOMERY RD	EB	2		70	1.00	2200	1	1			3	1.5	0.9	0.985	1	3902	1951
CROSS CO	READING RD (US 42) - MONTGOMERY RD	WB	2					1						0.9			3902	1951
SR-562	I-75 - I-71	EB	2		70	1.00	2000	1	1			6	1.5	0.9	0.971	1	3496	1748
SR-562	I-75 - I-71	WB	2					1						0.9			3496	1748
6TH ST	I-75 - RIVER ROAD	EB	3		70	1.00	2300	1	1			6	1.5	0.9	0.971	1	6030	2010
6TH ST	I-75 - RIVER ROAD	WB	3					1						0.9			6030	2010
OH 32	I-275 - EASTGATE BLVD	EB	2		70	1.00	2000	1	1			6	1.5	0.9	0.971	1	3496	1748
OH 32	I-275 - EASTGATE BLVD	WB	2					1						0.9			3496	1748
OH 32	MAIN ST (BATAVIA)- SR 132	E8	2		70	1.00	2000	1	1			9	1.5	0.9	0.957	1	3444	1722
OH 32	MAIN ST (BATAVIA)- SR 132	WB	2					1						0.9			3444	1722
OH 32	BATAVIA ROAD - SR 133	EB	2		70	1.00	2000	1	1			8	1.5	0.9	0.962	1	3462	1731
OH 32	BATAVIA ROAD - SR 133	WB	2					1						0.9			3462	1731
OH I-471	LIBERTY STREET- 6TH STREET	NB	2		70	1.00	2200	1	1			4	1.5	0.9	0.980	1	3882	1941
OH I-471	LIBERTY STREET- 6TH STREET	SB	2					1						0.9			3882	1941
OH I-471	6TH STREET - KY STATE LINE	NB	3		70	1.00	2300	1	1			4	1.5	0.9	0.980	1	6087	2029
OH I-471	6TH STREET - KY STATE LINE	SB	3					1						0.9			6087	2029
KY I-471	OHIO STATE LINE - CAROTHERS RD	NB	3		70	1.00	2300	1	0			6	1.5	0.9	0.971	1	6030	2010
KY I-471	OHIO STATE LINE - CAROTHERS RD	SB	3					1		3.0	0.8		2.5	0.9	0.917		5697	1899

State& Route	Section Description	Dir.	Lanes	Truck Lanes	Design Speed	V/C_ LOS E	S_Vol	f(W)	Ter._ Type	Grade %	Grade_ Length	Truck %	PCE	PHF	f(HV)	f(P)	Cap_E	Cap_E
KY I-471	CAROTHERS RD- I-275	NB	3		70	1.00	2300	1	1			6	1.5	0.9	0.971	1	6030	2010
KY I-471	CAROTHERS RD- I-275	SB	3					1						0.9			6030	2010
KY I-71	GALLATIN CO LINE- I-71/75 JCT	NB	2		70	1.00	2200	1	1			34	1.5	0.9	0.855	1	3384	1692
KY I-71	GALLATIN CO LINE- I-71/75 JCT	SB	2					1						0.9			3384	1692
KY I-75	GRANT CO LINE - I-71/75 JCT	NB	3		70	1.00	2300	1	1			23	1.5	0.9	0.897	1	5571	1857
KY I-75	GRANT CO LINE - I-71/75 JCT	SB	3					1						0.9			5571	1857
KY I-71/75	I-71/75 JCT - KENTON CO LINE	NB	4		70	1.00	2300	1	1			22	1.5	0.9	0.901	1	7460	1865
KY I-71/75	I-71/75 JCT - KENTON CO LINE	SB	4					1						0.9			7460	1865
KY I-71/75	KENTON CO LINE- KYLES LANE	NB	4		70	1.00	2300	1	1			12	1.5	0.9	0.943	1	7812	1953
KY I-71/75	KENTON CO LINE -KYLES LANE	SB	4					1						0.9			7812	1953
KY I-71/75	KYLES LANE - JEFFERSON ST	NB	3		60	1.00	2300	1	0			11	1.5	0.9	0.948	1	5886	1962
KY I-71/75	KYLES LANE - JEFFERSON ST	SB	4					1		5.0	1.3		2.5	0.9	0.858		7108	1777
KY I-71/75	JEFFERSON ST- 4TH STREET	NB	3		70	1.00	2300	1	1			11	1.5	0.9	0.948	1	5886	1962
KY I-71/75	JEFFERSON ST- 4TH STREET	SB	4					1						0.9			7848	1962
KY I-71/75	4TH STREET - OHIO STATE LINE	NB	3		70	1.00	2300	1	1			12	1.5	0.9	0.943	1	5859	1953
KY I-71/75	4TH STREET - OHIO STATE LINE	SB	4					1						0.9			7812	1953
KY I-275	INDIANA STATE LINE- KY SR 237	EB	2	1	70	1.00	2200	1	0	5.0	0.6	15	3.0	0.9	0.769	1	4569	1523
KY I-275	INDIANA STATE LINE - KY SR 237	WB	2					1					1.5	0.9	0.930		3684	1842
KY I-275	KY SR 237 - KENTON CO LINE	EB	3		70	1.00	2300	1	2			9	2.5	0.9	0.881	1	5472	1824
KY I-275	KY SR 237 - KENTON CO LINE	WB	3					1						0.9			5472	1824
KY I-275	KENTON CO LINE - TURKEYFOOT RD	EB	3		70	1.00	2300	1	2			7	2.5	0.9	0.905	1	5619	1873
KY I-275	KENTON CO LINE - TURKEYFOOT RD	WB	3					1						0.9			5619	1873
KY I-275	TURKEYFOOT RD- KY SR 17	EB	3		70	1.00	2300	1	0			6	1.5	0.9	0.971	1	6030	2010
KY I-275	TURKEYFOOT RD- KY SR 17	WB	3					1		3.5	2.4		3.0	0.9	0.893		5544	1848
KY I-275	KY SR 17 - KY SR16	EB	3		70	1.00	2300	1	0	4.0	1.2	6	4.0	0.9	0.847	1	5262	1754
KY I-275	KY SR 17 - KY SR16	WB	3					1					1.5	0.9	0.971		6030	2010
KY I-275	KY SR 16- LICKING RIVER	EB	3		70	1.00	2300	1	0			6	1.5	0.9	0.971	1	6030	2010
KY I-275	KY SR 16- LICKING RIVER	WB	3					1		4.0	2.0		4.0	0.9	0.847		5262	1754
KY I-275	LICKING RIVER- KY SR 9	EB	3		70	1.00	2300	1	0	4.0	0.5	6	3.0	0.9	0.893	1	5544	1848
KY I-275	LICKING RIVER- KY SR 9	WB	3					1					1.5	0.9	0.971		6030	2010
KY I-275	KY SR 9- OHIO STATE LINE	EB	3		70	1.00	2300	1	2			6	2.5	0.9	0.917	1	5697	1899
KY I-275	KY SR 9- OHIO STATE LINE	WB	3					1						0.9			5697	1899

State& Route	Section Description	Dir.	Lanes	Truck Lanes	Design Speed	V/C_ LOS E	S_Vol	f(W)	Ter._ Type	Grade %	Grade_ Length	Truck %	PCE	PHF	f(HV)	f(P)	Cap_E	Cap_E
IND I-74	OHIO STATE LINE - RIPLEY CO LINE	EB	2		70	1.00	2200	1	1			16	1.5	0.9	0.926	1	3666	1833
IND I-74	OHIO STATE LINE - RIPLEY CO LINE	WB	2					1						0.9			3666	1833
IND I-275	KENTUCKY STATE LINE - OHIO STATE LINE	NB	2		70	1.00	2200	1	2			15	2.5	0.9	0.816	1	3232	1616
IND I-275	KENTUCKY STATE LINE - OHIO STATE LINE	SB	2					1						0.9			3232	1616
KY AA	PENDELTON COUNTY-IVOR RD	NB	2		70	1.00	2000	1	0			18	1.5	0.9	0.917	1	3302	1651
KY AA	PENDELTON COUNTY-IVOR RD	SB	2					1		5.6	0.5		3.0	0.9	0.735		2648	1324
KY AA	IVOR RD - WASHINGTON TRACE RD	NB	2		70	1.00	2000	1	2			18	2.5	0.9	0.787	1	2834	1417
KY AA	IVOR RD - WASHINGTON TRACE RD	SB	2					1						0.9			2834	1417
KY AA	WASHINGTON TRACE RD - CALIFORNIA CROSSROAD	NB	2		70	1.00	2000	1	0	3.0	1.2	19	2.5	0.9	0.778	1	2802	1401
KY AA	WASHINGTON TRACE RD - CALIFORNIA CROSSROAD	SB	2					1					1.5	0.9	0.913		3288	1644
KY AA	CALIFORNIA CROSSROAD - KY 1997 (12 MILE ONEONTA RD)	NB	2		70	1.00	2000	1	0			19	1.5	0.9	0.913	1	3288	1644
KY AA	CALIFORNIA CROSSROAD - KY 1997 (12 MILE ONEONTA RD)	SB	2					1		5.0	0.6		3.0	0.9	0.725		2608	1304
KY AA	KY 1997 (12 MILE ONETONTA RD) - LICK BRANCH RD	NB	2		70	1.00	2000	1	0	3.2	0.7	18	2.0	0.9	0.847	1	3050	1525
KY AA	KY 1997 (12 MILE ONETONTA RD) - LICK BRANCH RD	SB	2					1					1.5	0.9	0.917		3302	1651
KY AA	LICK BRANCH RD - KY 547 (ALEXANDRA 4 MILE RD)	NB	2		70	1.00	2000	1	0			14	1.5	0.9	0.935	1	3364	1682
KY AA	LICK BRANCH RD - KY 547 (ALEXANDRA 4 MILE RD)	SB	2					1		5.0	0.5		3.0	0.9	0.781		2812	1406
KY AA	KY547 (ALEXANDRIA 4 MILE RD) - POPULAR RIDGE RD	NB	2		70	1.00	2000	1	0	5.3	0.5	10	3.0	0.9	0.833	1	3000	1500
KY AA	KY547 (ALEXANDRIA 4 MILE RD) - POPULAR RIDGE RD	SB	2					1					1.5	0.9	0.952		3428	1714
KY AA	POPULAR RIDGE RD - ENZWEILER RD	NB	2		70	1.00	2000	1	2			8	2.5	0.9	0.893	1	3214	1607
KY AA	POPULAR RIDGE RD - ENZWEILER RD	SB	2					1						0.9			3214	1607
KY AA	ENZWEILER RD - KY 709 (EAST ALEXANDRIA PK)	NB	2		70	1.00	2000	1	0			8	1.5	0.9	0.962	1	3462	1731
KY AA	ENZWEILER RD - KY 709 (EAST ALEXANDRIA PK)	SB	2					1		4.0	0.8		3.0	0.9	0.862		3104	1552
KY AA	KY 709 (EAST ALEXANDRIA PK) - US-27	NB	2		70	1.00	2000	1	0	4.2	1.6	8	3.5	0.9	0.833	1	3000	1500
KY AA	KY 709 (EAST ALEXANDRIA PK) - US-27	SB	2					1					1.5	0.9	0.962		3462	1731
KY AA	US-27 - MURNAM RD	NB	2		70	1.00	2000	1	2			10	2.5	0.9	0.870	1	3130	1565
KY AA	US-27 - MURNAM RD	SB	2					1						0.9			3130	1565
KY AA	MURNAM RD - KY 915 (LINKING PK)	NB	2		70	1.00	2000	1	0			13	1.5	0.9	0.939	1	3380	1690
KY AA	MURNAM RD - KY 915 (LINKING PK)	SB	2					1		3.5	1.3		2.5	0.9	0.837		3012	1506
KY AA	KY 915 (LINKING PK) - I-275	NB	2		70	1.00	2000	1	1			15	1.5	0.9	0.930	1	3348	1674
KY AA	KY 915 (LINKING PK) - I-275	SB	2					1						0.9			3348	1674

Table 3.2.4 – Capacity Calculation For Proposed Freeways

CLASS	Facility. Class & SC Code	Ideal Service Flow(1)	Percent Grade	Length (MI)	Trucks (%)	Value of Et (2)	Fhv	Fw	Fp	PHF	Computed Max. Serv. Flow (SF)	Recom. LOS E Capacity
Freeway, Short Upgrade	1 11	2300	5.0	0.4	10.00%	5.00	0.71	1	1	0.9	1470	1475
> 5% Trucks		2200	5.0	0.4	10.00%	5.00	0.71	1	1	0.9	1406	1400
Freeway, Short Upgrade	1 12	2300	5.0	0.4	4.00%	7.00	0.81	1	1	0.9	1677	1675
< 5% Trucks		2200	5.0	0.4	4.00%	7.00	0.81	1	1	0.9	1604	1600
Freeway, Long Upgrade	1 13	2300	5.0	1.5	10.00%	7.00	0.63	1	1	0.9	1304	1300
> 5% Trucks		2200	5.0	1.5	10.00%	7.00	0.63	1	1	0.9	1247	1250
Freeway, Long Upgrade	1 14	2300	5.0	1.5	4.00%	9.50	0.75	1	1	0.9	1553	1550
< 5% Trucks		2200	5.0	1.5	4.00%	9.50	0.75	1	1	0.9	1485	1500
Freeway, Rolling	1 21	2300	-	-	5.00%	3.00	0.91	1	1	0.9	1884	1900
		2200	-	-	5.00%	3.00	0.91	1	1	0.9	1802	1800
Freeway, Downhill	1 22	2300	-5.0	2.0	5.00%	1.50	0.98	1	1	0.9	2029	2025
		2200	-5.0	2.0	5.00%	1.50	0.98	1	1	0.9	1940	1950
Freeway Level	1 31	2300	0.0	0.4	5.00%	2.00	0.95	1	1	0.9	1967	1975
Close Interchange Spacing		2200	0.0	0.4	5.00%	2.00	0.95	1	1	0.9	1881	1875
Freeway Level	1 32	2300	0.0	2.0	5.00%	1.50	0.98	1	1	0.9	2029	2025
Long Interchange Spacing		2200	0.0	2.0	5.00%	1.50	0.98	1	1	0.9	1940	1950

1. Ideal Service Flow of 2300 used for 6 or more lane and 2200 used for 4 lane freeways.
2. Using HCM Tables 3-3, 3-4 and 3-6

Capacity for Expressways with Ramps

Like freeways, capacity for expressway with ramps is calculated on a segment-by-segment basis using a spreadsheet developed for this purpose, and the calculated capacity is also subjected to slight adjustments if needed to achieve better assignments between competing routes. The spreadsheet is based on HCM, and uses a maximum Service Flow Rate of 2000 vphpl under ideal conditions for capacity calculation of 4 lane expressways. In addition to the freeways, Table 3.2.3 also lists capacity calculations for OKI area expressway segments.

For proposed facilities for which segment-specific information is not available, generalized capacities are calculated based on OKI expressway classifications. The capacity of expressways with ramps is determined on the basis of information provided in HCM for freeways and multilane highways with little or no side friction due to driveways. The concept and procedure for the determination of Service Flow Rate (SF) corresponding to a given LOS is the same for both freeways and multilane highways. However, Maximum Service Flow (MSF) of 2200 or 2300 is considered too high for expressways and not adopted in the determination of capacity. HCM provides a general procedure for Planning Analysis of multilane highways that is based on an MSF of 2000 to 2200 pcphpl. Referring to Table 3.2.5 (which is a reproduction of HCM Table 7-11), the suggested values of SF (or LOS E capacity) corresponding to free-flow speed of 50 and 60 mph, are 1800 and 1630 respectively (10 % trucks, level terrain, lane width 12 ft., shoulders 6 ft, divided highway). Consequently, a close to average value of 1700 is considered to be reasonable estimate of LOS E capacity for such roadways.

Table 3.2.5 – Service Flow Rates in Vehicles Per Lane For Use in Planning Analysis

TYPE OF TERRAIN	LOS	FREE-FLOW SPEED = 60 MPH					FREE-FLOW SPEED = 50 MPH				
PERCENT TRUCKS		0	5	10	15	20	0	5	10	15	20
LEVEL	A	590	580	570	550	540	490	470	460	450	440
	B	990	970	940	920	900	810	790	770	750	740
	C	1360	1330	1290	1260	1240	1130	1110	1080	1050	1030
	D	1620	1580	1540	1510	1470	1350	1320	1290	1260	1230
	E	1890	1840	1800	1760	1720	1710	1670	1630	1590	1550
ROLLING	A	590	540	500	460	420	490	440	410	370	350
	B	990	900	830	760	710	810	740	680	620	580
	C	1360	1240	1130	1050	970	1130	1030	950	870	810
	D	1620	1470	1350	1250	1160	1350	1230	1130	1040	960
	E	1890	1720	1580	1450	1350	1710	1550	1430	1320	1220
MOUNTAINOUS	A	590	480	400	340	300	490	390	320	280	240
	B	990	790	660	570	500	810	650	540	460	410
	C	1360	1090	910	780	680	1130	910	760	650	570
	D	1620	1300	1080	930	810	1350	1080	900	770	680
	E	1890	1510	1260	1080	950	1710	1370	1140	980	860

Note : HCM Table 7-11

Capacity for Major and Minor Roadways

This section discusses details of the procedure adopted for analysis of interrupted flow facilities. This includes all signal controlled facilities that account for most of the OKI classifications. Major road, sparse intersections with 4-way Stop are also discussed which shares some explanation with other facilities.

For interrupted flow facilities, the Saturation Flow rate (SF) is affected by numerous factors which can be applied to an ideal flow rate of 1900 vehicles per hour of green per lane (vphgpl) for adjusted SF calculation. Details of the factors that affect SF can be seen in chapter 9 of HCM. For planning applications, HCM suggests a range of 1750 to 1850 vphgpl. For the purpose of this study, however, adjusted SF is calculated separately for each case using the HCM equation.

$$SF = ISF * f_w * f_{HV} * PHF * f_g * f_p * f_{bb} * f_a * f_{RT} * f_{LT} \quad \text{(HCM Eq. 9-12)}$$

Where

SF =the adjusted saturation flow rate per hour of green time, vehicles per hour per lane
ISF =the saturation flow rate under ideal conditions, vehicle per hour per lane
f_w = the adjustment factor for lane width

f_{HV} I = the adjustment factor for truck traffic
f_g = the adjustment factor for grade
f_p = the adjustment factor for curb parking
f_{bb} = the adjustment factor for bus blocking
f_a = the adjustment area type
f_{RT} = the adjustment factor for right turn traffic
f_{LT} = the adjustment factor for left turn traffic

Table 3.2.6 shows the adjustment factors and adjusted saturation flow rates. Values of adjustment factors are taken from Tables 9-5 to 9-12 of HCM. Since the intersection is shared by competing approaches and their use of the intersection is controlled by a traffic signal, the subject approach moves traffic only during the green phase allocated to it. The capacity of an approach of an intersection may be calculated using the following equation:

$$C = SF * g/c$$

Where
C = the level of service E capacity, vehicles per hour per lane
SF = the intersection saturation flow, vehicle per hour per lane
g/c = the ratio of green time to cycle time

The level of service E capacity calculation is shown in Table 3.2.7.

The approach capacity of a 4-way stop intersection is calculated using the following HCM relationships :

$$C = 1000\,V_{ps} + 700\,V_{po} + 200\,L_s - 100\,L_o - 300\,LT_{po} + 200\,RT_{po} - 300\,LT_{pc} + 300\,RT_{pc}$$

(HCM Eq. 10-15)

Where.
C = capacity of subject approach (vph);
L_s = number of lanes on subject approach;
L_o = number of lanes on opposing approach;
LT_{po} = proportion of volume on opposing approach turning left;
LT_{pc} = proportion of volume on conflicting approaches turning left;
RT_{po} = proportion of volume on opposing approach turning right;
RT_{pc} = proportion of volume on conflicting approaches turning right;
V_{ps} = proportion of intersection volume on subject approach;
V_{po} = proportion of intersection volume on opposing approach;

A hypothetical scenario of a simple intersection was used for analysis involving one lane in each direction with 10% turning traffic in all directions and the traffic flow in major road approach being twice of the flow in intersecting road approach. With this scenario, $V_{ps} = V_{po} = 0.33$, $LT_{po} = RT_{po} = 0.083$, $LT_{pc} = RT_{pc} = 0.083$, and C = 660 vph.

Table 3.2.6 – Adjusted Saturation Flow Rate Calculation for Interrupted-Flow Facilities

Category Description	Ideal Saturation Flow ISF	Adjustment Factor									Adjusted Saturation Flow Rate	
		Lane Width f_w	Heavy Vehicle f_{HV}	Peak Hour PHF	Grade f_g	Parking f_p	Bus Block f_{bb}	Area Type f_a	Right Turn f_{RT}	Left Turn f_{LT}	Calculated Saturation Flow SF	Rounded to Nearest 10
Expressway, Signals	1900	1.00	0.95	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1625	1630
Off-Ramp	1900	1.00	0.95	0.90	1.00	1.00	1.00	1.00	0.98	0.98	1560	1560
Major Road, Sparse Intersection, No Signals	1900	1.00	0.95	0.90	1.00	1.00	0.98	1.00	0.98	0.98	1529	1530
Major Road, Sparse Intersections, Signals	1900	1.00	0.95	0.90	1.00	1.00	0.98	1.00	0.95	0.95	1437	1440
Major Road, Dense Intersections, Residential	1900	0.95	0.98	0.90	1.00	0.90	0.95	1.00	0.95	0.95	1228	1230
Major Road, Dense Intersections, Access Control	1900	1.00	0.95	0.90	1.00	1.00	0.95	1.00	1.00	1.00	1543	1540
Major Road, Dense Intersections, Blocking Control	1900	0.95	0.95	0.90	1.00	1.00	0.95	1.00	0.98	1.00	1437	1440
Major Road, Dense Intersections, No Blocking Control	1900	1.00	0.95	0.90	1.00	0.85	0.95	1.00	0.95	0.95	1184	1200
Major Road, CBD	1900	0.93	0.95	0.90	1.00	0.80	0.95	0.90	0.95	0.95	933	950
Minor Road, Sparse Intersections	1900	0.93	0.98	0.90	1.00	0.85	0.95	1.00	0.95	0.95	1136	1150
Minor Road Dense Intersections	1900	0.93	0.98	0.90	1.00	0.85	0.95	1.00	0.95	0.95	1136	1140
Minor Road, Intermediate Intersections	1900	0.93	0.98	0.90	1.00	0.85	0.95	1.00	0.95	0.95	1136	1140

Table 3.2.7 – Capacity Calculation for Interrupted-Flow Facilities

Category Description	Saturation Flow SF	Green / Cycle Time Ratio g/c	Calculated Capacity C	Recommended Capacity
Expressway, Signals	1630	0.85	1386	1380
Off-Ramp	1560	0.60	936	910
Major Road, Sparse Intersection, No Signals	1530	0.90	1377	1350
Major Road, Sparse Intersections, Signals	1440	0.80	1152	1160
Major Road, Dense Intersections, Residential	1230	0.70	861	840
Major Road, Dense Intersections, Access Control	1540	0.60	924	930
Major Road, Dense Intersections, Blocking Control	1440	0.60	864	880
Major Road, Dense Intersections, No Blocking Control	1200	0.65	780	780
Major Road, CBD	950	0.50	475	490
Minor Road, Sparse Intersections	1150	0.50	575	560
Minor Road Dense Intersections	1140	0.40	456	480
Minor Road, Intermediate Intersections	1140	0.45	513	520

Capacity Determination for On-Ramp and Freeway-Freeway Ramps

The ramp merge area is considered as a three-legged two-way-stop-controlled intersection with no stop sign on freeway approach. The HCM gap acceptance model used to calculate capacity of minor road approach of a two-way-stop-controlled intersection is used for the calculation of ramp capacity. In this calculation the freeway curb lane traffic is treated as the through movement on major road and ramp flow as the right turn movement on minor road. The gap acceptance model is given by the following relationship:

$$C_{p,x} = \frac{3600}{t_f} e^{-\frac{[\Sigma_y V_{c,y}] t_o}{3600}} \qquad \text{(HCM Eq. 10-1)}$$

Where

$C_{p,x}$ is the potential per lane capacity of minor movement x (vphpl)
$V_{c,y}$ is the volume of traffic in conflicting stream y (vph)
$t_o = t_g - (t_f /2)$
tg is the critical gap (i.e., minimum length time interval in seconds, that allows intersection entry to one minor street vehicle). HCM recommended for intersection is 5.5 seconds. 3.0 and 2.8 seconds are used for on-ramps and freeway-to-freeway ramps in this case.

t_f is the follow-up time in seconds, (i.e., time span between departure of one vehicle from minor street and departure of next vehicle under a continuous queue condition). HCM recommended for intersection is 2.1 seconds. 1.5 and 1.3 second are used for on-ramps and free-to-freeway ramps in this case.

The ramp capacity is about 1,000 vehicle per hour per lane for on-ramps and 1,200 vehicle per hour per lane for freeway-to-freeway ramps with an average of 1,400 vehicle per hour of side lane freeway traffic assumed as $V_{c,y}$.

3.2.1.2.3 Speed

The speeds coded in the OKI network are free flow speeds that are the initial speeds for the first iteration of the assignment process. Free speed is the speed at which a vehicle can traverse the roadway link in the absence of traffic but subject to such permanent traffic controls on the facility as signals and signs, and it is also an input variable for travel speed-traffic volume relationship equations to calculate congested speeds.

The free flow speeds are determined using the equations proposed in Transportation Research Reports "Special Report 209, Highway Capacity Manual" and " National Corporative Highway Research Program 387, Planning Techniques to Estimate Speeds and Service Volumes for Planning Applications" The equations used are summarized below:

(A) Freeways

FFS = 0.88 * Posted Speed (65) + 14 mile/hour = 71.2 mph (NCHRP 387)
FFS = 0.88 * Posted Speed (55) + 14 mile/hour = 62.4 mph (NCHRP 387)

Note: FFS is adjusted using the speed data collected in 1996
FFS is capped at 69 mile/hour

(B) Expressways, Ramp Controlled

FFS = 0.88 * Posted Speed (55) + 14 mile/hour = 62.4 mph (NCHRP 387)
FFS = 0.79 * Posted Speed (50) + 12 mile/hour = 51.5 mph (NCHRP 387)

Note: Average FFS = 56.95
FFS is adjusted using the speed data collected in 1996

(C) Freeway-Freeway Ramps

FFS = 0.79 * Posted Speed (45) + 12 mile/hour = 47.55 (NCHRP 387)

(D) On-Ramps

FFS = 0.79 * Posted Speed (35) + 12 mile/hour = 39.65 (NCHRP 387)

(E) Signalized Roads

$FFS = [3600*LENGTH / TIME_{Segment}]$ (NCHRP 387)
$TIME_{Segment} = TIME_{Mid Block FFS} + DELAY_{Intersection} + TIME_{Side Friction}$ (NCHRP 387, modified)
$TIME_{Mid Block FFS} = 3600*LENGTH/Mid Block FFS$
$DELAY_{Intersection} = 1.3 * 0.38*C*(1-g/C)^2 *DF$ (HCM94 Equations 11-2, 11-4 and 11-4)
$TIME_{Side Friction} = [3600*LENGTH/(Mid Block FFS – 0.25*N)] - TIME_{Mid Block FFS}$

Mid Block FFS = 0.79 * Posted Speed + 12 mile/hour
DF = (1-P)*fp/(1-g/C) (HCM94 Equation 9-26)

Where

FFS = Average free flow speed of the roadway segment (in mile per hour)
Mid Block FFS = Speed at mid block of the roadway segment (in mile per hour)
Posted Speed = Posted speed for the roadway segment (in mile per hour)
$TIME_{Segment}$ = Total travel time traveling the roadway segment (in second)
$DELAY_{Intersection}$ = Delay time at the intersection (in second)
$TIME_{Side\ Friction}$ = Delay time due to turning vehicles at major driveways and minor intersections (in second).
$TIME_{Mid\ Block\ FFS}$ = Travel time traveling the roadway segment at mid block speed (in second)
C = Cycle length (in second)
g = Effect green time (in second)
DF = Delay adjustment factor for signal progression and control type
P = Proportion of all vehicles in movement arriving during green phase
fp = supplemental adjustment factor for platoon arrival during the green
(0.93 for moderately dense platoon arriving in the middle of the red phase,
1.15 for moderately dense platoon) arriving in the middle of the green phase,
1.00 for all others)
N = Number of access points per mile
LENGTH = Length of the roadway segment (in mile).

The calculated speeds for the roadway types are then compared to the observed off-peak speed data collected. Minor adjustments are made to the calculated speeds. The adopted free-flow speeds for all roadway types are shown in Table 3.2.8.

Table 3.2.8 – Classified Free-Flow Speeds

OKI ROADWAY TYPE & CODE	SUGGES-TED FFS	SURVEYED		COMMENTS
		RANGE	MEAN	
Freeways, Short Upgrade, >5% Trucks (1 11)	64	-	-	Not surveyed
Freeways, Short Upgrade, <5% Trucks (1 12)	67	62-72	67	Good comparison
Freeways, Long Upgrade, >5% Trucks (1 13)	62	56-65	60.5	Good comparison, FFS for higher trucks percentage category has been intentionally kept lower.
Freeways, Long Upgrade, <5% Trucks (1 14)	64	61-68	64.5	
Freeways, Rolling (1 21)	68	60-74	69.4	Good comparison, rolling is expected to be slightly lower that downhill.
Freeway, Downhill (1 22)	69	53-77	69	
Freeway, Level, Close Interchange Spacing (1 31)	65	47-79	67.5	Acceptable comparison. Suggested FFS indicates the possible effect of weaving in short segments.
Freeway, Level, Long Interchange Spacing (1 32)	70	61-78	72.2	Acceptable comparison. Suggested FFS is kept within 70 mph to avoid model assigning short trips to freeways.
Expressway, Ramp Controlled (2 11)	57	34-61	51.9	Acceptable comparison. Suggested on the higher side, but within observed range.
Expressways, Signal Controlled (2 12)	47	30-58	44.8	Good comparison. Suggested FFS slightly higher than observed mean, but within acceptable range.
Freeway-Freeway Ramps (3 11)	48	-	-	Not surveyed
On-Ramps (3 12)	41	-	-	Not surveyed
Off-Ramps (3 13)	33	-	-	Not surveyed
Maj. Rd., Sparse Intersections, No Signals (4 11)	42	25-51	38.2	The wide range of upper and lower observed values indicates variations in operating conditions in each surveyed roadway which might belong to a particular category. The analysis is however based on an assumed set of parameters. For this reason, it is difficult to establish a very close match between analyzed and observed FFS. However, all the suggested FFS are within a reasonable range from observed mean speed. Considering this, all these are acceptable.
Maj. Rd., Sparse Intersections, Signals (4 12)	41	14-45	35.7	
Maj. Rd., Sparse Intersections, 4-WSC (4 13)	37	35-45	39.5	
Maj. Rd., Dense Intersections, Residential (4 21)	32	18-45	30	
Maj. Rd., Dense Intersection, Access Control (4 22)	36	19-47	34.3	
Maj. Rd., Dense Intersections, Blocking Control (4 23)	34	11-51	31.5	
Maj. Rd., Dense Intersections, No Blocking Control (4 24)	29	11-44	26.3	
Major Rd., CBD (4 31)	24	-	-	Not surveyed
Minor Rd., Sparse Intersection (5 11)	29	24-52	35.6	(See note above for major road categories)
Minor Rd., Dense Intersection (5 12)	26	18-42	31	

Minor Rd., Intermediate Intersection (5 13)	28	18-41	30.1	

3.2.1.2.4 Travel Speed – Traffic Volume Relationship

There is a close relationship between the speed a vehicle can travel on a roadway segment and the traffic volume around the vehicle. The heavier the traffic volume the slower the vehicles in the traffic can travel.

OKI recognized a need to implement different speed/ volume relationships for different roadway types. A variation of equation was developed for each type of roadway, and regression analysis was used to derive those equations. The data used for regression is calculated primarily based on the data and delay equations (in Chapters for Basic Freeway Section, Ramps and Ramp Junctions, Multilane Rural and Suburban Highways, Signalized Intersections, Un-signalized Intersections, Urban and Suburban Arterials) provided in Transportation Research Board's report "Highway Capacity Manual".

These equations permit speeds to "decay" at different rates depending on the type of roadway. The equations take the form of

$$S = S_0 / (1+\alpha*(V/C)^{\beta})$$

Where S = Peak Speed (mph)
S_0 = Free Flow Speed (mph)
V = Service Volume (vph)
C = Capacity (vph)
α and β = BPR coefficients

The coefficient (α) and the exponent (β) are varied for different roadway groups. A higher value of "α" means a shorter flat portion of the curves (Figure 3.2.2 and Figure 3.2.3) indicating earlier reduction in speed, and on the other hand, a lower value of "β" means gentler slopes of the curves, and indicating relatively slower rate of speed reduction. The original equation developed by Bureau of Public Road (BPR) use 0.15 for α and 4 for β

The equations for five roadway groups are shown below. The average free-flow speeds for the roadway group are different. Figure 3.2.2 and Figure 3.2.3 show the equations graphically. The curves in Figure 3.2.2 depict the equations with their individual free-flow speeds while the curves in Figure 3.2.3 show the equations with a same free-flow speed of 45 mile per hour.

Speed – Flow Relationship Equations

$S = 63.5 * [1 + 0.2 * (V/C)^{8}]$ for group 1 (freeways, ramp controlled expressways)

$S = 43.8 * [1 + 0.195 * (V/C)^{8.16}]$ for group 2 (expressways, freeway-to-freeway ramps, on-ramps, rural major roads)

$S = 37.0 * [1 + 0.198 * (V/C)^{4.67}]$ for group 3 (major roads with four-way stop)

$S = 31.3 * [1 + 0.196 * (V/C)^{7.18}]$ for group 4 (urban major roads, off-ramps)
$S = 27.3 * [1 + 0.259 * (V/C)^{6.12}]$ for group 5 (minor roads)

Figure 3.2.2 – Speed – Flow Relationship Curves

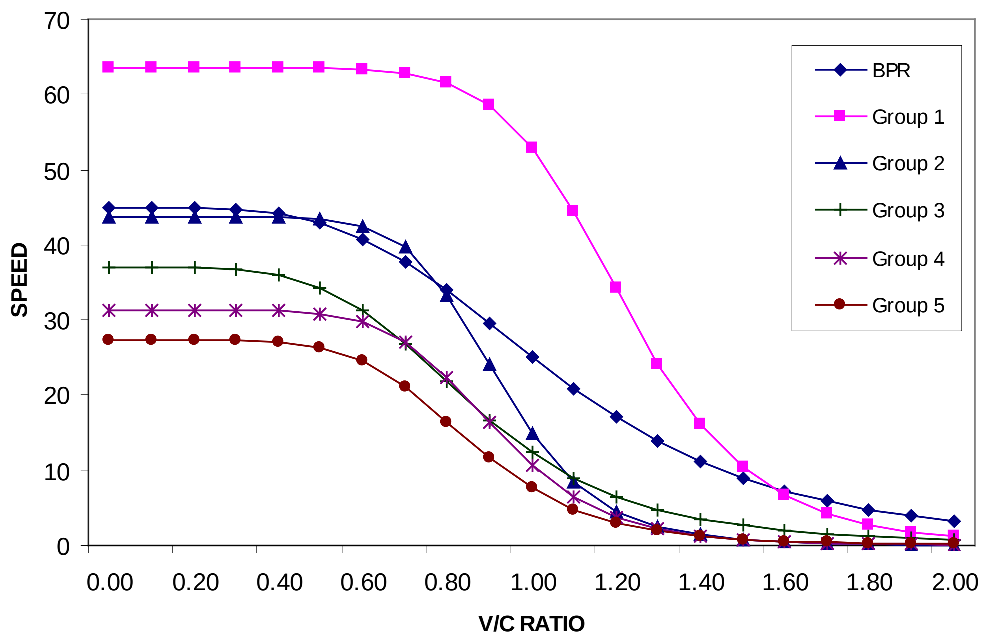
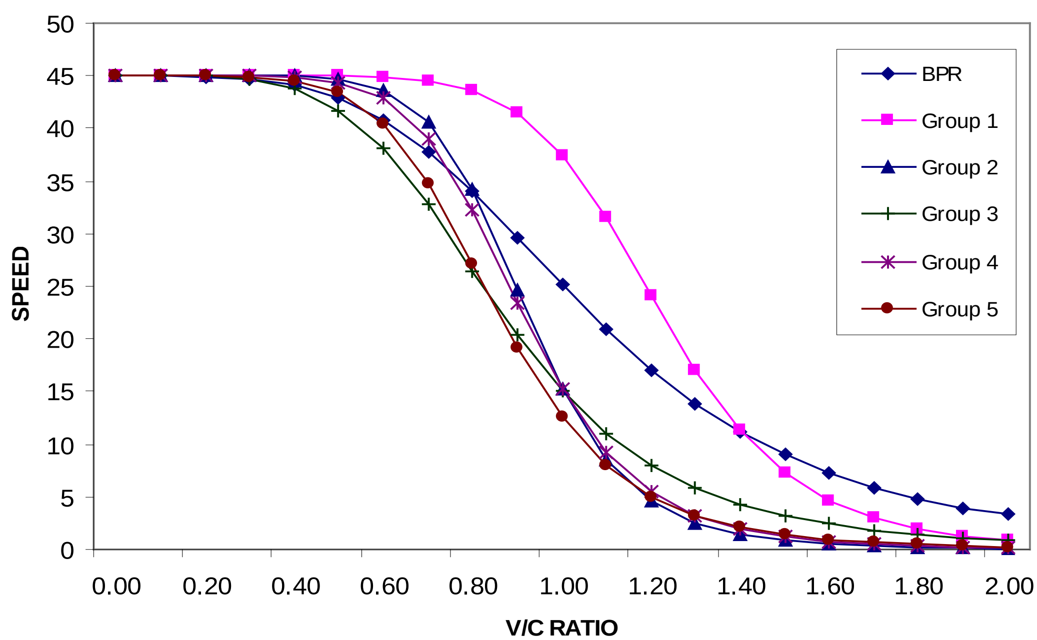


Figure 3.2.3 – Speed – Flow Relationship Curves with Same Free-Flow Speed



3.2.1.2.5 Distance and Coordinates

For the highway network, the distance coded is centerline roadway distance in hundredths of a mile. Computer software Visual Planning Environment (VIPER) are used to edit the highway network, and the link distances are calculated automatically by the software in editing, but decimal places have to be eliminated by rounding because of the requirement of PLANPAC ASCII format after conversion.

The distance is very important to the travel demand model, and the travel time is computed by dividing the coded distance by the coded speed. Link distances for centroid connectors are estimates since they are not actual roadways. Estimates are also made to attempt to derive the average travel time for trips from a zone to reach the network links. Travel time is the essential variable of logsum impedance, and critical for trip distribution, modal choice, and trip assignment. It is also used for model validation, and post processing programs such as VMT calculations, unit cost computations, etc.

Distance display relates to a coordinate system. The highway network has X and Y coordinates stored in ASCII node card file, and it can be displayed as a map in VIPER or a GIS software through defining a coordinate system, and file transformation with a link card. It also can overlay on top of a street map and show distances in real life at scaled manner.

Coordinate systems link X and Y coordinates to real-world locations. A coordinate system specifies a datum and a map projection. A datum is a mathematical representation of the shape of the earth's surface, and is defined as a spheroid, which approximates the earth. A horizontal datum provides a frame of references for measuring locations on the surface of the earth. Local datum, such as NAD1927 has an origin on the earth's surface as a control point, and geocentric datum like WGS84 does not has an initiate point, earth's center is its origin.

Map projections are systematic transformation of the spheriodal shape of the earth so that the curved, three dimensional shape of a geographic area on the earth can be represented in two dimensions, as X and Y system.

The coordinate system of the highway network is NAD 1927 State Plane Ohio South 3402, and it can be transformed easily to other coordinate systems using GIS software. However, the X and Y of the network are 1/10th of the State Plane coordinate system under the limitation of the TRANPLAN early versions. Changes are planed that the real unit NAD 1983 State Plane Ohio South 3402 will be used in future. NAD 1983 is widely used and satellite based, can be coordinated with GPS survey.

3.2.1.2.6 Other Link Data

The highway network link data is maintained at PLANPAC ASCII format because of historical reasons (compatible to ODOT main frame model), and is converted to TRANPLAN format at model run. The link data will be maintained at database format in future. Except most critical attributes discussed above such as speed, capacity, distance, functional classes, facility class and speed capacity code, there are other link attributes, and some of them are blank, and reserved for future use. More link data fields may be added after the network is converted into database format based on ODOT manual. [1]

Number of lanes: used by the model with the per lane capacity for total capacity computation. The number of lane coded is the number of through lanes. Continuous turning lanes are considered separately on a link by link basis via speed capacity code definition, or discount factor adjustments. Turn bays at intersections are ignored. Reversible lanes are considered as a lane in each direction.

Discount factor: used to increase or decrease speed and capacity because of special circumstances for a particular link. Since the roadway groups are defined based on generalized terms, and some roadways have certain conditions that may warrant a higher or lower speed and capacity than the average, for example, intense commercial development or concentrated access points or uphill grade may decrease the speeds, and down hill grade may increase the speeds. However, the usage of the discount factors should have empirical reasons, and should not be a tool to artificially fit the assignment. The limits of the discount factors are set at + - 15 percent.

Directional Counts: are 24-hour traffic counts by AB and BA direction for the 2000 base year highway network only. For one-way link, last two digits of count in AB direction represent year of count collection, for example count 20<u>99</u> means that the count was collected at year 1999. For two-way link, the last two digits of count summation on both directions represent count collection year. For the links without a count collected in 1998, 1999 or 2000, estimated counts are coded. For ODOT/KYTC estimated counts, the last two digits are “50”. For OKI estimated counts, the last two digits are “51”.

Area type: used for post model calculation and model validation. All links are classified as CBD, urban, suburban or rural, and the urban designation has been verified by 2000 census urbanized area boundaries.

Simplified area type: are either urban (1) or rural (2) based on FHWA guidance. This is not used anymore.

[1] “Highway Network Coding Procedures” Ohio Department of Transportation, Office of Technical Services, Modeling & Forecasting Section, March 2000.

District: is used to enable the aggregation and reporting of data in a spatial manner. OKI/MVRPC region has 303 districts (248 for OKI). Districts can be grouped into counties using equivalency tables.

Region Code: is used to separate OKI (1), MVRPC (2) and Miami County (3).
Number of lanes by time of day and directions: are varies because of curb parking regulations at different time periods. Number of lanes by three time periods (AM, MD, PM) and two directions (AB, BA) are used for time of day networks

Street width: is coded for AB and BA directions in feet, but not fully updated, and not used for any model calculations.

Fields of Anode leg number, Bnode leg number, turn penalty, conversion factor, parking code, cross-street functional class, exclusive turning lanes are not coded and used. Turn penalties are on a separated file and will be discussed later on.

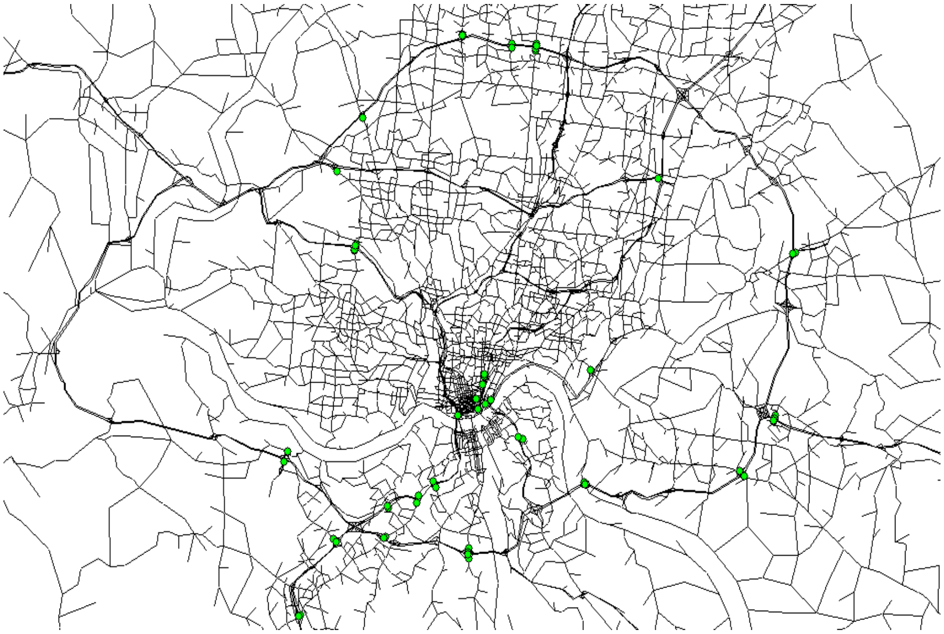
3.2.1.2.7 Terminal and Intra-zonal time

The terminal time is a component of the travel time, and is the time it takes to get to or from a vehicle on each end of the trip, and includes parking seek time and walk time. The terminal time is estimated outside the model, and the more urbanized zones have a higher terminal time than rural and suburban. Mostly it is based on the availability of parking near traffic generators. The terminal time is coded for each zone. Intra-zonal time is the average travel time of intra-zonal trips. The intra zonal time of a zone is calculated using the area of the zone.

3.2.1.2.8 Turn Prohibition

For the highway network, some traffic movements are prohibited at certain locations because of roadway configuration or traffic regulation. For example, left turn movement is prohibited at an interchange due to grade separation or no through traffic due to a traffic sign. This data is an input to highway network building along with the link and node cards. Figure 3.2.4 is a map for turn prohibition (green dots), and majority of the turn prohibitions are at interchanges.

Figure 3.2.4 – Turn Prohibitions in OKI Area



3.2.2 Contents of Highway Network Files

As mentioned before, the highway network is an abstraction of the actual roadway system with attributes illustrating the physical and operational characteristics. As a summary of discussion about the link attributes above, Table 3.2.10 presents the highway link fields at PLANPAC ASCII link card format, Table 3.2.11 presents the PLANPAC ASCII node file and Table 3.2.12 shows the fields for turn prohibition file.

Table 3.2.9 – Year 2000 highway Network Link File Format

PLANPAC FIELD NAMES	COLUMNS	TYPE	UNITS/DESCRIPTION
Jurisdiction	1	Integer	not used
A node	2 - 6	Integer	Anode number
A node leg number	7	Integer	not used
B node	8 - 12	Integer	Bnode number
B node leg number	13	Integer	not used
Distance	14 - 17	Integer	implied decimal between columns 15 and 16
Field Option (AB)	18	Character	T(time)or S(speed)
Speed (AB)	19 - 21	Integer	implied decimal between columns 20 and 21
A node turn penalty codes	22 - 24	Integer	not used (listed as 0)
Hourly Capacity (AB)	25 - 28	Integer	vehicles/lane/hour
Conversion Factor (AB)	29 - 31	Integer	not used (listed as 100)
Directional Count (AB)	32 - 36	Integer	24-hour count

PLANPAC FIELD NAMES	COLUMNS	TYPE	UNITS/DESCRIPTION
Street Width (AB)	37 - 38	Integer	in feet
Parking Code (AB)	39	Integer	not used
Number of Lanes (AB)	40	Integer	Range: 1-9
Field Option (BA)	41	Character	T(time)or S(speed)
Speed (BA)	42 - 44	Integer	implied decimal between columns 43 and 44
B node turn penalty codes	45 - 47	Integer	not used (listed as 0)
Hourly Capacity (BA)	48 - 51	Integer	vehicles/lane/hour
Conversion Factor (BA)	52 - 54	Integer	not used (listed as 100)
Directional Count (BA)	55 - 59	Integer	24-hour count
Street Width (BA)	60 - 61	Integer	in feet
Parking Code (BA)	62	Integer	not used
Number of Lanes (BA)	63	Integer	Range: 1-9
Facility Class	64	Integer	1 - Freeway 2 - Expressway 3 - Ramps 4 - Major Road 5 - Minor Road 6 - Centroid Connector 7- HOV lane 8 - HOV ramp
Functional Class	65	Integer	0 - Freeway 1 - Interstate 2 - Major Arterial 3 - Minor Arterial 4 - Major Collector 5 - Minor Collector 6 - Local 7 - Centroid Collector 8 - Ramp 9 - Expressway
Cross-Street Functional Class	66 - 67	Integer	not used
Simplified Area Type	68	Integer	1 - all links in 1995 urban area 2 - all other links
Exclusive Turn Lanes	69 - 70	Integer	Truck Prohibitions: 0 – trucks allowed on the link 1 – trucks not allowed on the link
Speed/Capacity Code	71 - 72	Integer	See OKI Methodology Report for details
District Number	73 - 75	Integer	Range: 1-302
Discount Factor	76 - 78	Integer	Range: ± 99 %
Area Type	79	Integer	1 – CBD 2 - Urban 3 - Suburban 4 – Rural
Region Code	80	--	Planning Region: 1 – OKI Council

PLANPAC FIELD NAMES	COLUMNS	TYPE	UNITS/DESCRIPTION
			2 – MVRPC, Montgomery & Greene Co. 3 – MVRPC, Miami Co.
Truck Percentage	81 - 83	Integer	Est. Percent of Trucks/Volume (freeways only)
Number of lanes, AM period (AB)	84 - 85	Integer	--
Number of lanes, PM period (AB)	86 - 87	Integer	--
Number of lanes, MD period (AB)	88 - 89	Integer	--
Number of lanes, AM period (BA)	90 - 91	Integer	--
Number of lanes, PM period (BA)	92 - 93	Integer	--
Number of lanes, MD period (BA)	94 -95	Integer	--

Table 3.2.10 – Year 2000 highway Network Node File Format

COLUMNS	FORMAT	DESCRIPTION
1	A1	‘X’
2-6	I5	Node number
7-12	I6	X-coordinate
13-18	I6	Y-coordinate

Table 3.2.11 – Turn Prohibition File Format

COLUMNS	FORMAT	DESCRIPTION
1	A1	‘T’
2-6	I5	‘From’ node
7-11	I5	‘Through’ node
12-16	I5	‘To’ node

3.2.3 Highway Projects Included to E+C Highway Network

The E+C highway network is one of the future year networks with existing and committed (E+C) projects, and the E+C projects are transportation improvement projects in FY2002-2005

Transportation Improvement Program (TIP). These are projects for which funding is allocated and thus "committed" for implementation. Year 2000 highway network is a base year network, represents existing traffic condition, and is used for creation of the E+C network and other future year networks by adding TIP or long range plan projects. The OKI and MVRPC base and future year networks are developed separately by two MPOs, and then consolidated together by OKI. The OKI 2000 network was developed based on 1995 network, and the projects from 1995 to 2000 were examined and added. In order to create a clean base network, the 2000 network alignments, link attributes and traffic counts were thoroughly checked and updated, and errors were corrected.

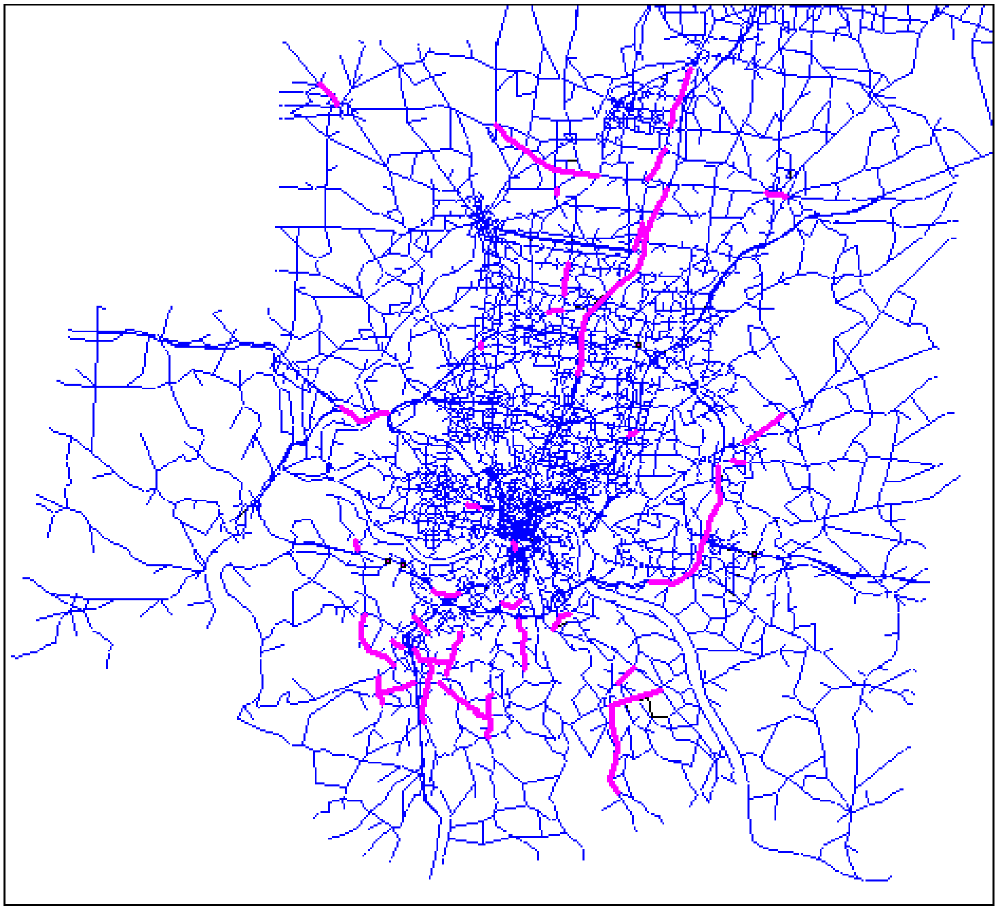
After the completion of 2000 highway network, the capacity improvement projects on the TIP were added to the base network to create the E+C network. Table 3.2.13 lists the TIP projects, and Figure 3.2.5 show them on a map

Table 3.2.12 – Projects on the E + C Network

PID	County	Facility	Location	Description
351.0	Boone	US25	SR1829 to SR338	Widen to 5 lanes (Add 2 lanes)
64.01	Boone	US42	SR3060 to Florence W. Corp Line	Widen to 4 lanes
146.0	Boone	Connector	Hopeful Road to Mall Road	New Roadway
8000.10	Boone	I-275	@ KY-212	Airport Access Interchange Improvements
316.0	Boone	SR1017 (Turfway Rd.)	US25 to SR717 (Thoroughbred Ave)	Widen to 5 lanes
158	Boone	KY 536	US 42 to I-75	Add 2 lanes
152.00	Boone	KY 237	From I-275 north 3 miles toward KY8	Reconstruct and Widen to 3 lanes
8001.0	Boone	KY 237	KY 18 to US 42	Widen KY18 to Pleasant Valley 5 lanes, P Valley to US 42 3 lanes
	Boone	KY1829	US42 to KY1303	Widen to 5 lanes
14114	Butler	CR113	Bridge over Great Miami River	Replace, Add 2 Lanes
17381	Butler	Muhlhauser Road	SR4 to SR747	Widening to 5 Lanes
14919	Butler	SR747	0.75 Mi S of Smith Rd to Tylersville Rd	Widen to 5 Lanes
10751 (Ham)	Butler	I-75	Ham Co Lane to 0.33 Mi N of Hamilton-Mason Rd	Add 1 lane each direction
10752	Butler	I-75	North of Hamilton-Mason to War. Co. Line	Add 1 lane each direction
18961	Butler	CR 19	SR129 to Princeton Rd.	Widen to 3 lanes
21063	Butler	CR 119	Princeton Rd. to Milliken Rd.	Widen to 3 lanes
20499	Butler	SR 63 Extension	US127 Eastward to Existing SR63 at SR4	New 2-lane facility
21740	Butler	SR 747	1.1 Mi. N. of Port Union Road	Bridge Replacement
17947	Butler	CR19	Oxford State Road to War Co	Widen to 4 Lanes
24440	Butler	US 27	Locust/Church St to Corp line	Add Center Turn Lane
352.0	Campbell	Extension	US27 to KY9	Extension

PID	County	Facility	Location	Description
46.1	Campbell	US27	1.0 Mile South of KY10 to Parkside Drive	Widening to 5 Lanes
46.2	Campbell	US27	Parkside Drive to KY154	Widening to 5 Lanes
125.0	Campbell	KY2938	Poole's Creek Road No. 1 - US27 to AA Hwy	Reconstruction
156.0	Campbell	KY 547	AA Highway to KY10	Reconstruction, add climbing lane
7948	Clermont	SR28	1.56 East of I-275 to 1.98 West of SR 48 (w)	Widen to 4 lanes
20056	Clermont	SR32	At Stonelick-Oliver Branch Road	New Interchange
12436	Clermont	I-275	0.30 Miles S of US50 to 0.58 Miles S of SR32	Add Third Lane
10914	Clermont	I-275	0.58 Miles South of SR32 to Hamilton Co Line	Add Third Lane
7606	Clermont	SR131	Wolfpen-Pleasant Hill to Buckwheat Rd.	Two-way left turn lanes
4909	Hamilton	Queen City Avenue	White to Sunset Ave.	Add 2 lanes
8347	Hamilton	US127	I-275 to 0.07 Miles South of Waycross Road	Widen to 4 lanes
17621	Hamilton	US22	Kenwood Road to Hosbrook Road	Widen to 7 lanes
10914	Hamilton	I-275	Hamilton Co Line to 0.30 Mi S of Five Mile Road	Add Third Lane
10751	Hamilton	I-75	Glendale-Milford Rd. to Butler County Line	Add one Lane
20128	Hamilton	I-275	@Reed Hartman Hwy.	Upgrade Interchange
313.1	Kenton	KY17	Pelley Road to KY16	Widening to 5 Lanes
71.02	Kenton	KY1303	Dudley Pike to Lindenwood Drive	Widening to 5 Lanes
71.01	Kenton	KY1303	Lindenwood Drive to Autumn Road	Widening to 5 Lanes
71.03	Kenton	KY1303	Autumn Road to Richardson Road	Widening to 5 Lanes
344.0	Kenton	SR16	I-275 to SR1501	Widen to 5 lanes
286.02	Kenton	New Connector	2200'E of Dolwick to 2800'W of E-CS Road	Construct New Connector
286.03	Kenton	New Connector	Erlanger-Crescent Spring Road to 2800'W	Construct New Connector
162.0	Kenton	KY 536	Boone Co Line to KY 17	Add 2 Lanes
350.0	Kenton	New KY 1072	KY 17 to KY 16	New 2-lane connector
NP	Warren	CR19	US122 to SR73	Widen to 4 Lanes
4932	Warren	SR63/SR123	0.28 Miles West of West Street to SR48	Widening to 3 Lanes
17947 (But)	Warren	CR19	But Co Ln to US122	Widen to 4 Lanes

Figure 3.2.5 – Projects on E+C highway network



3.2.4 Highway Link Data Summary Tables for 2000 and E+C

3.2.4.1 Link Data Summaries

Table 3.2.14 and Table 3.2.15 show 2000 and E+C highway network attribute summaries for OKI/MVRPC consolidated region, and Table 3.2.16 and Table 3.2.17 display these link data for OKI region only. These summaries described the characteristics of the highway network such as link counts, route miles, lane miles, per-lane capacity, peak and off-peak speeds, and numbers of link without counts. Table 3.2.18 and Table 3.2.19 demonstrate the comparison of 2000 and E+C network, and describe the growth.

Table 3.2.13 – 2000 Highway Network Summaries for OKI/MVRPC Region

Functional Class	Link Count	Route Miles	Lane Miles	Capacity/ Lane	Avg. Off-peak Speed	Avg. Peak Speed	Zero Counts
Freeway	1,173	342.21	1,878.00	1,871.06	66.55	62.64	254
Major Arterial	2,368	648.24	2,087.85	1,075.43	38.60	35.55	684
Minor Arterial	2,605	909.49	2,397.38	951.40	37.20	34.46	874
Major Collector	4,378	1,942.25	4,158.22	808.62	34.61	32.73	1,315
Minor Collector	525	444.86	890.12	580.14	31.79	31.28	157
Local	1,521	741.25	1,509.99	554.49	29.05	28.35	797
Centroid Connector	4,797	1,945.14	0.00	0.00	22.87	22.87	4,797
Ramp	1,425	240.89	280.94	958.10	36.59	30.05	494
Expressway	340	101.05	414.49	1,716.84	56.01	55.32	105
Total	**19,132**	**7,315.37**	**13,616.99**	**1,008.81**	**33.22**	**31.69**	**9,477**

Table 3.2.14 – E+C highway Network Summaries for OKI/MVRPC Region

Functional Class	Link Count	Route Miles	Lane Miles	Capacity/ Lane	Avg. Off-peak Speed	Avg. Peak Speed	Zero Counts
Freeway	1,182	342.17	1,979.85	1,872.15	66.51	63.27	261
Major Arterial	2,367	647.67	2,106.85	1,073.53	38.54	35.70	685
Minor Arterial	2,609	910.26	2,491.88	954.36	37.22	34.77	877
Major Collector	4,417	1,966.24	4,250.22	811.48	34.61	32.79	1,322
Minor Collector	525	444.57	897.68	586.08	31.87	31.41	157
Local	1,524	743.39	1,516.07	554.37	29.05	28.35	798
Centroid Connector	4,802	1,944.67	0.00	0.00	22.87	22.87	4,802
Ramp	1,432	242.41	284.86	958.48	36.66	30.22	518
Expressway	350	103.52	435.31	1,716.03	56.01	55.66	113
Total	**19,208**	**7,344.89**	**13,962.72**	**1,015.71**	**33.23**	**31.81**	**9,533**

Table 3.2.15 – 2000 Highway Summaries for OKI Region

Functional Class	Link Count	Route Miles	Lane Miles	Capacity/ Lane	Avg. Off-peak Speed	Avg. Peak Speed	Zero Counts
Freeway	917	236.735	1323.691	1853.921	67.913	62.564	91
Major Arterial	1,455	421.1	1429.431	1053.565	37.908	33.547	20
Minor Arterial	1,346	552.34	1466.831	999.632	36.049	32.513	14
Major Collector	2,589	1246.959	2691.072	826.012	33.101	30.306	41
Minor Collector	287	250.38	501.16	595.763	29.337	28.453	5
Local	491	253.12	529.54	544.982	27.888	25.978	33
Centroid Connector	2,503	1069.99	0	0	21.126	21.126	2503
Ramp	1,020	160.32	185.21	967.833	39.173	30.657	324
Expressway	207	65.4	264.05	1734.435	54.122	53.603	19

Total or average	**10,815**	**4256.344**	**8390.985**	**1057.511**	**32.753**	**30.379**	**3050**

Table 3.2.16 – E+C Highway Summaries for OKI Region

Functional Class	Link Count	Route Miles	Lane Miles	Capacity/Lane	Avg. Off-peak Speed	Avg. Peak Speed	Zero Counts
Freeway	917	235.38	1,374.52	1,854.90	67.84	63.269	91
Major Arterial	1,457	421.77	1,443.93	1,052.28	37.861	33.766	20
Minor Arterial	1,349	552.87	1,541.22	1,003.07	36.086	32.921	14
Major Collector	2,619	1,268.11	2,769.46	830.00	33.128	30.414	41
Minor Collector	287	250.09	508.72	606.02	29.47	28.683	5
Local	494	254.98	535.08	544.72	27.889	25.987	33
Centroid Connector	2,508	1,070.60	0.00	0.00	21.129	21.129	2,508
Ramp	1,030	161.63	187.31	967.59	39.15	30.682	328
Expressway	207	65.40	264.05	1,734.44	53.964	53.444	19
Total or average	**10,868**	**4,280.83**	**8,624.29**	**1,061.26**	**32.752**	**30.526**	**3,059**

Table 3.2.17 – Percentage Comparison Between 2000 and E+C Highway Network for OKI/MVRPC Region

Functional Class	Link Count	Route Miles	Lane Miles	Capacity/ Lane	Avg. Off-peak Speed	Avg. Peak Speed	Zero Counts
Freeway	0.77%	-0.01%	5.42%	0.06%	-0.07%	1.00%	2.76%
Major Arterial	-0.04%	-0.09%	0.91%	-0.18%	-0.15%	0.41%	0.15%
Minor Arterial	0.15%	0.08%	3.94%	0.31%	0.05%	0.89%	0.34%
Major Collector	0.89%	1.24%	2.21%	0.35%	0.01%	0.16%	0.53%
Minor Collector	0.00%	-0.07%	0.85%	1.02%	0.24%	0.42%	0.00%
Local	0.20%	0.29%	0.40%	-0.02%	-0.01%	-0.01%	0.13%
Centroid Connector	0.10%	-0.02%	0.00%	0.00%	0.00%	0.00%	0.10%
Ramp	0.49%	0.63%	1.40%	0.04%	0.18%	0.58%	4.86%

Expressway	2.94%	2.44%	5.02%	-0.05%	-0.01%	0.61%	7.62%
Total Percentage	**0.40%**	**0.40%**	**2.54%**	**0.68%**	**0.05%**	**0.38%**	**0.59%**

Table 3.2.18 – Percentage Comparison Between 2000 and E+C Highway Network for OKI Region

Functional Class	Link Count	Route Miles	Lane Miles	Capacity/Lane	Avg. Off-peak Speed	Avg. Peak Speed	Zero Counts
Freeway	0.00%	-0.57%	3.84%	0.05%	-0.11%	1.13%	0.00%
Major Arterial	0.14%	0.16%	1.01%	-0.12%	-0.12%	0.65%	0.00%
Minor Arterial	0.22%	0.10%	5.07%	0.34%	0.10%	1.25%	0.00%
Major Collector	1.16%	1.70%	2.91%	0.48%	0.08%	0.36%	0.00%
Minor Collector	0.00%	-0.12%	1.51%	1.72%	0.45%	0.81%	0.00%
Local	0.61%	0.73%	1.05%	-0.05%	0.00%	0.03%	0.00%
Centroid Connector	0.20%	0.06%	0.00%	0.00%	0.01%	0.01%	0.20%
Ramp	0.98%	0.82%	1.13%	-0.02%	-0.06%	0.08%	1.23%
Expressway	0.00%	0.00%	0.00%	0.00%	-0.29%	-0.30%	0.00%
Total percentage	0.49%	0.58%	2.78%	0.35%	0.00%	0.48%	0.30%

3.2.5. Maps of Highway Attributes for 2000 Network

Figures below show link attributes of 2000 highway network. E+C network link data are very similar to that of base network except added projects and absence of the traffic counts. Some maps show the attributes in AB direction only such as number of lanes .

Figure 3.2.6 – Area Type (Based Census 2000 urban boundary map)

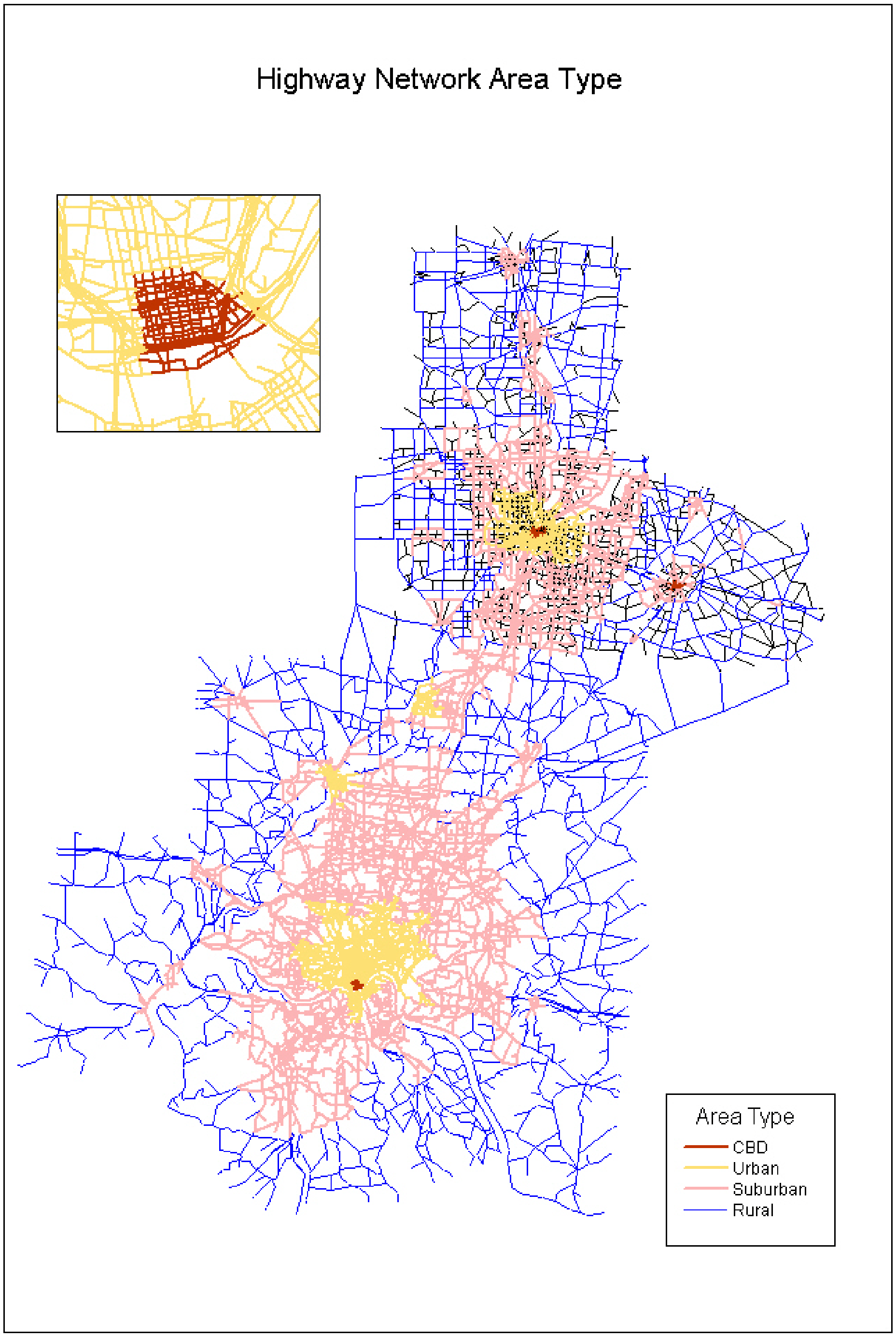


Figure 3.2.7 – Facility Class

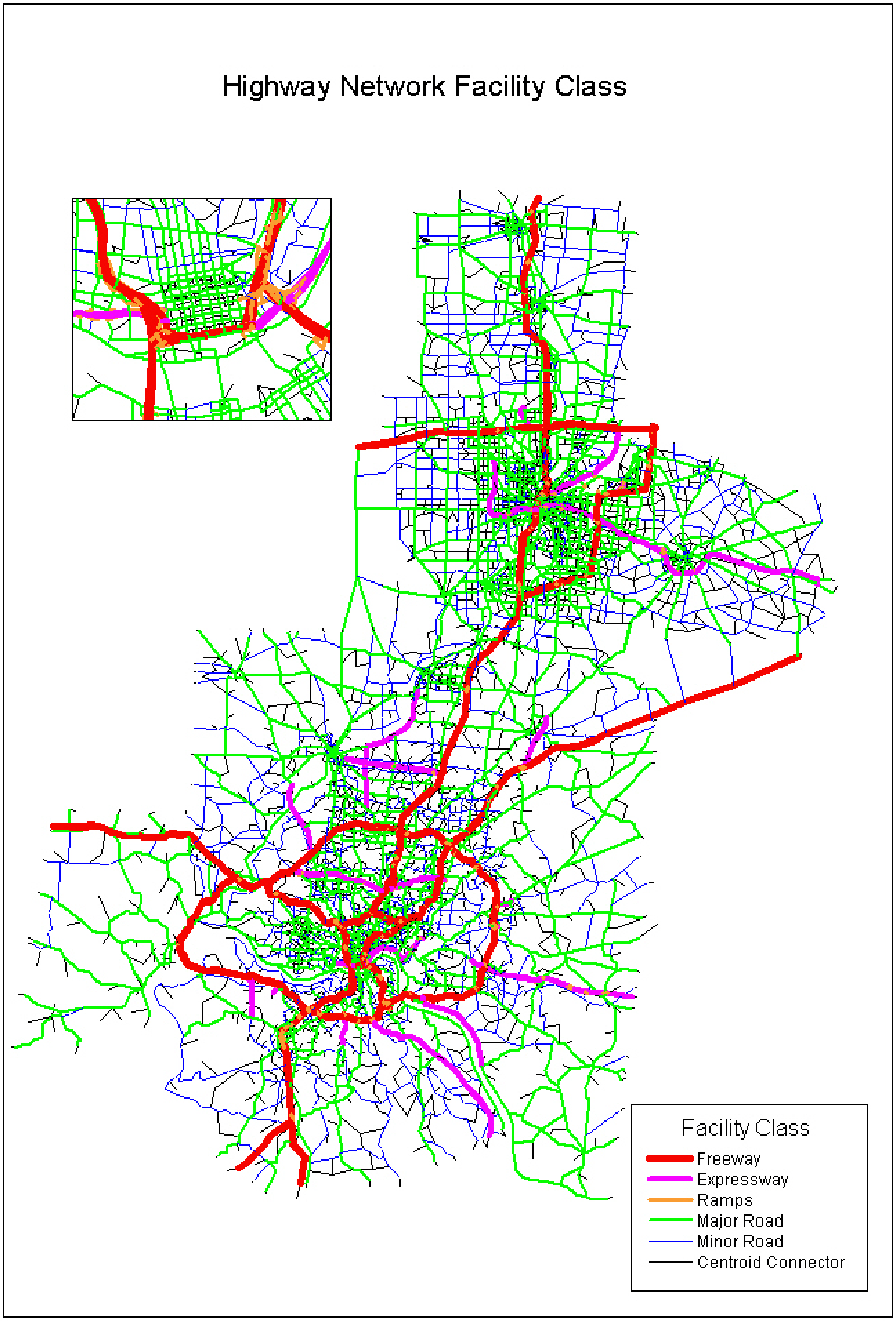


Figure 3.2.8 – Functional Class

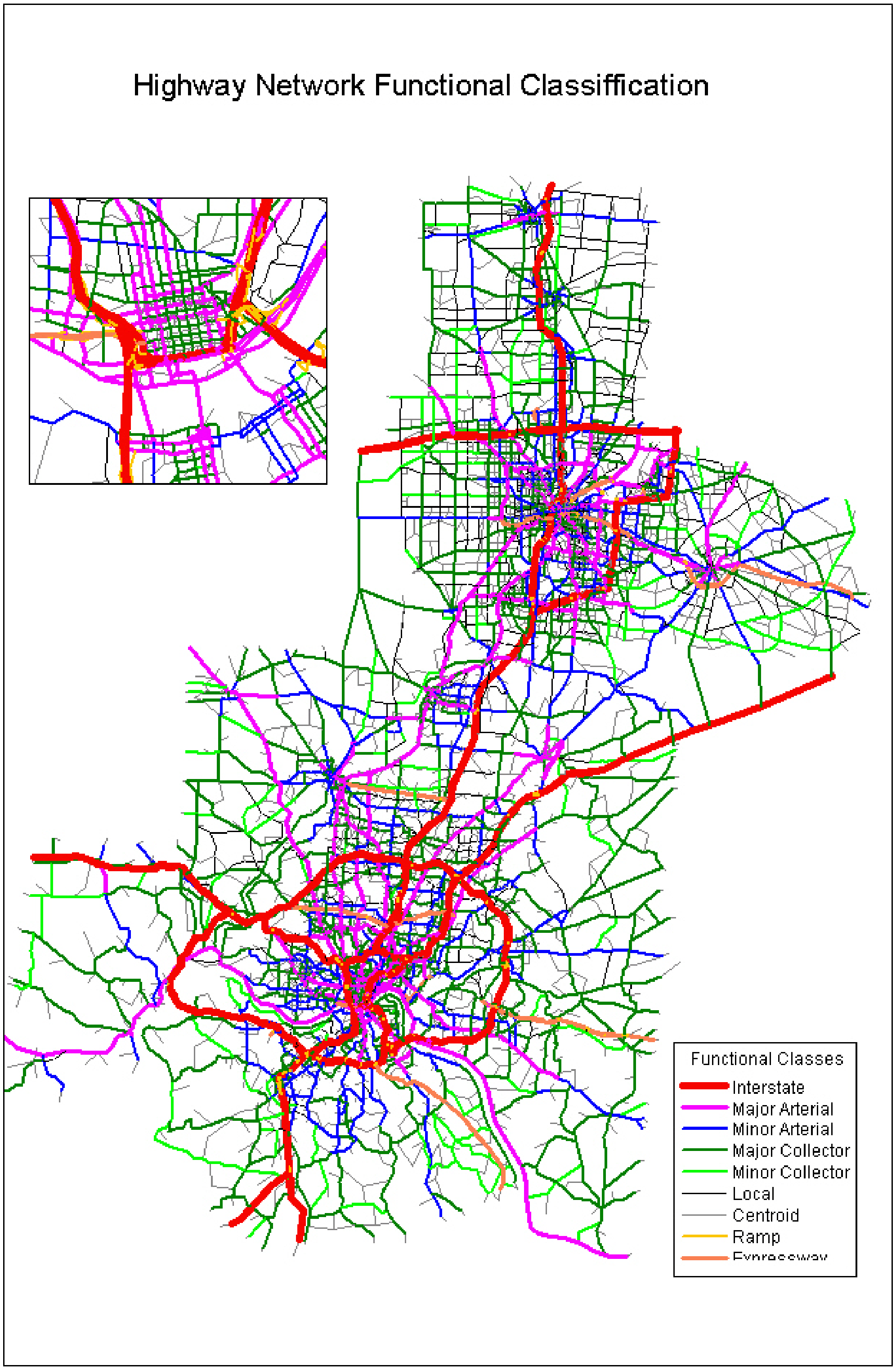


Figure 3.2.9 – Speed (Off Peak speed)

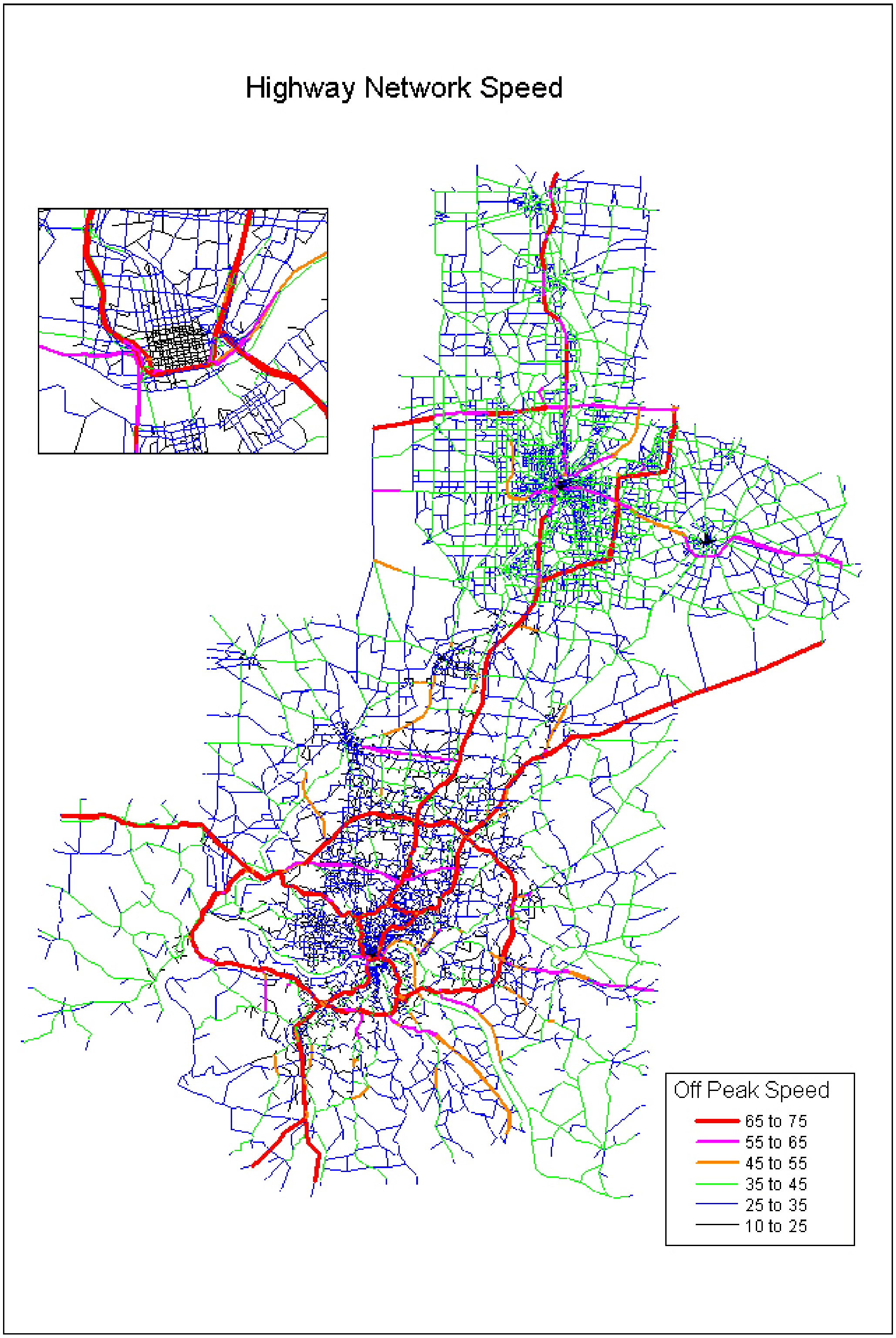


Figure 3.2.10 – Number of Lanes (AB Direction)

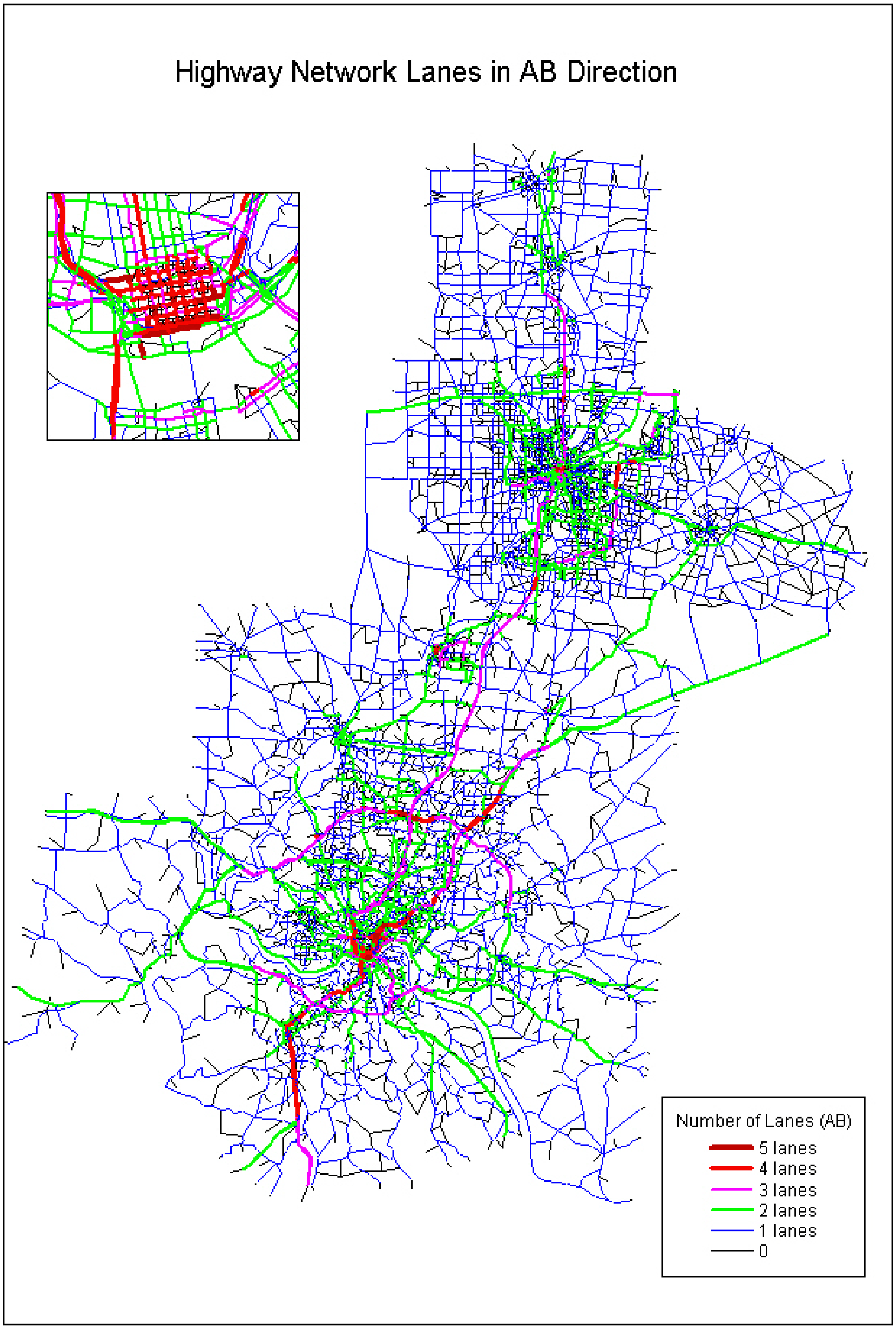


Figure 3.2.11 – Traffic Count

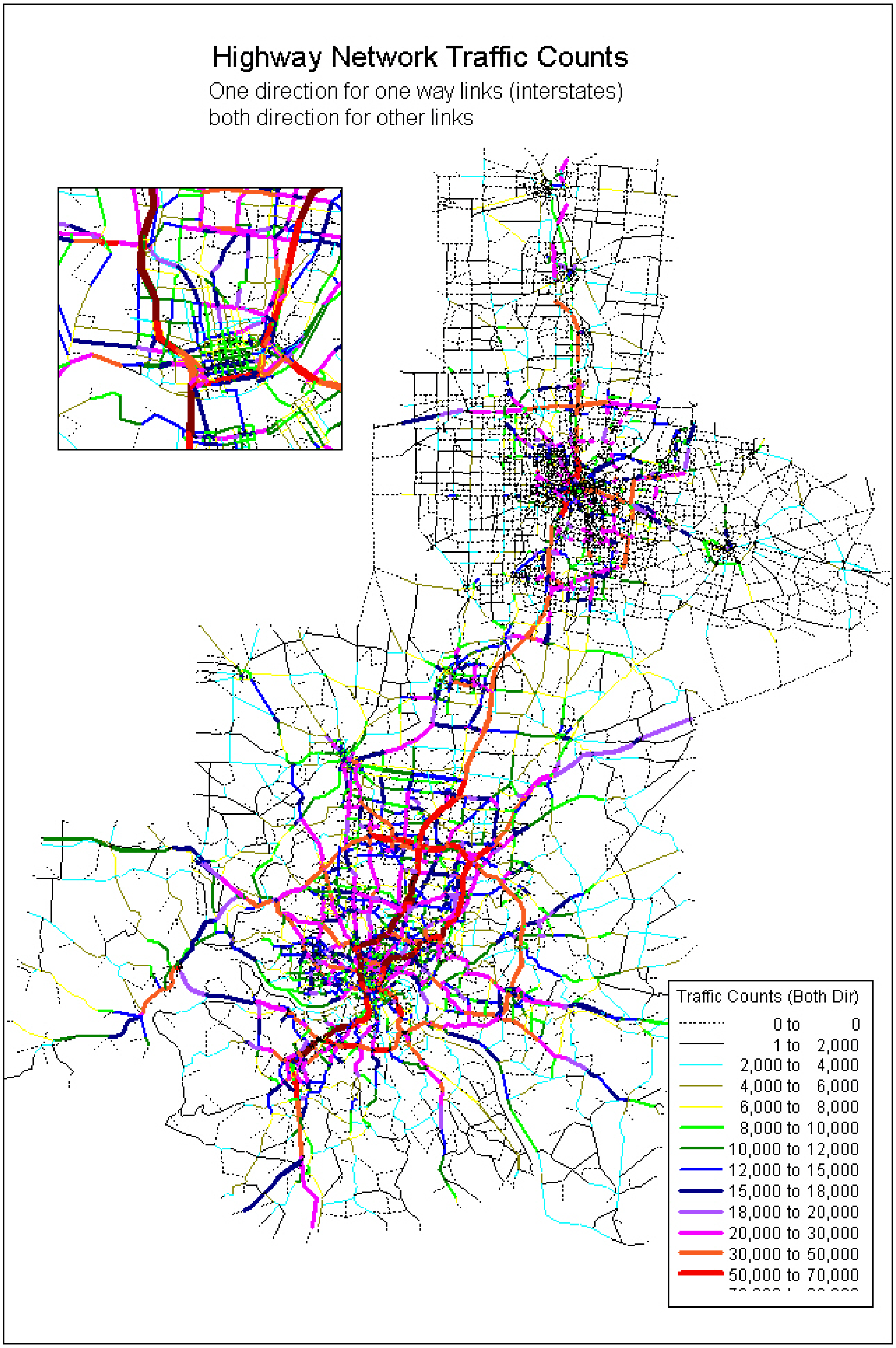


Figure 3.2.12 – Per-Lane Capacity for AB Link

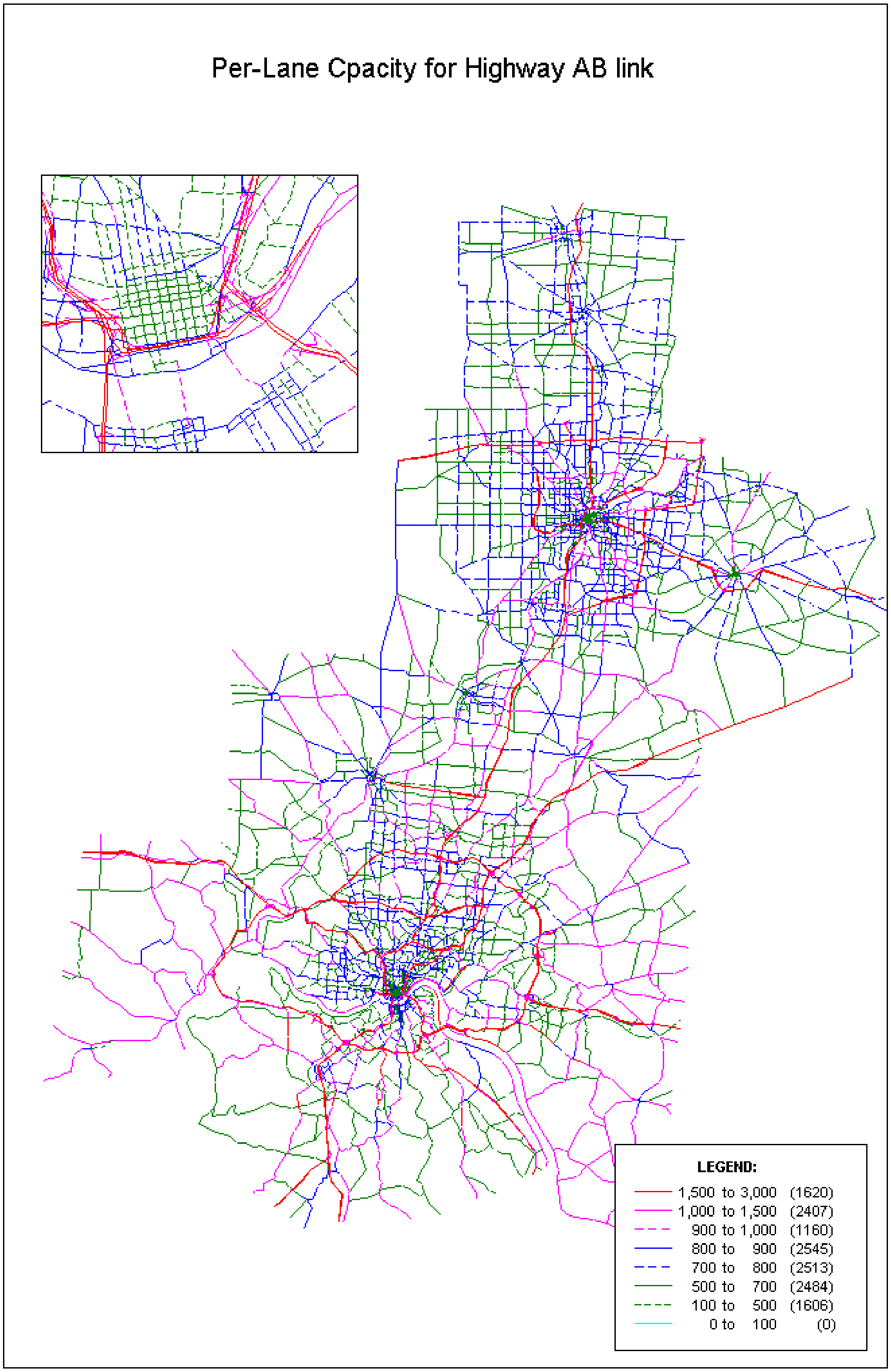


Figure 3.2.13 – Total Counts vs. Total Capacity

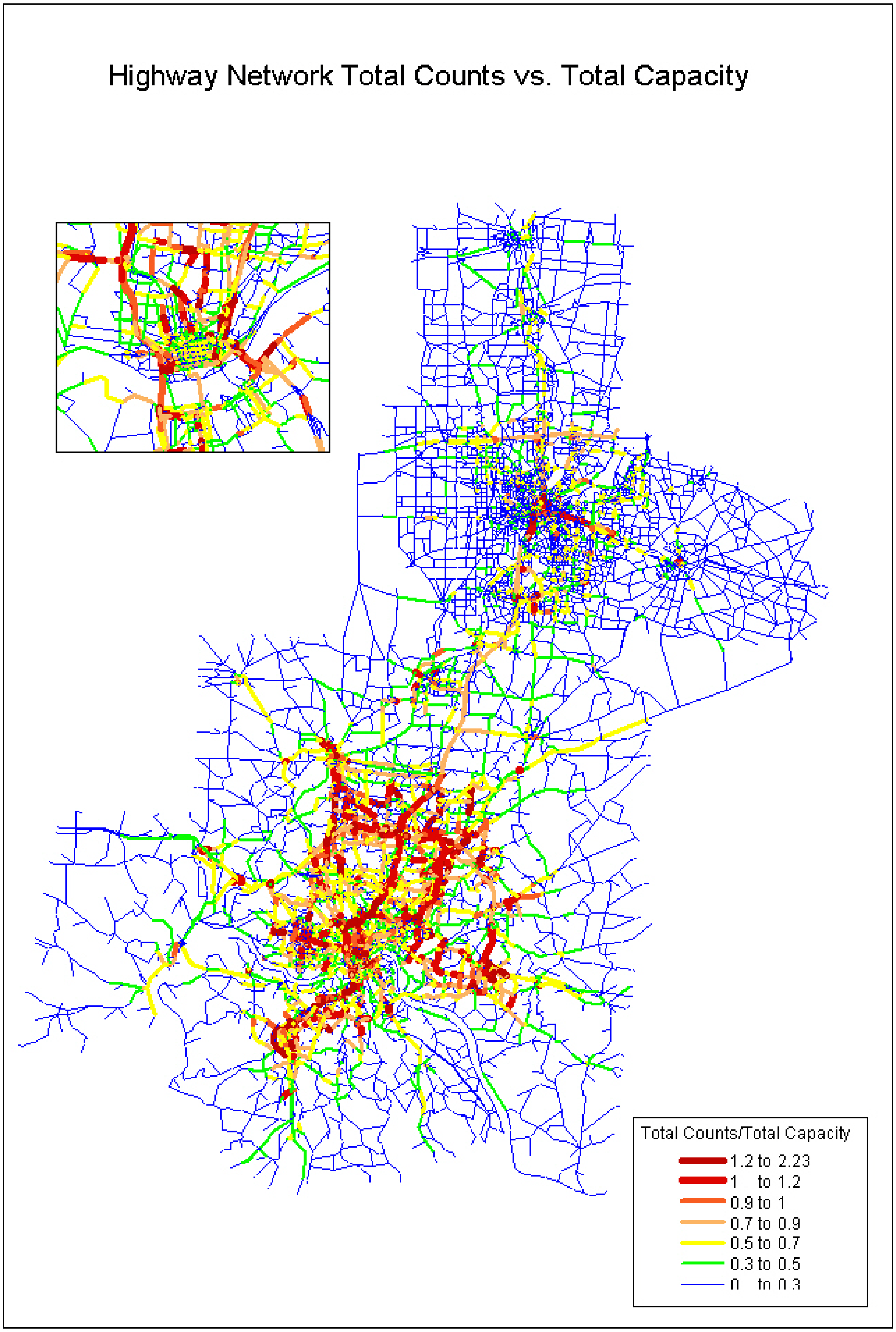


Figure 3.2.14 – Facility Class and Speed Capacity Code

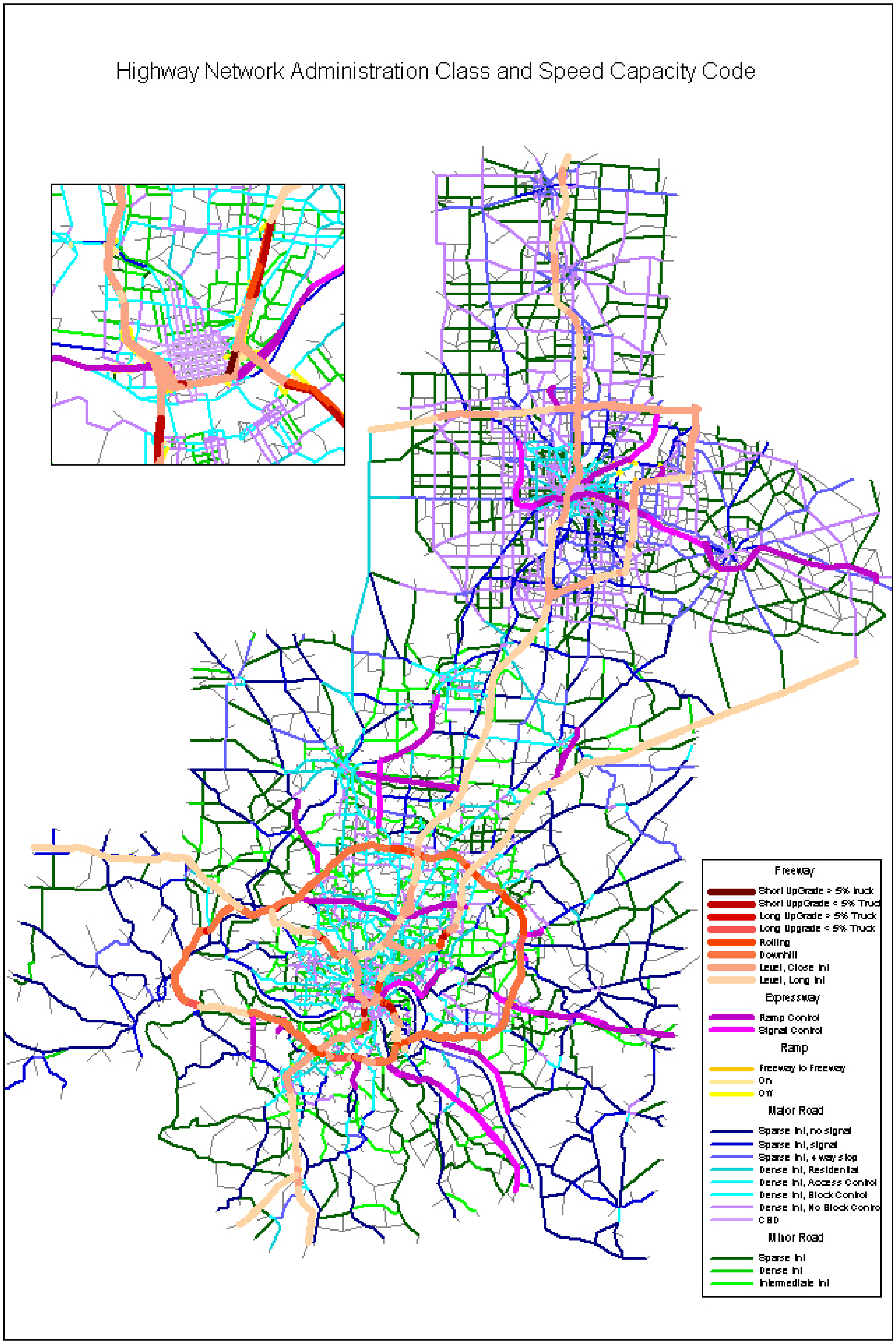


Figure 3.2.15 – Districts

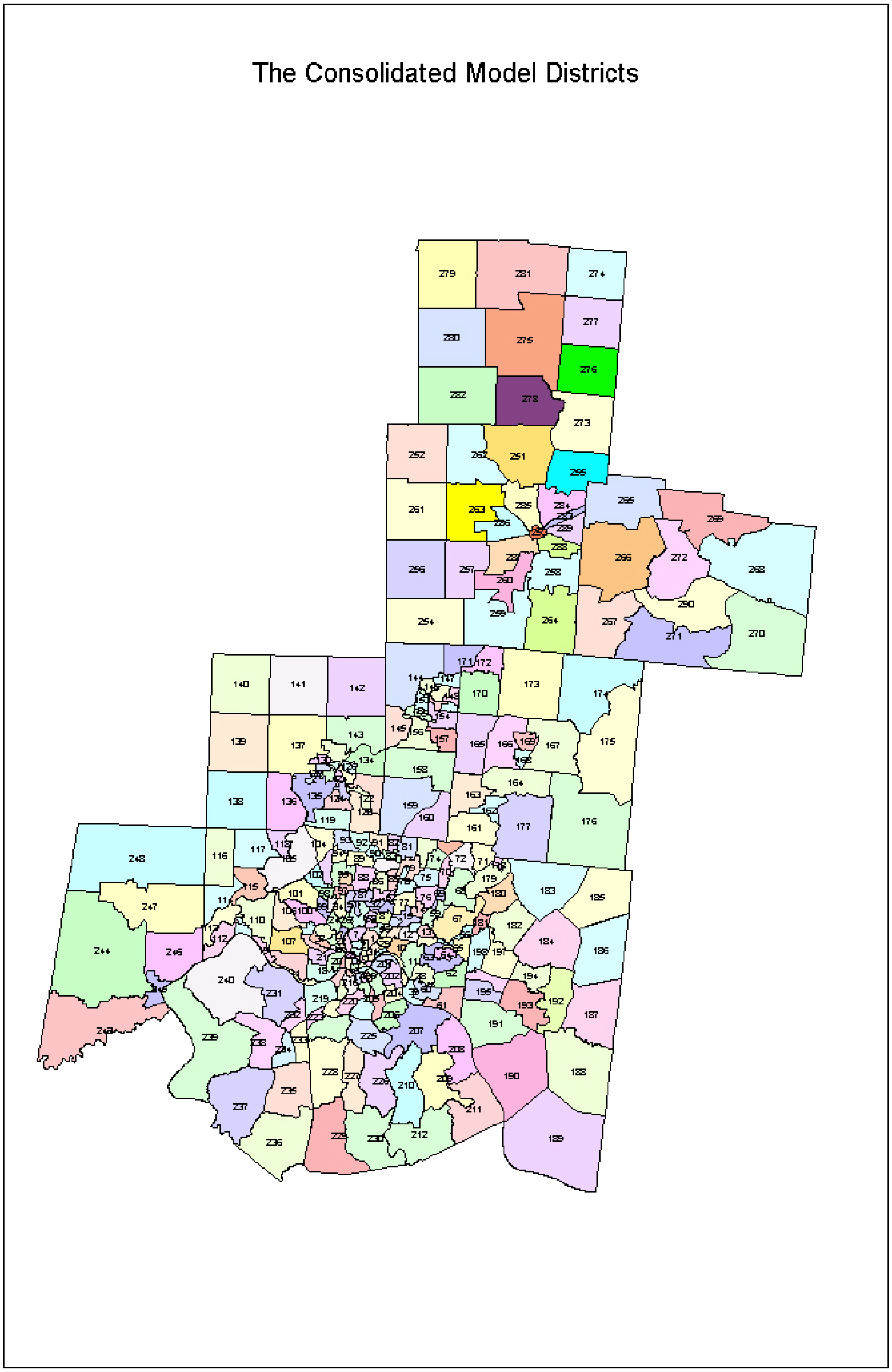
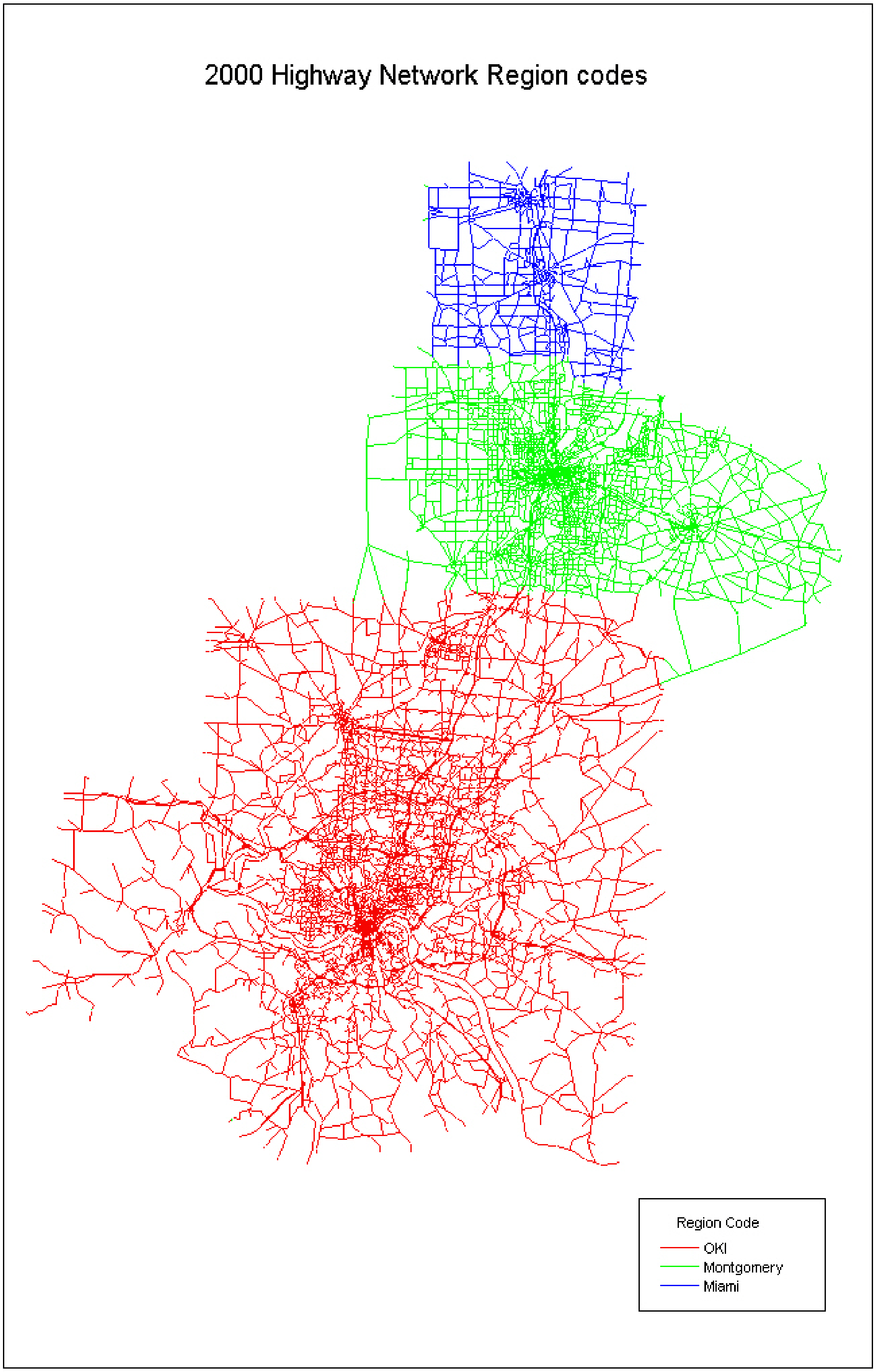


Figure 3.2.16 – Region Code


2000 Highway Network Region codes
Region Code
OKI
Montgomery
Miami

3.3 Development of the Transit Networks

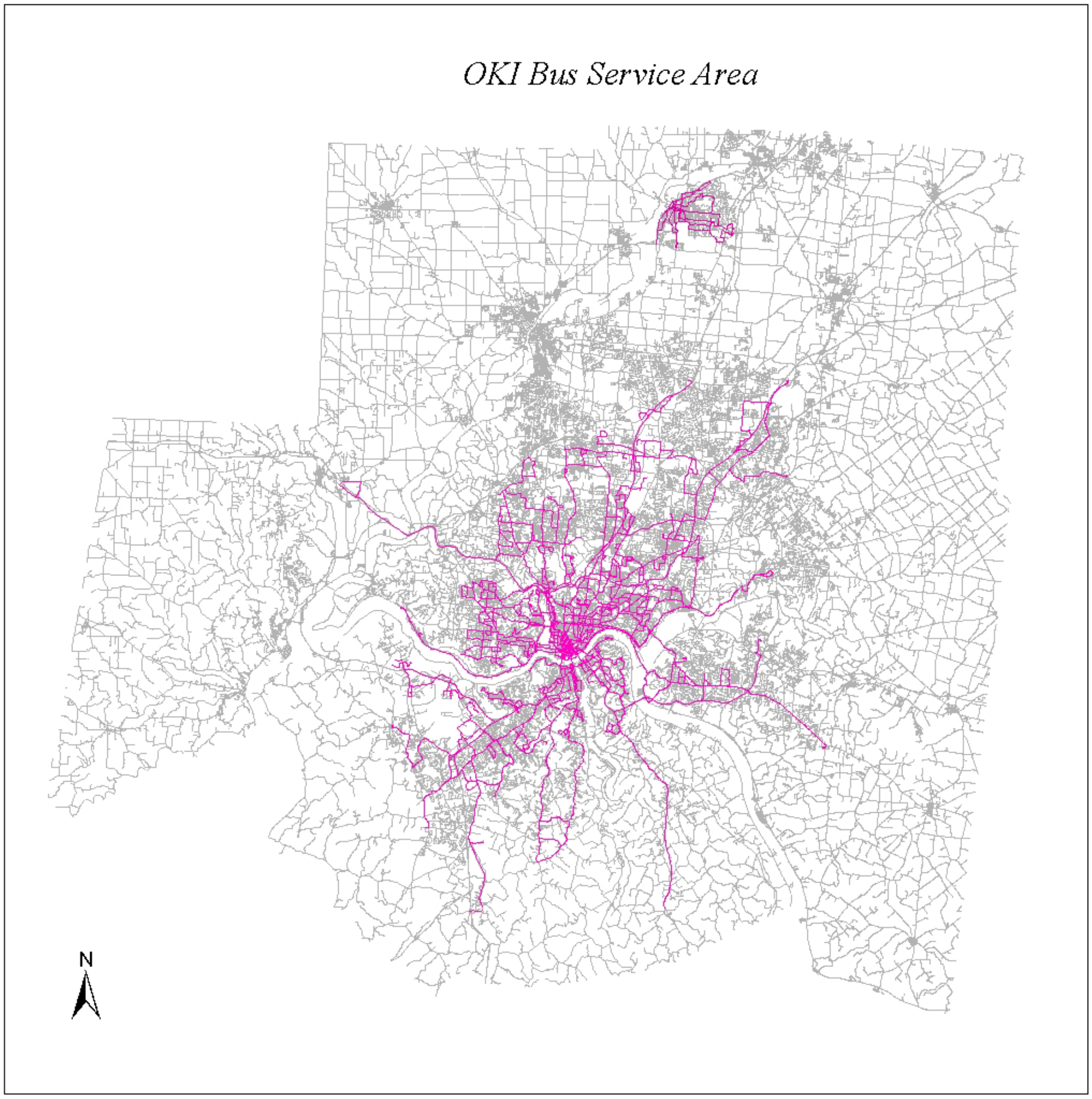
The bus routes are coded to be used with the INET transit network building program within TRANPLAN. The main advantage of INET is that transit operating speeds are based on the highway speeds. After reading the transit networks, the speed-delay tables (discussed below), and the highway networks, INET builds peak and off-peak networks in UNET format. The two transit networks (peak and off-peak) are then used for transit path building and transit assignment.

The bus is just one part of the overall transit network. Access links (sidewalks, walk connectors and drive connectors), park/rides, and fixed-guideway stations are some examples of the information the model incorporates as part of the transit network. Sidewalks in the areas served by many transit routes are identified and coded to allow transfer between transit stops by walk. Other access links are created using special programs that search the transit network and the highway network for the best access to transit. Connectors are automatically created each time the model is executed. Park/rides and fixed-guideway stations are listed for each alternative. These help in developing alternative-specific sidewalks and auto connectors.

3.3.1 Coding Transit Networks

The transit network consists of two parts: a peak period and an off-peak period. For scheduling and operational statistic purposes, the peak period is defined as 6:30 a.m. to 8:30 a.m. and the off-peak 8:30 a.m. to 3:30 p.m. Each period has three files: a transit route file, a transit link file, and exclusive guideway route files. Figure 3.3.1 shows the bus routes in OKI region simulated in year 2000 transit network.

Figure 3.3.1 – Year 2000 Bus Routes (Metro and TANK) in OKI Region



In the route file (ROUTES## files), the bus transit lines are described in terms of its operational characteristics. All of the characteristics are taken from the transit schedules distributed by each transit agency. Each line are assigned:

- Line number (L),
- Company (C),
- Mode (M),
- Headway (H),
- Period of operation (PERIOD),
- Direction (ONEWAY),
- Corridor Code (RG),
- Identification Field (ID), and
- Node list.

A line number is simply an incremental record of the transit lines in the network. The company and mode of the line is assigned according the guidelines in the following section. Headway is defined as the length of the period of operation divided by the number of complete runs. For example, if a bus made 3 complete runs in the peak period, the corresponding headway would be 40 (120 minutes ÷ 3 runs). The period of operation is simply the upper and lower time limits for the period (6:30 a.m. to 8:30 a.m. for the peak period and 8:30 a.m. to 3:30 p.m. for the off-peak period).
A period which has no service is assigned a headway value of 0.0. The maximum value allowed by the transit network building program is 99.9 minutes. The identification field is simply a character string describing the line. Corridor code is the transit corridor the line is assigned to. The direction is a logical flag (either true or false) indicating whether or not the bus “drives” the node list in both directions.

The node list is a catalog of the nodes representing the bus path. The nodes are from the highway network, not special transit nodes. In INET, the bus routes are coded using the same nodes and links as the highway network. There are some cases where this is not adequate. One solution is to code the route to “double back”; that is, the route will go one direction and then appear to turn around 180 degrees. This solution is used on routes that have loops at the beginning or end of an inbound or outbound trip. Another solution uses special transit links. This procedure is done when the first solution is inadequate or not practical.

The transit link file (TRLINK.## files) represents links used only by transit vehicles. Sometimes when coding bus routes in INET, the highway geometry is unable to adequately represent the bus route. In these cases, a special transit link must be added. Transit links have to include: nodes, distance (or speed), directional flag, and the allowable modes. The nodes, taken from the highway network, are the endpoints of the link. The distance (or speed) of the link is either estimated using accurate maps or, in rare cases, simply asserted. Allowable modes are explicitly stated for each link because all modes will not use a link in most cases. The direction flag, as in the route files, indicates whether or not the bus “drives” the link in both directions.

Because of their exclusive nature, LRT (Light Rail Transit) / CRT (Commuter Rail Transit) / BRT (Bus Rapid Transit) routes are placed in their own separate input files. The routes are coded by time period (LRT##, CRT##, or BRT## files). When the transit network build step is activated, the LRT/CRT/BRT lines are appended to the bus route files. Coding LRT/CRT /BRT routes using INET is quite similar to coding buses. The single difference is that all links between stops must be transit links, not highway links as used in normal bus coding. Transit links are coded by period and coded in transit link file (TRLINK.## files).

The bus route, LRT/CRT/BRT route and transit link files must be created for each alternative. These files are manually edited outside the model job stream.

In addition, a station data file is created to better model park/ride and kiss/ride behavior. This file, STATDATA, includes characteristics of rail stations, park-and-ride lots, and major transit centers, including: nearest network node, nearest TAZ centroid, availability of parking, maximum driving distance, parking cost (if appropriate), and additional parking and drop-off impedances. The file also contains a usage flag so a common file can be set up for a range of alternatives. The attributes in the STATDATA file are used in the computation of the impedances for modal choice. They are not used in path finding nor are they appended directly to the transit skims. This is because the in-vehicle, out-of-vehicle, and cost elements each have different coefficients in the impedance calculation.

INET allows lines to be one-way or two-way in direction. Because many of the routes of METRO and TANK rely on one-way streets and loops, most of the lines in this model are one-way. Most routes, therefore, consist of two one-way lines. There are two exceptions to this rule. One is express buses that do not carry an outbound trip. The other exception are lines that require more than two lines to reflect rate variations.

A few route variations may not be represented in the transit network. These include: non-revenue trips (i.e., short trips to and from the garages), special event buses (e.g., Labor Day Fireworks, etc.), and those buses that occur once a day.

3.3.2 Modes and Companies

There are four transit authorities in the OKI region and one in MVRPC region. Four additional ones are added for future year forecasting purposes.

- Company 1 - Southwest Ohio Regional Transit Authority (SORTA/METRO).
- METRO, a service of SORTA, serves the city of Cincinnati and parts of Hamilton and Clermont Counties. Both peak and off-peak services are coded.

- Company 2 - Transit Authority of Northern Kentucky (TANK).
- The Transit Authority for Northern Kentucky services Northern Kentucky and downtown Cincinnati. Both peak and off-peak services are coded.
- Company 3 - Middletown Transit System (MTS).
- Middletown, Ohio is served by the Middletown Transit System. MTS offers only local service and is represented by line one through 10, mode six. All routes have

60-minute headways.

- Company 4 - Butler County Transit Authority.
  Butler County Transit Authority services the Hamilton! and Fairfield areas. Since 1993, this system has offered point deviation bus service. Unfortunately, there is no direct methodology for representing this type of service within TRANPLAN. Therefore, the transit service for Hamilton!, Ohio was coded to match the 1990 model. It consists of lines 11 through 29, mode six.
- Company 6 – Miami Valley Regional Transit Authority (MVRTA).
  Miami Valley Regional Transit Authority services the Dayton area. Both peak and off-peak services are coded.
- Company 7 –MVRPC Light Rail System
- Company 8 – OKI Commuter Rail System
- Company 9 – OKI/MVRPC Intercity Express Bus
- Company 10 – OKI Light Rail System

Figure 3.3.2 – Year 2000 Transit Companies in OKI/MVRPC Region

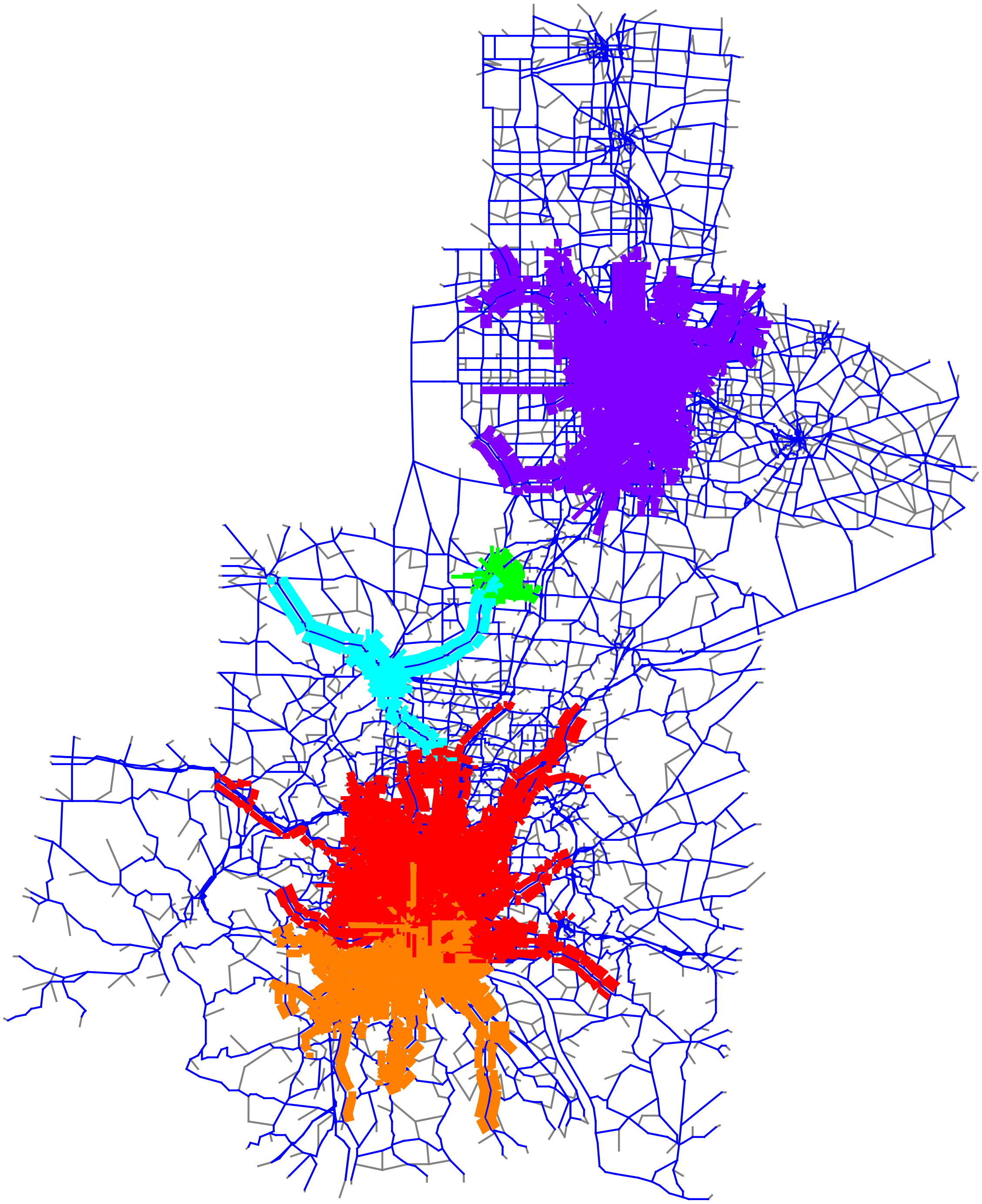


Table 3.3.1 shows the mode definitions for the model. In OKI region, METRO and TANK express service is combined into mode 5. METRO local service is designated as mode 4, while the other local services (TANK, Hamilton!, and Middletown) are placed in mode 6. In MVRPC region, MVRTA local is designed as mode 9 and express as mode 10. Modes 7 and 8 are added for LRT and CRT.

Table 3.3.1 – Transit Mode Definitions

Mode	Description
1	Walk connector
2	Auto connector
3	Sidewalk
4	SORTA local bus service
5	SORTA and TANK express bus service / Bus rapid transit / Intercity express bus
6	TANK, Middletown, and Hamilton! local bus service
7	Light rail transit
8	Commuter rail transit
9	MVRTA local bus service
10	MVRTA express bus service

3.3.3 Fares

There are three type of transit fares used in the OKI region: boarding, transfer, and zone charge. Boarding fares are charged for patrons boarding a bus at the beginning of their trip (i.e., not transferring). Transfer fares, typically lower than boarding fares, are imposed when a patron transfers from another system or within the same system. Zone charges are levied in addition boarding and transfer charges. METRO is currently the only transit system in the OKI region with these charges. METRO divides their service region into three zones: inside the Cincinnati corporate limits, outside the Cincinnati corporate limits but within Hamilton County, and outside Hamilton County. Each $0.30 charge is applied when riders enter one zone from another zone. Transit trips that do not enter two different zones are not assessed the zone charge. Table 3.3.2 shows the 2000 fare system in the OKI/MVRPC region.

Boarding and transfer fares are coded using the TRANPLAN program. Zone charges for METRO are added using the FAREZONE program. For each bus route, the program reads each link and determines whether or not the link crosses a fare zone. If it does, FAREZONE outputs an added fare file, which is included for transit path building. FAREZONE is run for both the peak and off-peak periods prior to path building.

Table 3.3.2 – Transit Fares

		METRO	TANK	Middletown	Butler County	MVRTA
PEAK	Boarding Fare	$0.80	$0.75	$1.00	$0.55	$0.90
	Transfer to METRO	$0.10	$0.40	n/a	n/a	n/a
	Transfer to TANK	$0.35	free	n/a	n/a	n/a
	Zone Charge	$0.30	n/a	n/a	n/a	n/a
MIDDAY	Boarding Fare	$0.65	$0.75	$1.00	$0.55	$0.90
	Transfer to METRO	$0.10	$0.35	n/a	n/a	n/a
	Transfer to TANK	$0.40	free	n/a	n/a	n/a
	Zone Charge	$0.30	n/a	n/a	n/a	n/a

Note: all fares are in 2000 dollars.
n/a - not applicable

3.3.4 Speeds

INET characterizes the rate a transit vehicle traverses a highway link as a proportion of the highway speed. The transit speed function is called a speed-delay curve, which consists of three lines and two sets of "breakpoints". Each line is separated by a breakpoint, a point at which the relationship between the transit speed and the highway speed changes. The assignment of the breakpoints and a listing of the breakpoints can be found in Tables 3.3.3, 3.3.4, and 3.3.5. Figure 3.3.3 is an example of an INET speed-delay curve. At highway speed X1, the ratio between the transit and highway speed lowers. For instance, the first line (up to and including X1) indicates that the transit vehicle operates at a high percentage of the highway speed. The second line shows transit operation at a lower percentage of the highway speed. The second line shows transit operating at a lower percentage of the highway speed. The last line is horizontal, which serves as a speed "barrier" to the transit vehicle. Transit vehicles will not exceed this speed regardless of the highway speed.

The relationship between bus and highway speeds is implemented in the model using the speed/delay relationships in program INET. This feature relates the appropriate bus operating speed to the transit mode and the area type and facility type of the highway link over which the vehicle is operating. The speed/delay curves are also used to provide speeds for walk and auto access links, although these are set elsewhere in the model.

For the model, a series of bus routes were identified which operated over a range of link characteristics and areas within the region. For each selected route, time checks were determined from the published schedule and the most appropriate area type and facility type traversed between the time checks was identified. Relationships between transit time and highway time was noted for the various links, which were then grouped into similar area type and facility type categories. Speed/delay relationships were computed for each group and the INET parameters were estimated. The network was then rebuilt and the resulting times compared to the schedule times, with some refinements made to the curves.

It was also found necessary to create two slightly different sets of peak and off-peak speed/delay curves, especially for express routes operating on freeways.

Table 3.3.3 – Speed Delay Curve Assignment

		Facility Type					
Modes	**Area Type**	**Freeway**	**Expressway**	**Ramps**	**Major Roads**	**Minor Roads**	**Centroid Connectors**
4,5,6	**CBD**	3	3	8	6	6	2
9,10	**CBD**	3	3	8	11	11	2
4,5,6	**Urban**	10	10	10	7	7	2
9,10	**Urban**	10	10	10	12	12	2
4,5,6,9,10	**Suburban**	5	5	10	9	9	2
4,5,6,9,10	**Rural**	5	5	10	9	9	2

Figure 3.3.3 – Sample INET Speed Delay Curve

Table 3.3.4 – INET Peak Speed Delay Curves

Curve	First Breakpoint		Second Breakpoint	
	Highway Speed	Bus Speed	Highway Speed	Bus Speed
1	30	2.5	70	2.5
2	30	30	70	70
3	26	26	43	35
4	18	8	32	12
5	39	36	60	55
6	20	8	35	12
7	23	12	47	18
8	18	10	37	15
9	23	13	49	18
10	35	30	60	50
11	20	10	46	16
12	18	5	32	7

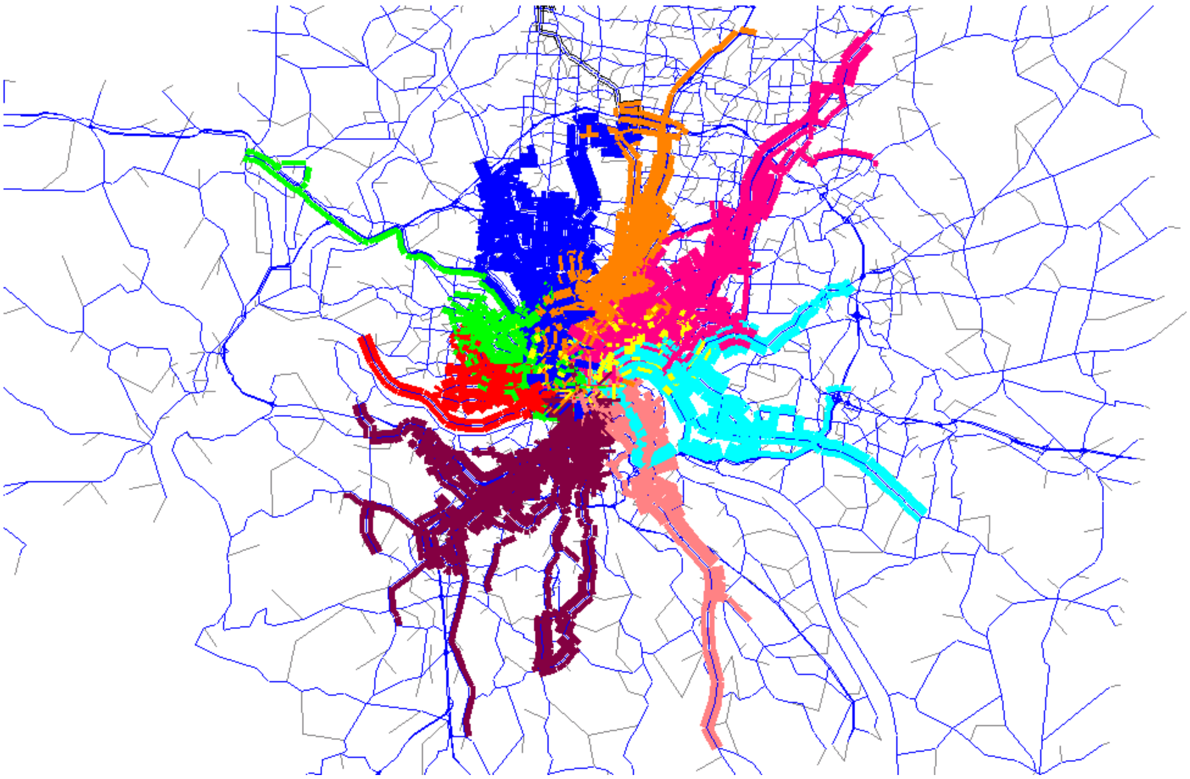
Table 3.3.5 – INET Off-peak Speed Delay Curves

Curve	First Breakpoint		Second Breakpoint	
	Highway Speed	Bus Speed	Highway Speed	Bus Speed
1	30	2.5	70	2.5
2	30	30	70	70
3	26	26	43	35
4	18	8	32	12
5	42	42	55	50
6	18	8	32	12
7	20	12	46	18
8	18	10	37	15
9	24	13	48	18
10	35	33	50	45
11	20	10	46	16
12	18	5	32	7

3.3.5 Comparison of Network and Observed Operational Characteristics

The 2000 transit network characteristics were summarized and compared to the observed characteristics to ensure the network was reasonably close to existing conditions. Table 3.3.6 and Table 3.3.7 lists network and observed operational characteristics for AM peak and midday periods. The characteristics are listed by transit corridor. A map of the transit corridors is shown in Figure 3.3.4.

Figure 3.3.4 – Transit Corridors in OKI Region



The observed number of bus runs for each line was taken from the operators' bus schedules. The number of bus runs is based on the AM peak period from 6:30 am - 8:30 am and the midday period from 8:30 – 3:30. The network number of bus runs was calculated by dividing the network vehicle miles of travel (VMT) by the network route miles of each line. Since the maximum headway which can be coded into the network is 99.9 minutes, the network bus runs for lines whose observed headway is over 99.9 minutes is misrepresented. This in turn misrepresents the network VMT and VHT. This occurs more often in midday period. Route miles are derived form the highway network. The observed route travel times are derived form the bus schedules for AM peak and Midday periods. The network travel times are calculated using highway link times and speed-delay curves. The run times for the network are slightly higher than the observed for AM peak period and slightly lower for midday period. This indicates inconsistency of travel times on bus schedules and the times calculated form the highway network. On some routes, may have several variations of one primary route contributing different run times. Network simplification is partly responsible for discrepancies.

Table 3.3.6 – OKI 2000 Transit Network Operating Characteristics (AM Peak Period)

CORRIDOR	OBS Bus Runs	NET Bus Runs	NET Route Miles	OBS Run Time	NET Run Time	OBS VMT	NET VMT	OBS VHT	NET VHT
1. Price Hill	46	43	162	649	649	459	422	33	30
2. Western Hills	105	106	215	876	1022	1090	1075	82	83
3. Colerain / Winton	93	89	397	1330	1862	1380	1314	104	98
4. Reading / Vine	119	123	384	1556	1615	1529	1603	93	98
5. Montgomery / Madison	107	108	489	1732	1976	1561	1492	102	100
6. Eastern	60	56	283	769	888	993	928	50	47
7. Crosstown	70	70	135	659	675	589	579	50	47
8. Kenton County	126	127	489	1660	2031	1506	1525	108	109
9. Campbell County	64	65	228	952	879	587	592	40	41
SYSTEM-WIDE TOTAL	**790**	**787**	**2782**	**10183**	**11597**	**9694**	**9531**	**662**	**653**

Table 3.3.7 – OKI 2000 Transit Network Operating Characteristics (Midday Period)

CORRIDOR	OBS Bus Runs	NET Bus Runs	NET Route Miles	OBS Run Time	NET Run Time	OBS VMT	NET VMT	OBS VHT	NET VHT
1. Price Hill	73	79	108	438	377	732	788	42	45
2. Western Hills	220	260	199	941	810	2044	2398	141	163
3. Colerain / Winton	117	118	249	982	1014	1660	1664	113	113
4. Reading / Vine	260	271	273	1348	1145	2350	2478	162	175
5. Montgomery / Madison	139	151	256	1157	1063	1611	1741	112	120
6. Eastern	43	44	110	328	328	754	778	39	40
7. Crosstown	216	243	118	589	499	1602	1696	114	124
8. Kenton County	248	297	408	1238	1350	2487	3400	156	200
9. Campbell County	98	127	231	1003	800	853	1171	54	73
SYSTEM-WIDE TOTAL	**1414**	**1590**	**1952**	**8024**	**7386**	**14093**	**16115**	**933**	**1053**

3.3.6 Sidewalks

Sidewalks have been added to the transit network to allow walk access to all transit options in downtown areas. Also, in dense developments, walking may be the chosen mode for a particular trip pattern.

Sidewalks, defined as mode 3, are located in the downtown areas of Cincinnati, Covington, Newport, Hamilton!, Middletown, and Carlisle/Franklin. The sidewalk models in Cincinnati, Covington, and Newport are set up as grids; that is, each street is a "route". Each city has a designated range of lines in the transit network. These lines can be found in the SIDEWALK.PK (for the peak period) and SIDEWALK.OFF (for the offpeak period) files. The split sidewalk files allow the possibility of having period-specific sidewalk networks. In most cases, however, they will be identical. Table 3.3.8 shows the line range corresponding to each city.

Table 3.3.8 – Sidewalk Line Ranges

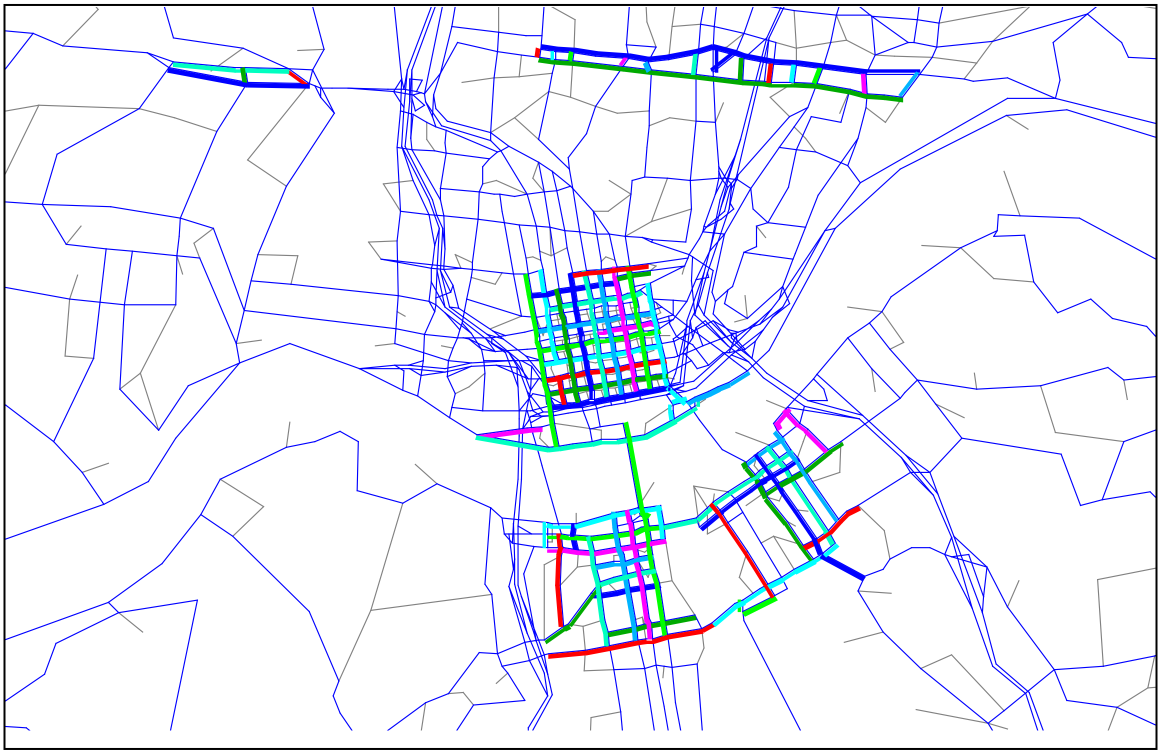
Line Range	City
1 - 49	Cincinnati
50 - 99	Covington
100 - 149	Newport
150 - 199	Carlisle/Franklin and Middletown
200 - 255	Hamilton!

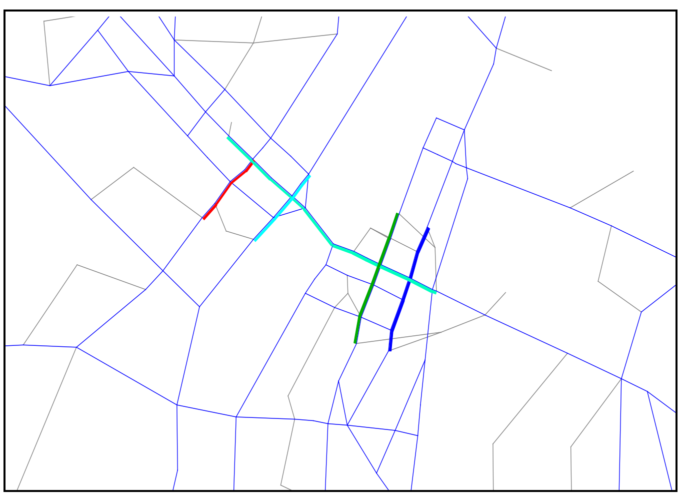
In Cincinnati, the grid ranges from Mehring Street to 13th Street and from Central Avenue to Broadway. Additional sidewalks have been placed along the riverfront area. Other sidewalks in Cincinnati can be found on Taft & McMillan and Queen City & Westwood Avenues to allow access to transit routes operating directionally on these one-way pairs. In Covington, the sidewalk system stretches from 2nd Street to 12th Street and from Pike Street (east of I-71/75) to Garrard Street. The Newport grid system extends from the Fourth and 11th Street bridges to I-471 and from 2nd to Carothers Road. The Roebling Bridge, 4th Street, and 12th Street bridges also serve as walk links.

The sidewalk links in Hamilton! and Middletown are much simpler models. In these cities, sidewalks are created solely to connect the downtown centroids with all local bus routes. Sidewalks appear in Hamilton! On Main, Third, Second, B, and D Streets. The walk links in Middletown are located on Verity Parkway, Central & Main Streets, and Garfield & Iglehart Streets.

In the Carlisle/Franklin area, the walk link exists on 2nd Street from Miami Avenue to Main Street.

Figure 3.3.5 – Sidewalk Links in Year 2000 Transit Network



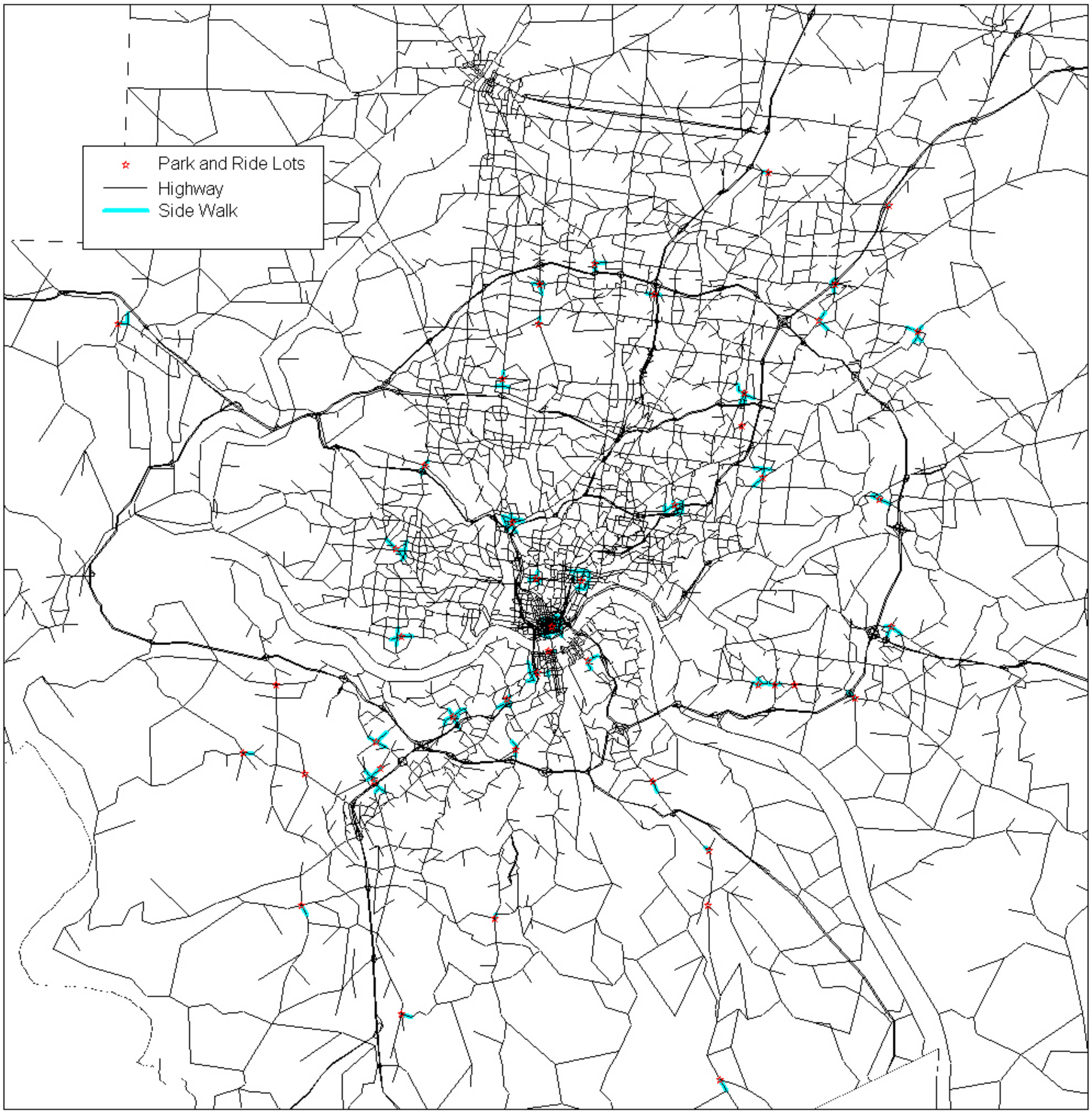


3.3.7 Transit Access Coding

Transit access coding is provided through a largely automated process to facilitate the development of access connectors for a variety of transit alternatives. As noted below, provision is made to modify or supplement the automated coding and more elaborate coding modifications could accommodated through rather minor changes in the overall program control files. A total of six special-purpose programs are used to perform this coding.

A special-purpose program, SIDECN, reads the highway link file, coordinate file, and station data file and prepares additional sidewalk links if they are needed to provide access to these facilities from nearby zones. A sidewalk link is a representation of the transit user's ability to walk from transit/transfer station to either their destination or another transit service. SIDECN finds sidewalk links by searching highway links within one-half mile of the transit/transfer stations listed in the STATDATA.yya file. This process recognizes the tendency of transit users to walk relatively longer distances to major transit facilities and avoids the need to provide special centroid-to-station links which often overstate transit accessibility. The program also produces a special data set containing the facilities flagged as used in the station data file for input to the station path building part of the overall transit impedance calculation process. The program builds sidewalk links along qualifying highway links (no freeway links), within a "box" of about 0.4 miles around each station or major transit center identified in the STATDATA file. These links will extend to centroid connectors in the vicinity of the station so that nearby zones are connected but the distance generally reflects a more realistic walking path than an airline distance from the centroid to the station. The program simply produces access links in TRANPLAN format which are then included in the available link files for transit path building. Sidewalk links are coded at 2.5 miles per hour, reflecting some delay for crossing streets, etc.

Figure 3.3.6 – Sidewalk Links Around Park and Ride Lots in Year 2000 Transit Network



The second special-purpose program, WALKCN, reads the highway network, coordinate file, transit network, percent walk file, and other inputs to identify walk connectors to the transit system. A transit walk connector link is a link connecting a centroid to a node or more nodes within a given distance from the centroid. Highway cnetroid connector links are converted to transit walk connector links if they fall within appropriate distance ranges based on the percent walks and some basic network topology considerations. The transit walk connector links will be built to those nodes having transit service or connected to the sidewalk network. If no suitable links are found, the program "sweeps" nearby (an area with a radius of 1.7 mile or 1.5 times the length of the highway centroid connector whatever is larger) nodes and adds connectors as needed. The program produces two sets of transit walk connector links, one from the highway network and "new" links from the sweep process. The sweep process can be restricted in specific areas by coding "barriers" if required. The program can add other links supplied by the user (XTRAWKPK and XTRAWKOP). Transit walk centroid connectors (mode 1) are coded at 2.5 miles per hour. Figure 3.3.7 shows the centroid walk connector links created for year 2000 transit network.

The transit market is segmented into seven groups in modal choice phase, depending on the proportion of trips within short, long or no walk, both at the origin and destination zones (see Table 3.3.9). For the OKI/MVRPC model, a short walk is 1/6 of a mile or less, and a long walk is between 1/6 and 1/3 of a mile. Within each market segment, the transit walk time is estimated as the minimum of a pre-specified time (see Table 3.3.10) and the walk time estimated from the transit skims.

Table 3.3.9 – Walk Distance to Transit Market Segmentation

	Destination Zone			
Origin Zone	**Walk Distance**	Short	Long	No Walk
	Short	short -> short	short -> long	No Transit
	Long	long -> short	long -> long	
	No Walk	drive -> short	drive -> long	

Table 3.3.10 – Maximum Walk Time (Sum of Access & Egress)

Market Segment	Maximum Walk Time (min)	
	Walk to Transit	Drive to Transit
short -> short	10	5
short -> long	15	10
long -> short	15	5
long -> long	20	10
drive -> short	-	5
drive -> long	-	10

Implementation of the "short" and "long" walk connectors in the modal choice model requires estimation of the percentage of each TAZ within "short" and "long" walking distance of transit.

The percent walks, found in the PCWALK file, are computed from the zonal boundary files and the transit link files using GIS buffering. Centroid highway connector links that access a bus route or sidewalk link are included in the transit walk connector link file with the appropriate time and distance. If the zone has a non-zero percent short walk and no usable highway connectors are found, the program sweeps all transit stop nodes in the vicinity, up to a maximum distance of1.7 mile or 1.5 times the length of the highway centroid connector for long and short walk connectors. Barrier links are used to prevent the sweep from falsely connecting across barriers. If the sweep finds the same service at more than one location, it generally keeps the short connector. Separate calculations are made for peak and off-peak services, as the route coverage may differ and separate estimates are also made for the production and attraction end of the trip, with the latter usually being larger reflecting the tendency for trip attractions to concentrate along major facilities served by transit while trip productions are spread more evenly across the TAZ.

A third special-purpose program, AUTOCN, builds auto connectors from each zone to one or more stations or park-and-ride lots flagged in the station data file. In the program, auto connectors are accepted if the total distance, derived from the highway skims from the TAZ in question to the TAZ nearest the station, is within a specified maximum. This maximum is bus park-and-ride lots is in STATDATA file. The program generally accepts the shortest and second-shortest connector to any given transit facility (as identified by service from the same route). The program uses network topology to eliminate the second connector if it does not provide meaningfully different transit service. The program will also eliminate auto connectors that involve extensive backtracking relative to the CBD, the primary destination for most park-and-ride trips. Like the walk connector program, the auto connector program will accept user-supplied additional connectors (XAUTOAM, XAUTOMD). While the auto connector links are represented as straight lines from centroids to the stations, the travel time for auto connector links are extracted from the highway travel time skims for the appropriate period. Figure 3.3.8 shows the auto connector links created for year 2000 transit network.

A fourth special-purpose program, DRVLINKS, builds auto connectors from each zone to a station or park-and-ride lot in the fixed-guideway station / park and ride lot data file (e.g. PNRLRTAM, PNRLRTMD). Auto connectors are built from each centroid to the nearest station / park and ride lot nodes within 7 miles of the centroid. Thus each cnetroid is connected to at most one station. The proximity is in term of distance which is calculated from the coordinates of the centroids and the station / park and ride lot nodes. The connector links are represented as straight lines from centroids to transit stations / park and ride lot nodes.

A fifth special-purpose program, ACCSPD determines the travel times for the auto connectors for stations or park-and-ride lots in the fixed-guideway station / park and ride lot data file. It takes the output of the DRVLINKS program and generates the file that is used in transit network building. The program identifies the nearest zone (which is coded in STATDATA file) for each of the transit station / park and ride nodes, gets the travel time from the highway skims and generates the auto connector link file. If the travel time exceeds the TRANPLAN limit of 25.5 minutes, the program will create multiple auto connector links.

A sixth special-purpose program, WLKLINKS, builds walk connectors from selected zones to board nodes of fixed-guideway system as specified station data file (e.g. STALRTAM, STALRTMD). The program searches all the boarding nodes within an area with a radius of one mile from a centroid, sorts the candidate boarding nodes by distance from centroid and creates a walk link from the centroid to the closest boarding node. Additional walk connectors are also created to the subsequent nearest boarding nodes if one or more transit lines passing through the boarding nodes do not pass through the previous selected boarding nodes. While the connectors are represented as straight lines from centroids to stations, the distance posted on the link and used to calculate travel time is calculated assuming the walk trip takes place on a square grid (i.e. as the sum of the two sides of a right triangle that has the connector as its hypotenuse). Walk travel time is calculated by assuming a walk speed of 3.0 mile per hour.

Figure 3.3.7 – Centroid Walk Connectors in Year 2000 OKI/MVRPC Transit Network

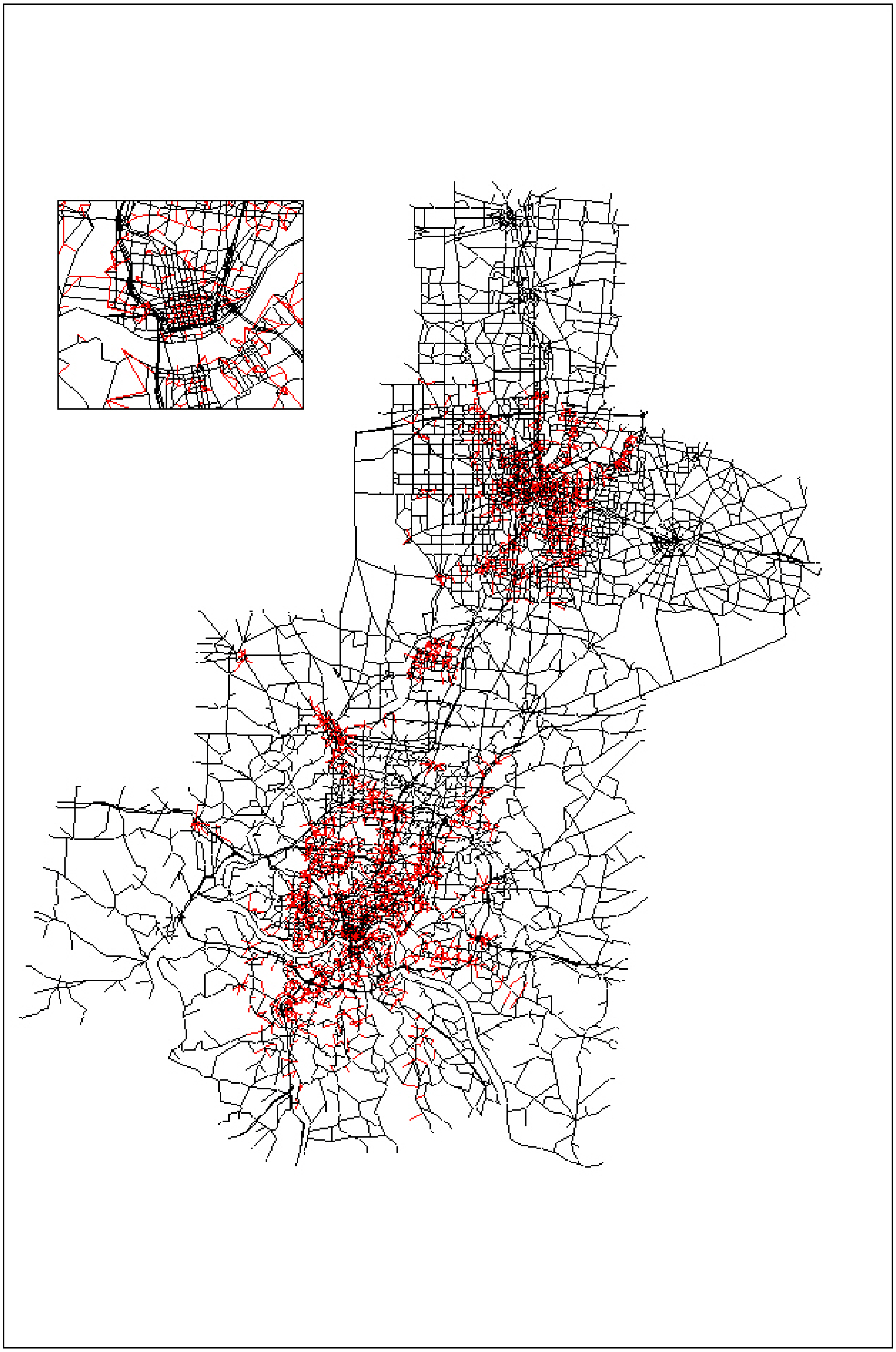
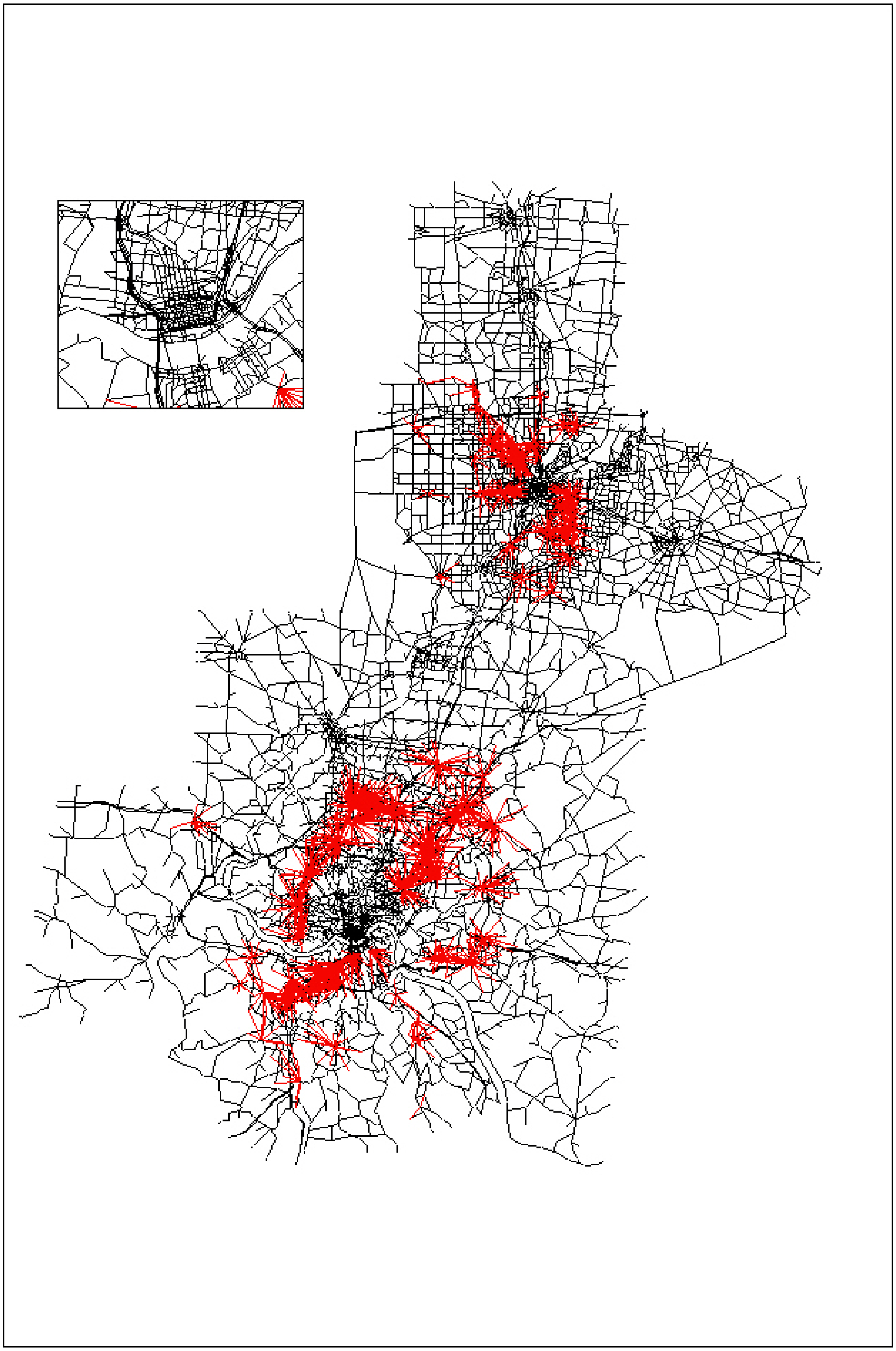


Figure 3.3.8 – Centroid Auto Connectors in Year 2000 OKI/MVRPC Transit Network



3.3.8 Transit Centers and Park/Ride Lots

Transit Centers and Park/ride lots are major aspects of a transit network. A Transit Center is a location, typically with pedestrian access only, with an increased bus service level. An example would be a downtown center that serves as a common stop for suburban routes. Consequently, transit patrons typically have wide route availability and transfer capability at these centers. Patrons will also walk longer distances to a transit center, as the larger amount of options offset the increase in walk time. A park/ride lot is a location where patrons may drive (i.e., a typical park/ride trip) or be dropped off (i.e., a typical kiss/ride trip) to board a bus that will take them to their ultimate destination.

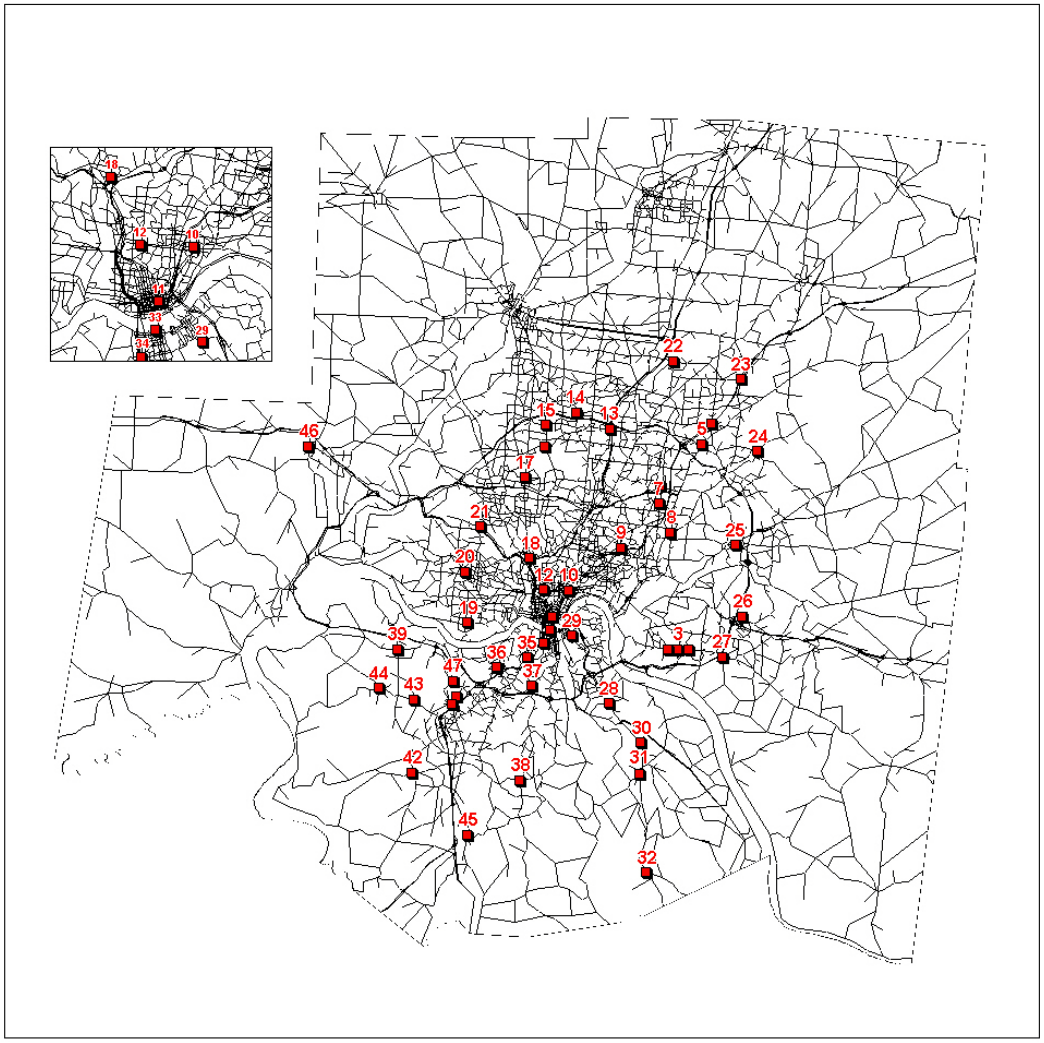
In the OKI region, five transit centers and forty-two park/ride lots are included in the 2000 regional transit network. Government Square is the primary downtown center and is visited by almost all METRO buses. Dixie Terminal served as the downtown center for TANK. It ceased operations in 1996, and therefore it is not included. Three transit centers outside downtown Cincinnati are Peebles Corner, Knowlton's Corner, and Hughes Corner. These areas provide good transfers as they are served by both crosstown and suburban-to-CBD routes. Park/ride lots in Cincinnati are located in the suburban areas. They typically have peak service only, shuttling suburban commuters to the CBD. Park/ride areas in Cincinnati are either official and unofficial lots. Official lots are publicly broadcasted as areas available to the public for accessing transit by auto. Unofficial lots have bus service and auto access patrons, but are not declared or advertised in any way.

Transit centers and park/ride lots are coded in the STATDATA file. Various information about each station is included in this file, including: zone number, parking availability (i.e., park/ride lot or transit center), and parking cost. Information in the STATDATA file is used to develop walk and auto access links prior to transit network building. Table 3.3.11 shows a list of the transit centers and park/ride lots in the 2000 transit network. Figure 3.3.9 show the location of the transit centers and park/ride lots.

Table 3.3.11 – Year 2000 Transit Stations in OKI region

Number	Name	Node	TAZ	Auto Access	Parking Cost
1	Anderson Township	6640	4	Yes	Free
2	Mt. Washington Church of Christ	10656	15	Yes	Free
3	Beechmont Mall	6384	26	Yes	Free
4	Fields-Ertel Park and Ride	6305	61	Yes	Free
5	Harpers Station	5533	69	Yes	Free
6	Blue Ash	5853	104	Yes	Free
7	Kenwood Baptist Church	5579	144	Yes	Free
8	Madiera	5644	152	Yes	Free
9	Silverton	6102	322	Yes	Free
10	Peebles Corner	5029	243	No	N/A
11	Government Square	4339	276	No	N/A
12	Hughes Corner	4707	322	No	N/A
13	Radisson Hotel (Chester Rd.)	5935	404	Yes	Free
14	Tri-County Assembly of God	5476	425	Yes	Free
15	Forest Park	5470	436	Yes	Free
16	Greenhills Shopping Center	5932	443	Yes	Free
17	Hilltop Plaza	5392	459	Yes	Free
18	Knowlton's Corner	5400	490	No	N/A
19	Delhi Plaza	5893	529	Yes	Free
20	Western Hills	5227	553	Yes	Free
21	Sam's Club (North Bend Rd.)	5300	592	Yes	Free
22	West Chester Meijer	7067	972	Yes	Free
23	Paramount's Kings Island	7172	1014	Yes	Free
24	Loveland City	6550	1128	Yes	Free
25	Milford Krogers	6799	1147	Yes	Free
26	Eastgate (Clepper Ln.)	6512	1183	Yes	Free
27	Cherry Grove Park and Ride	6711	1201	Yes	Free
28	St Joseph Church	3115	1306	Yes	Free
29	Newport Shopping Center	3137	1285	Yes	Free
30	Alexandria Village Green SC	4173	1317	Yes	Free
31	Alexandria Park and Ride	7882	1327	Yes	Free
32	Grants Lick	3912	1339	Yes	Free
33	Covington Transit Center	3349	1341	No	N/A
34	Jillians	8250	1359	Yes	Free
35	Lookout Heights Civic Center	3067	1370	Yes	Free
36	Buttermilk Crossings	3482	1373	Yes	Free
37	TANK Office	3073	1398	Yes	Free
38	Independence Park and Ride	3887	1445	Yes	Free
39	Hebron Lutheran Church	8347	1474	Yes	Free
40	Biggs – Florence	3623	1481	Yes	Free
41	Turfway	8221	1482	Yes	Free
42	Union Presbyterian Church	3833	1507	Yes	Free
43	Oakbrook	8368	1514	Yes	Free
44	Burlington	8364	1516	Yes	Free
45	Walton First Baptist Church	3851	1538	Yes	Free
46	Harrison Kroger	6406	1571	Yes	Free
47	Mary Queen of Heaven Church	3013	1606	Yes	Free

Figure 3.3.9 – Year 2000 Transit Centers and Park and Ride Lots in OKI Region



3.3.9 Transit Network Building

The transit network building process amalgamates all the files discussed earlier in the previous sections. Specifically, these include sidewalk links, centroid walk connectors, centroid auto connectors, special transit links, bus routes, and LRT routes.

The sidewalk connectors are created using the SIDECN program. The program reads the list of station/park-and-rides, and uses the highway network to develop connectors from close TAZs to the station or park/ride. The centriod walk connectors are developed using the WALKCN program. While the sidewalk links only connect to stations or park/rides, the walk connectors connect to nearby local and express buses. The program compares the bus network to the highway network and creates a list of transit walk connectors. Auto connectors for bus service, developed using the AUTOCN program, are created by comparing the station/park-and-rides to the highway networks. DRVLINKS, ACCSPD and WLKLINKS programs create walk connectors and auto connectors to transit stations. The bus and LRT route files use the highway network and special transit links. All of these files are assembled and built using the TRANPLAN program. Having the access modes together with the transit network is quite useful because when the network is skimmed for travel times, transfers, and waiting time, the access modes are part of the skim tree.

Chapter 4 Model Validation and Output Summaries

4.1 Model Validation

This chapter validates the model outputs with observed data including local and national surveys, census data and modeling findings of other metropolitan areas. The discussion focuses on OKI area and the OKI/MVRPC consolidated region. The local trip data mainly are from OKI 1995 household trip survey. The most recent observed data for the validation are updated traffic counts on the 2000 highway network, and 2000 route ridership information from transit companies. The national survey and census data including 2001 National House Travel Survey (NHTS), 2000 Census Transportation Planning Package (CTPP), and Census data summary files. Transportation Research Board (TRB) and Federal Highway Administration (FHWA) reports are also used as references such as NCHRP report 255, NCHRP report 365 and "Model Validation and Reasonableness Checking Manual".[1]

The following sections discuss model validation in trip generation, trip distribution, modal choice and trip assignment. The discussion includes both highway and transit components.

4.1.1 Trip Generation

This section compares the model trip rates, daily person trips and daily vehicle trips with the observed data. The validation purpose here is to see if the daily person trip per household, the daily person trip percentages by trip purposes, and other statistics are reasonably match the observed data, or within their reasonable range.

Table 4.1.1 compares the estimated trip productions per household with OKI 1995 household survey. Overall, the model estimations are quite good, particularly for home based work and home based other. But, the home based university in rural area is over estimated (0.14 and 0.16 vs. 0.07). The trip rates for rural will be analyzed further. Since the productions in this category are small, they will not have big impact on the model.

[1] "NCHRP Report 255, Highway Traffic Data for Urbanized Area Project Planning and Design" Transportation Research Board, December 1982.
"NCHRP Report 365, Travel Estimation Techniques for Urban Planning", William A Martin and Nancy A McGuckin, Barton-Aschman Associates, Inc. Transportation Research Board 1998
"Model Validation and Reasonableness Checking Manual", Barton-Aschman Associates, Inc and Cambridge Systematics, Inc. Federal Highway Administration 1997.

Table 4.1.1 – Year 2000 Daily Person Trip Per Household by Area Types

Trip Purposes	Area Type	1995 Observed	2000 Estimated OKI	2000 Estimated OKI/MVRPC
Home Based Work	CBD		1.48	1.77
	Urban	1.86	1.83	2.01
	Suburban	2.16	2.07	2.33
	Rural	2.16	2.17	2.16
Total			2.01	2.18
Home Based Univ.	CBD		0.07	0.08
	Urban	0.09	0.08	0.09
	Suburban	0.08	0.07	0.08
	Rural	0.07	0.14	0.16
Total			0.08	0.09
Home Based Other	CBD		1.96	1.75
	Urban	3.44	3.64	3.40
	Suburban	4.88	5.22	5.00
	Rural	4.75	5.30	5.06
Total			4.69	4.49

Source for 1995 observed: 1995 OKI household trip survey
Note: Home based work trip rates are in relation to households with workers

Table 4.1.2 and table 4.1.3 are pairs of tables for comparison. Table 4.1.2 shows daily person trip rates by travel purposes, and table 4.1.3 displays the rates of similar regions. The model estimations are reasonable and the rates are in the neighborhood of data from the other metropolitan areas.

Table 4.1.2 – Year 2000 Daily Person Trip Per Household by Travel Purposes

Trip Purposes	OKI/MVRPC	OKI
Home based work	2.18	2.01
Home based university	0.09	0.08
Home based other	4.49	4.69
Home based school	0.03	0.03
Non home based	2.50	2.52
Total	9.28	9.45

Note: Home based work trip rates are in relation to total households.

Table 4.1.3 – Daily Person Trip Per household by Travel Purposes for Selected Metropolitan Areas

Purpose	Houston 1985 Models	Dallas/Ft. Worth 1984 Travel. Survey.	Denver 1985 Travel Survey	San Francisco 1985 Travel Survey.	Atlanta 1980 Travel Survey.	Delaware Valley 1986 Travel Survey.
HBW	1.71	2.29	1.96	1.89	1.95	2.27
HBNW	4.8	4.32	3.4	4.49	4.45	4.19
NHB	2.96	2.07	1.97	2.35	1.87	1.64
Total	9.47	8.68	7.33	8.71	8.27	8.1

Source: "Model Validation and Reasonableness Checking Manual", TMIP, FHWA, 1997

Table 4.1.4 compares model trip rates with national data. The comparisons include rates for both daily person trips and vehicle trips. The national daily trip rates are from 2001 National Household Travel Survey (NHTS). The table shows that the model rates are close to the national average. The daily person trips per household and daily person trips per person are a little lower than the national average, and the rates for daily vehicle trips per household and daily vehicle trips per person are slightly higher.

Table 4.1.4 – Year 2000 Regional Daily Trip Summaries and Comparison to National Data

	OKI/MVRPC	OKI	Nation
Daily Person Trips	9,835,416	6,955,441	
Daily Vehicle Trips	7,285,042	5,114,591	
Households	1,059,734	735,837	
Population	2,632,533	1,848,687	
Daily person trips per household	9.28	9.45	10.49
Person trip per person	3.74	3.76	4.06
Vehicle trips per household	6.87	6.95	6.00
Vehicle trips per person	2.77	2.77	2.32

Source of National Data: 2001 National Household Travel Survey, Table of Summary Statistics on demographic characteristics and Total Travel.

Table 4.1.5 and table 4.1.6 are another pair of tables for comparison: the comparison of trip distribution by trip purposes. Table 4.1.5 presents the distribution calculated using the model output, and Table 4.1.6 lists those of similar metropolitan areas. The distributions in Table 4.1.5 and Table 4.1.6 are very similar. Home based work trips account for about 19.31 percent of total trips in the OKI/MVRPC region, and about 17.78 percent of total in the OKI area. The numbers of listed metropolitan areas for that are from17.9 percent to 27 percent on Table 4.1.6. The percentages of home based other (or home based non work, HBNW) and non-home based purposes on Table 4.1.5 are also in the close range of the numbers of listed areas on Table 4.1.6.

Table 4.1.5 – Year 2000 Daily Person Trip Distribution by Trip Purposes

Trip Purpose	Consolidate Region		OKI	
	Trips	% of Total	Trips	% of Total
Home Based Work	1,741,864	19.31%	1,120,024	17.78%
Home Based University	98,097	1.09%	55,249	0.88%
Home Based Other	4,528,418	50.19%	3,268,094	51.87%
Non Home Based	2,653,499	29.41%	1,857,694	29.48%
Total HB & NHB Trips	9,021,878	100.00%	6,301,061	100.00%

Table 4.1.6 – Trip Distribution by Travel Purposes for Selected Metropolitan Areas.

	Houston	Dallas/Ft. Worth	Denver[2]	San Francisco[2]	Minn/St. Paul[4]	Atlanta[2]
Purpose	1985 Models	1984 Travel. Survey.	1985 Travel Survey.	1985 Travel Survey.	1982 Travel Survey.	1980 Travel Survey.
HBW	18.10%	27.00%	26.00%	23.60%	17.90%	23.60%
HBNW	50.60%	47.70%	47.00%	49.70%	53.70%	53.80%
NHB	31.30%	25.30%	27.00%	26.70%	28.40%	22.60%
Total	100%	100%	100%	100.00%	100.00%	100%

Source: "Model Validation and Reasonableness Checking Manual", TMIP, FHWA, 1997

4.1.2 Trip Distribution

This section validates trip distribution, and compares trip lengths and trip flow interchanges with observed data, and also discusses intra-zonal trip percentages. Even though the impedances for trip distribution are logsums, in this validation analysis, travel times and distances are used to calculate the trip lengths. The travel time is the most important independent variable in the logsum time/cost utility equations, and it is also more measurable and easy to comprehend and compare to the observed data.

4.1.2.1 Average Trip Length

The average trip length for a region relates to region size and compactness, and also relates to travel behavior. Table 4.1.7 displays daily average travel times by trip purposes, and Table 4.1.8 shows the trip length in both time and distance by peak and off-peak time periods for OKI and OKI/MVRPC regions. The trip lengths on these two tables are quite reasonable for the metropolitan areas of their sizes. Furthermore, the tables demonstrate that the external trips (EI and EE) are much longer than internal trips (HB and NHB) in time and distance, and average length for working trips (HBW) are longer than that for shopping and recreation trips (HBO), and NHB trips are the shortest such as lunch or shopping from one store to another. The relative differences among various trip purposes are quite reasonable. It is necessary to mention that the trips between MVRPC zone and OKI zones are categorized as internal trips in the calculation of trip length for the consolidated region, but as external - internal trips for the OKI area.

Table 4.1.7 – Year 2000 Regional Daily Average Travel Time by Trip Purposes

Purpose/Time Period	Average Travel Time OKI/MVRPC (minutes)	Average Travel Time OKI (minutes)
Home based work	18.83	20.74
Home based other	12.01	13.04
Home based university	18.65	20.88
Non home based	9.09	9.66
Home based school	14.20	13.44
External - Internal (vehicle)	32.68	34.84
External - External (vehicle)	47.18	67.59
Taxi (vehicle)	7.16	7.16
Internal Trucks	21.23	20.43

Table 4.1.8 – Year 2000 Regional Average Trip Length by Time Periods and Travel Purpose

	OKI/MVRPC			OKI		
Purpose/Time Period	Trips	Travel Distance (Miles)	Travel Time (Minutes)	Trips	Travel Distance (Miles)	Travel Time (Minutes)
Peak						
Home based work	1,059,027	12.35	22.39	678,284	12.93	24.98
Home based other	1,906,420	6.82	14.27	1,374,546	7.17	15.87
Home based university	36,116	13.59	23.31	20,119	14.52	26.67
Non home based	1,250,072	5.77	10.92	867,155	5.80	11.61
External - Internal (vehicle)	195,390	27.41	32.67	175,205	28.85	36.68
External - External (vehicle)	24,004	43.61	51.29	19,819	60.67	71.45
Taxi (vehicle)	30,606	3.59	7.45	30,606	3.59	7.45
Internal Truck	75,334	14.78	24.36	49,321	13.45	24.04
Off Peak						
Home based work	682,837	9.20	13.29	441,740	9.86	14.22
Home based other	2,621,998	6.62	10.36	1,893,548	6.96	10.98
Home based university	61,981	11.27	15.93	35,130	12.33	17.56
Non home based	1,403,427	4.91	7.46	990,539	5.23	7.96
Home based school	14,252	10.06	14.20	12,481	9.03	13.44
External - Internal (vehicle)	180,424	27.43	32.69	143,895	27.24	32.70
External - External (vehicle)	24,004	42.77	43.08	18,988	60.02	63.56
Taxi (vehicle)	7,824	3.54	6.00	7,824	3.54	6.00
Internal Truck	149,176	15.37	19.64	96,911	13.81	18.59

Table 4.1.9 compares estimated average trip length by time periods against 1995 household survey. The estimated average HBW trip lengths are slightly longer than the observed trip

lengths, and estimated NHB travel times and distances are slightly shorter than observed in both time periods. However, in general, the estimations are good and the errors are small in percentage, except the HBO trips in peak period. It is not sure if this reflects the reality that people travel shorter time and distance for shopping and other personal business because of urban growth since 1995. Another cause of the discrepancy may be due to the use of ES202 data as the base to derive employment. Employment data by three categories are used for trip attraction calculation. 1995 employment data were derived from 1990 census CTPP data and building permit data. For year 2000 employment data, since year 2000 census CTPP was not available when the data was developed, state employment data (ES202) were used instead. So the attraction pattern by traffic zones for year 2000 may be quite different from that for 1995. Additional analysis is needed.

Table 4.1.9 – Observed and Estimated Travel Time and Distance Comparison for OKI Region

	Travel Distance (Miles)			Travel Time (Minutes)		
Trip Purposes	**1995 Observed**	**2000 Estimated**	**% Error**	**1995 Estimated**	**2000 Estimated**	**% Error**
Peak						
HBW	11.7	12.93	10.50%	23.6	24.98	5.83%
HBO	6	7.17	19.47%	12.8	15.87	23.98%
NHB	6	5.80	-3.32%	12	11.61	-3.25%
Off Peak						
HBW	10.2	9.86	-3.38%	15.1	14.22	-5.81%
HBO	6.2	6.96	12.32%	10.3	10.98	6.58%
NHB	5.6	5.23	-6.57%	8.8	7.96	-9.58%

Source for 1995 observed: 1995 OKI household trip survey

Census's work to journey data (CTPP) is now available. The average trip lengths for work trips for the counties in OKI area and for OKI area are listed in Table 4.1.19. A comparison to census data indicates that even though the model's average trip length for work trips (HBW) is longer than 1995 observed, it is close to that of Census's.

Table 4.1.10 – Year 2000 Census Average Travel Time to Work for OKI Counties

Area	Mean Travel Time in Minutes
Ohio	22.90
OKI CMSA	24.30
Boone	24.40
Butler	23.00
Campbell	23.90
Clermont	28.20
Dearborn	30.50
Hamilton	23.00
Kenton	22.90
Warren	24.10

Source: CTPP 2000, Census Bureau Statistics Abstract of United States 2003

4.1.2.2 Trip Flow Interchange

Table 4.1.11 to Table 4.1.13 is a set of tables for the comparison. Table 4.1.11 shows the trip interchange pattern by counties from the model output, Table 4.1.12 shows the trip interchange pattern from census data, and Table 4.1.13 gives the difference. The comparison indicates trip flows by county are simulated reasonably well.

Table 4.1.11 – Year 2000 County-to-County Home Based Work Person Trip Flow Patterns for OKI Region

Counties	Butler	Clermont	Hamilton	Warren	Boone	Campbell	Kenton	Dearborn	Total Prod.
Butler	8.37%	0.18%	6.45%	1.44%	0.12%	0.08%	0.16%	0.07%	16.88%
Clermont	0.30%	3.46%	4.78%	0.44%	0.27%	0.25%	0.36%	0.01%	9.87%
Hamilton	2.64%	1.20%	37.77%	1.22%	0.52%	0.43%	0.88%	0.36%	45.01%
Warren	1.38%	0.26%	3.01%	2.81%	0.06%	0.05%	0.09%	0.01%	7.66%
Boone	0.02%	0.03%	0.70%	0.01%	2.92%	0.20%	0.98%	0.05%	4.92%
Campbell	0.05%	0.07%	2.08%	0.04%	0.58%	1.00%	0.93%	0.01%	4.76%
Kenton	0.07%	0.08%	2.41%	0.05%	2.47%	0.68%	2.66%	0.03%	8.46%
Dearborn	0.08%	0.01%	0.86%	0.01%	0.34%	0.03%	0.12%	0.98%	2.43%
Total Attr.	**12.91%**	**5.29%**	**58.06%**	**6.03%**	**7.29%**	**2.72%**	**6.18%**	**1.52%**	**100.00%**

Table 4.1.12 – Year 2000 Census Commuter Patterns from Resident County to Work Place County for OKI Region

Counties	Butler	Clermont	Hamilton	Warren	Boone	Campbell	Kenton	Dearborn	Total Prod
Butler	10.40%	0.12%	5.52%	1.28%	0.10%	0.04%	0.08%	0.02%	17.56%
Clermont	0.33%	4.08%	4.61%	0.38%	0.16%	0.09%	0.19%	0.02%	9.85%
Hamilton	2.12%	0.95%	38.66%	1.07%	0.75%	0.31%	0.91%	0.15%	44.93%
Warren	0.99%	0.17%	2.45%	3.39%	0.04%	0.01%	0.03%	0.00%	7.07%
Boone	0.07%	0.04%	0.96%	0.03%	2.71%	0.13%	0.95%	0.04%	4.93%
Campbell	0.07%	0.07%	1.72%	0.04%	0.47%	1.78%	0.66%	0.01%	4.81%
Kenton	0.10%	0.09%	2.32%	0.03%	1.96%	0.45%	3.54%	0.03%	8.53%
Dearborn	0.09%	0.01%	0.88%	0.01%	0.17%	0.02%	0.05%	1.09%	2.32%
Total Attr.	14.19%	5.52%	57.13%	6.22%	6.36%	2.82%	6.41%	1.36%	100.00%

Source: CTPP 2000

Table 4.1.13 – Year 2000 County-to-County Work Trip Flow Patterns Difference (CTPP-Model)

Counties	Butler	Clermont	Hamilton	Warren	Boone	Campbell	Kenton	Dearborn	Total Prod.
Butler	2.03%	-0.06%	-0.94%	-0.16%	-0.03%	-0.04%	-0.08%	-0.05%	0.68%
Clermont	0.04%	0.62%	-0.17%	-0.07%	-0.11%	-0.16%	-0.18%	0.01%	-0.02%
Hamilton	-0.52%	-0.25%	0.90%	-0.15%	0.23%	-0.12%	0.04%	-0.20%	-0.08%
Warren	-0.39%	-0.09%	-0.55%	0.58%	-0.02%	-0.04%	-0.06%	-0.01%	-0.59%
Boone	0.05%	0.01%	0.26%	0.01%	-0.21%	-0.07%	-0.03%	-0.01%	0.01%
Campbell	0.03%	-0.01%	-0.37%	-0.01%	-0.11%	0.78%	-0.26%	0.00%	0.05%
Kenton	0.04%	0.01%	-0.08%	-0.01%	-0.51%	-0.23%	0.87%	-0.01%	0.07%
Dearborn	0.01%	0.00%	0.02%	0.00%	-0.17%	-0.02%	-0.07%	0.11%	-0.11%
Total Attr.	**1.28%**	**0.22%**	**-0.93%**	**0.20%**	**-0.94%**	**0.10%**	**0.23%**	**-0.16%**	**0.00%**

4.1.2.3 Intrazonal Trips

Finally, intrazonal trips are checked. Intrazonal trips are trips with both ends inside a zone, and correlated to the zone size and mix of trip production/attraction in the zone. In general, the larger the zone size, the more the intrazonal trips. The intrazonal trips are high for the zones with trip production and attraction both high.

Intrazonal trips will not be loaded to the highway network, and percentages of intrazonal trips indicate how much trips will be excluded from trip assignment process. The highway network does not simulate all the roadways. Many of the minor / local streets are not included. The model assumes that intrazonal trips are short and most of them will use these minor/local streets to reach their destinations. A balance between the zone size and the details of the roadway simulated in the highway network is required to have the assumption prevailed.

Table 4.1.14 displays percentage of intrazonal trips by trip purposes. The overall intrazonal trip is 9.01 percent, and it is a little high. Typical intrazonal trips account for about 5 percent of total trips based on “Model Validation and Reasonableness Checking Manual” of FHWA. The main reason for the high overall intrazonal trip percentage is the high volume of NHB intrazonal trips (19.29% of total NHB trips). It needs further study.

Table 4.1.14 – Year 2000 Intrazonal Trip Percentages by Trip Purpose for OKI/MVRPC Region.

Purpose	**Zone to Zone**	**Intrazonal**	**Percentage**
Home based work	1,741,864	48,844	2.80%
Home based other	4,528,418	272,157	6.01%
Home based Univ.	98,097	317	0.32%
Home based School	14,252	41	0.29%
Non home based	2,653,499	511,878	19.29%
Truck (Internal)	224,510	1,422	0.63%
Total	9,260,640	834,659	9.01%

A comprehensive look of the trip distribution model is necessary. A consultant, The Corrodino Group, is contracted to enhance the model in the coming months. One of consultant’s tasks is to examine the performance of trip distribution model.

4.1.3 Modal Choice

This section uses OKI 1995 household survey and transit on board survey data to validate the model, and also uses 2000 census work to journey data. The 1995 household survey data are latest household survey data available, and were used to estimate and calibrate the nested logit model coefficients.

Table 4.1.15 to Table 4.1.18 compares the model’s modal share with 1995 household trip survey data by travel purposes and by time periods. The table shows the modal shares of drove alone, shared ride 2+ and shared ride 3+ in automobile mode, and local bus, express bus, urban rail and commuter rail in transit mode. The discrepancies of estimated and observed modal shares vary by travel purposes. The estimated shares match the observed ones very well for HBO, reasonably well for HBW and NHB, and poorly for transit part of HBU. The reason of poor HBU matches is that the trip data are too small.

Table 4.1.15 – Year 2000Comparison of Model Shares for Daily HBW Trips for OKI Region

	AUTO			TRANSIT				
	DRIVE ALONE	2 PERSON AUTO	3+ PERSON AUTO	LOCAL BUS	EXPRESS BUS	URBAN RAIL	COMMUTER RAIL	TOTAL
PEAK								
Model	546,629	77,797	26,326	24,734	2,798	0	0	678,284
1995 Observed	533,205	77,091	25,974	22,209	2,050	0	0	660,529
Model	84.0%	12.0%	4.0%	89.8%	10.2%	0.0%	0.0%	
1995 Observed	83.8%	12.1%	4.1%	91.5%	8.5%	0.0%	0.0%	
Model Total		650752			27532			
1995 Observed Total		636270			24259			
Model	95.9%			4.1%				
1995 Observed	96.3%			3.7%				
OFF PEAK								
Model	359,512	53,113	17,317	11,798	0	0	0	441,740
1995 Observed	347,025	51,620	16,836	10,771	0	0	0	426,252
Model	83.6%	12.4%	4.0%	100.0%	0.0%	0.0%	0.0%	
1995 Observed	83.5%	12.4%	4.1%	100.0%	0.0%	0.0%	0.0%	
Model Total		429942			11798			
1995 Observed Total		415481			10771			
Model	97.3%			2.7%				
1995 Observed	97.5%			2.5%				

Source for 1995 observed: 1995 OKI household trip survey

Table 4.1.16 – Year 2000Comparison of Model Shares for Daily HBU Trips for OKI Region

	AUTO			TRANSIT				
	DRIVE ALONE	2 PERSON AUTO	3+ PERSON AUTO	LOCAL BUS	EXPRESS BUS	URBAN RAIL	COMMUTER RAIL	TOTAL
PEAK								
Model	15,008	3,818	1,107	184	2	0	0	20,119
1995 Observed	15,459	3,855	1,091	288	14	0	0	20,707
Model	75.3%	19.2%	5.6%	98.9%	1.1%	0.0%	0.0%	
1995 Observed	75.8%	18.9%	5.3%	95.4%	4.6%	0.0%	0.0%	
Model Total		19933			186			
1995 Observed Total		20405			302			
Model	99.1%			0.9%				
1995 Observed	98.5%			1.5%				
OFF PEAK								
Model	30,347	3,993	679	111	0	0	0	35,130
1995 Observed	30,624	3,980	684	205	0	0	0	35,493
Model	86.7%	11.4%	1.9%	100.0%	0.0%	0.0%	0.0%	
1995 Observed	86.8%	11.3%	1.9%	100.0%	0.0%	0.0%	0.0%	
Model Total		35019			111			
1995 Observed Total		35288			205			
Model	99.7%			0.3%				
1995 Observed	99.4%			0.6%				

Source for 1995 observed: 1995 OKI household trip survey

Table 4.1.17 – Year 2000Comparison of Model Shares for Daily HBO Trips for OKI Region

	AUTO			TRANSIT				
	DRIVE ALONE	2 PERSON AUTO	3+ PERSON AUTO	LOCAL BUS	EXPRESS BUS	URBAN RAIL	COMMUTER RAIL	TOTAL
PEAK								
Model	474,370	459,636	428,018	12,264	258	0	0	1,374,546
1995 Observed	462,261	446,779	414,602	11,774	297	0	0	1,335,713
Model	34.8%	33.7%	31.4%	97.9%	2.1%	0.0%	0.0%	
1995 Observed	34.9%	33.8%	31.3%	97.5%	2.5%	0.0%	0.0%	
Model Total		1362024			12522			
1995 Observed Total		1323642			12071			
Model	99.1%			0.9%				
1995 Observed	99.1%			0.9%				
OFF PEAK								
Model	795,015	651,693	433,757	13,083	0	0	0	1,893,548
1995 Observed	777,644	630,234	418,426	12,960	0	0	0	1,839,264
Model	42.3%	34.7%	23.1%	100.0%	0.0%	0.0%	0.0%	
1995 Observed	42.6%	34.5%	22.9%	100.0%	0.0%	0.0%	0.0%	
Model Total		1880465			13083			
1995 Observed Total		1826304			12960			
Model	99.3%			0.7%				
1995 Observed	99.3%			0.7%				

Source for 1995 observed: 1995 OKI household trip survey

Table 4.1.18 – Year 2000Comparison of Model Shares for Daily NHB Trips for OKI Region

	AUTO			TRANSIT				
	DRIVE ALONE	2 PERSON AUTO	3+ PERSON AUTO	LOCAL BUS	EXPRESS BUS	URBAN RAIL	COMMUTER RAIL	TOTAL
PEAK								
Model	519,813	215,642	126,252	5,071	377	0	0	867,155
1995 Observed	511,329	209,613	123,755	6,261	535	0	0	851,493
Model	60.3%	25.0%	14.7%	93.1%	6.9%	0.0%	0.0%	
1995 Observed	60.5%	24.8%	14.7%	92.1%	7.9%	0.0%	0.0%	
Model Total		861707			5448			
1995 Observed Total		844697			6796			
Model	99.4%			0.6%				
1995 Observed	99.2%			0.8%				
OFF PEAK								
Model	581,268	248,155	156,906	4,210	0	0	0	990,539
1995 Observed	561,664	240,981	153,453	5,315	0	0	0	961,413
Model	58.9%	25.2%	15.9%	100.0%	0.0%	0.0%	0.0%	
1995 Observed	58.7%	25.2%	16.0%	100.0%	0.0%	0.0%	0.0%	
Model Total		986329			4210			
1995 Observed Total		956098			5315			
Model	99.6%			0.4%				
1995 Observed	99.4%			0.6%				

Source for 1995 observed: 1995 OKI household trip survey

Table 4.1.19 displays model's year 2000 person trips by modes and by travel purposes, and Table 4.1.20 presents census 2000 modal shares for work trips. The tables show the shares among trips of drove alone, share ride and transit (drove alone + share ride + transit = 100%). In Table 4.1.20, the public transportation category includes taxi trips. The modal shares are varied by counties due to the differences of the urbanization level and public transportation availability. The share of person trips of drove alone mode for HBW purpose on Table 4.1.19 is very close to the census's share of drive along mode for OKI CMSA (80.90% and 80.98% vs. 81.40%) in Table 4.1.20. However, the model's shares of trips for shared ride mode and public transit mode are slightly higher than the census data. As a national trend, the use of share ride and transit is reduced in the past ten years. This may explain some of the discrepancy. An analysis on the modal splits derived form 1995 survey data and CTPP data will be analyzed to decide any need of adjustment to the model.

Table 4.1.19 – Year 2000 Regional Modal Shares by Travel Purposes

Trip Purpose	Drive Alone		Share Ride		Transit	
	Trips	Percentage	Trips	Percentage	Trips	Percentage
OKI						
HBW	906,141	80.90	174,553	15.59	39,330	3.51
HBU	45,355	82.09	9,597	17.37	297	0.54
HBO	1,269,385	38.84	1,973,104	60.38	25,605	0.78
NHB	1,101,081	59.27	746,955	40.21	9,658	0.52
OKI/MVRPC Region						
HBW	1,410,551	80.98	271,888	15.61	59,425	3.41
HBU	80,607	82.17	16,992	17.25	568	0.58
HBO	1,767,895	39.04	2,724,598	60.17	35,925	0.79
NHB	1,572,685	59.27	1,066,147	40.18	14,667	0.55

Table 4.1.20 – Census Year 2000 Modal Share by Transportation Means to Work for OKI Counties

Counties	Drove Alone	Carpooled	Public Transportation	Others
Boone	84.60	10.10	1.10	4.20
Butler	84.20	9.10	0.90	5.80
Campbell	79.10	11.40	3.60	5.90
Clermont	84.50	9.90	1.10	4.50
Dearborn	83.00	11.70	0.50	4.80
Hamilton	78.90	9.70	5.00	6.40
Kenton	80.80	11.00	3.40	4.80
Warren	86.00	8.60	0.80	4.60
OH	82.80	9.30	2.10	5.80
OKI CMSA	81.40	10.00	2.90	5.70

Source: CTPP 2000, Census Bureau Statistics Abstract of the United States 2003
Note: CMSA = Census Metropolitan Statistical Analysis Area
Public Transportation includes taxi trips, and others in this table include walk, bicycle and work at home

4.1.4 Highway Assignments

This section checks the highway assigned traffic volumes against traffic counts. For this analysis, 2000 average daily traffic (ADT) were used for the 2000 observed ground counts. If a 2000 ADT was not available, one of three methods were used to determine the ground count for OKI area:

- 1998, 1999, 2001 counts were used if the volume was assumed not to differ much between the count year and 2000 (Counts last two digits represent year such as “98”, “99”, “00”, “01”)

- Estimated counts made by KYTC (as shown in KYTC’s 1999-2002 CTS) and ODOT (as shown in ODOT’s 1999-2002 Traffic Survey Reports) (Counts last two digits are “50”).

- If there were no recent counts or ODOT/KYTC estimation available for a particular link, an estimate was made using factor up old counts or using recent counts upstream and/or downstream of the link (counts last two digits are “51”). The old counts include the counts collected between years 1990 to 1996 and factored up to year 2000 using annual increase rate of two percent. There are about 3000 of them in the highway network. These counts account for the majority of the estimated counts.

Counts have been coded about 95 percent of the links for OKI area, and about 75 percent links of the OKI/MVRPC consolidated region excluding centroid connectors. Those not coded are for links where no current or historical counts exist and estimating a volume is not easy or reliable. Figure 4.1.1 and Figure 4.1.2 on next page show the percentages of various types of traffic counts coded. Regarding the data source, most of the actual counts were taken from public agencies such as ODOT, KYTC, IDOT, City of Cincinnati City, City of Fairfield, City of Middletown, Butler, Clermont, Hamilton and Warren Counties. Some of the data were from consulting companies like Pflam, Klausoneirer and Gehrum Consultants, Inc (PKG) and CDS Associates, Inc (CDS).

This validation analysis compares the model output from the trip assignment with corresponding traffic counts. However, the match between those two is not expected to be perfect for several reasons. The travel demand model is designed for regional analysis and long range transportation planning, and the highway network is an abstraction of the actual roadway system. The network includes regional significant roadways and some less important routes are by technical necessity left out. So, the simulation generally is better for the interstate and major arterial carrying heavy traffic loads, and not that great for minor roads.

Even though the comparison between estimated and observed volumes is not perfect, there are standards or criteria to measure the acceptance of the model assigned volumes for planning purpose. Transportation Research Board (TRB) and Federal Highway Administration (FHWA) have a few studies especially for these purposes such as TRB’s NCHRP report 255, NCHRP report 365 and FHWA “Model Validation and Reasonableness Checking Manual”. ODOT also issued guidelines for travel demand model traffic assignment procedure[2]. However, all the standards and criteria mentioned above are advisable, not mandatory. This validation analysis mainly uses ODOT standard, but also uses criteria in TRB and FHWA reports at a few occasions. Following checks were made to evaluate assignments against ground counts:

- Vehicle miles travel (VMT) checking
- Screenline and cutline checking
- Root Mean Square (RMSE) checking
- Individual link error scatter plot and regression plot checking

[2] “Travel Demand Forecasting Manual 1 Traffic Assignment Procedures”, Gregory Giaimo, Ohio Department of Transportation, Division of Planning, Office of Technical Services, August 2001.

Figure 4.1.1 – Year 2000 Count Structure for OKI/MVRPC Region

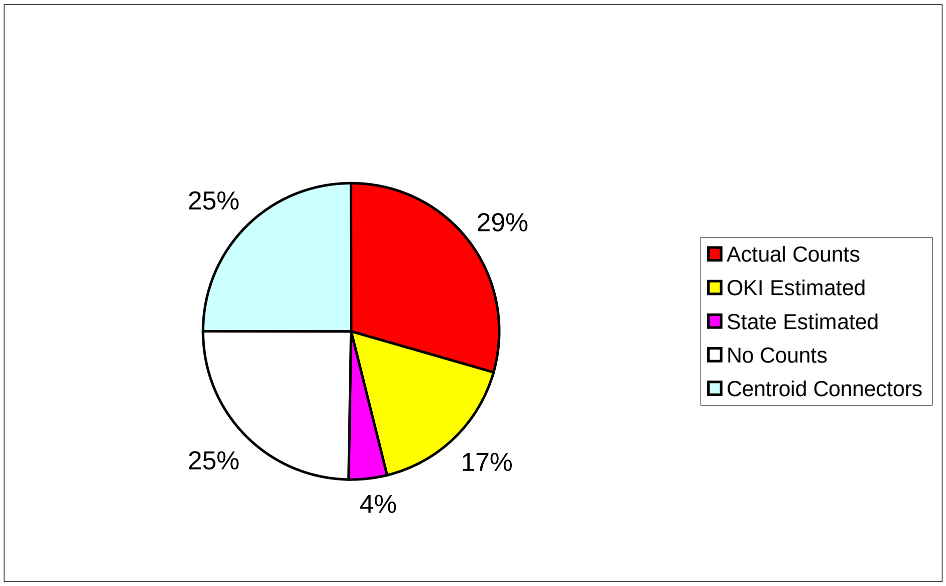
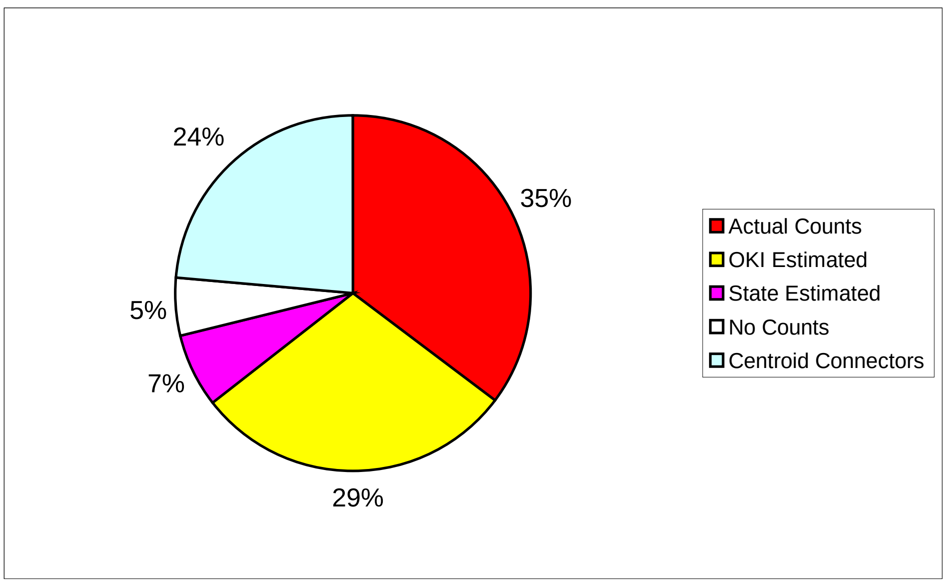


Figure 4.1.2 – Year 2000 Count Structure for OKI Region



4.1.4.1 Vehicle Miles Traveled

OKI/MVRPC region has well developed roadway system with full range of facility types carrying various traffic volumes. Vehicle miles traveled (VMT) are results of assigned volumes multiply link distances, and VMT checking is a system wide examination, and addresses not only the assignment (the path taken), also the trip generation (number of trips) and trip distribution (trip length).

Table 4.1.21 demonstrates the comparison of VMT by roadway class. The estimated VMT are calculated using the assigned traffic volumes and the observed using the traffic counts coded in the highway network. The links without traffic counts have been excluded in this comparison. The estimated VMT on interstates, major arterials, minor arterials, major collectors and ramps match the observed VMT very well with errors –1.14, 6.14,1.29, -9.20, and 1.36 percent respectively for consolidated region, and -0.34, 6.67, 3.56, -8.40, and 2.93 percent respectively for OKI. VMT on expressway are a little over estimated and on minor collector and local roads are under estimated. It is expected that the adjustment of high intrazonal NHB trips will reduce the underestimation on collector and local roads.

Table 4.1.21 – Year 2000 Observed and Estimated Vehicle Miles Traveled Comparison For OKI/MVRPC Region

Function Class	OKI Region			OKI/MVRPC Region		
	Observed	Estimated	% Error	Observed	Estimated	% Error
Interstates	17,403,221	17,344,275	-0.34%	21,217,792	20,976,963	-1.14%
Expressway	1,648,674	1,935,599	17.40%	2,188,968	2,506,903	14.52%
Major Arterial	6,960,999	7,425,341	6.67%	8,139,471	8,639,062	6.14%
Minor Arterial	6,524,488	6,756,980	3.56%	7,980,736	8,083,922	1.29%
Major Collector	7,279,049	6,667,664	-8.40%	8,508,937	7,726,472	-9.20%
Minor Collector	528,078	398,252	-24.58%	686,842	530,452	-22.77%
Local	1,020,945	891,689	-12.66%	1,284,970	1,052,791	-18.07%
Ramp	893,056	919,215	2.93%	1,149,798	1,165,378	1.36%
Grand Total	42,258,510	42,339,015	0.19%	51,157,513	50,681,944	-0.93%

Note: Links without counts are excluded

Furthermore, the VMT percentages by functional classes are checked against the typical situation based on the FHWA manual. Table 4.1.22 shows the VMT distributions by functional classes in the OKI/MVRPC Region, and Table 4.1.23 shows the typical VMT distributions for areas of different urban size. OKI/MVRPC region has population over 1 million, and falls into the large urban area in Table 4.1.23. VMT on Interstate/Freeways in the region is about 41.17 percent (36.62percent + 4.55 percent), and very close to the typical situation listed on Table 4.1.23 for this category (40 percent). However, the distributions for the other roadway classes are not compared well. Most likely, the grouping of roadway class in the model's highway network is different from those used in Table 4.1.23.

Table 4.1.22 – Year 2000 Regional Vehicle Miles Traveled Distribution by Functional Classes

Functional Classes	OKI Region		OKI/MVRPC Region	
	VMT	% of Total	VMT	% of Total
Interstates	18,125,688	38.58%	23,903,918	36.62%
Expressway	2,003,659	4.26%	2,969,343	4.55%
Major Arterial	7,493,876	15.95%	10,855,959	16.63%
Minor Arterial	6,822,516	14.52%	9,886,740	15.15%
Major Collector	6,774,266	14.42%	9,417,693	14.43%
Minor Collector	416,823	0.89%	722,794	1.11%
Local	901,302	1.92%	1,337,331	2.05%
Centroid Connector	3,181,429	6.77%	4,510,085	6.91%
Ramp	1,265,726	2.69%	1,665,660	2.55%
Grand Total	46,985,285	100.00%	65,269,523	100.00%

Note: All links are included

Table 4.1.23 – Typical Distributions of Vehicle Miles Traveled by Functional Classes and by Urban Area Sizes

Facility Type	Urban Area Population		
	Small (50-200K)	Medium (200K -1M)	Large (>1M)
Freeway/Expressway	18 -23%	33-38%	40%
Principal Arterials	37-43%	27-33%	27%
Minor Arterials	25-28%	18-22%	18-22%
Collectors	12-15%	8-12%	8-12%

Model Validation and Reasonableness Checking Manual, 1997

4.1.4.2 Screenline and Cutline

Screenline analysis is a widely used method for the assignment validation. ODOT sets standards for all the MPOs in Ohio, and the standards are derived from NCHRP Report 255. For OKI, screenslines are established across the four major rivers in region, and other screenlines were near or around major travel corridors. The screenlines are drawn in such a way as to be able to assess travel patterns east to west and north to south across a wide area of the region, and screenlines are developed across corridors where major travel is or expected to occur.

Twenty-two screenlines and one hundred twenty cutlines (which are a subset of the screenlines) are established for the highway network analysis in OKI area. Figure 4.1.3 and Figure 4.1.4 are maps showing all the screenlines and cutlines, and Figure 4.1.5 compares the screenline observed and estimated traffic volume discrepancies with the ODOT standard which is a curve representing the maximum desirable deviation, and Table 4.1.24 lists comparison errors in percentage. The comparison shows that the model performs at satisfactory level and all the errors were under the ODOT curve.

Figure 4.1.3 – Screenline Map for OKI Region

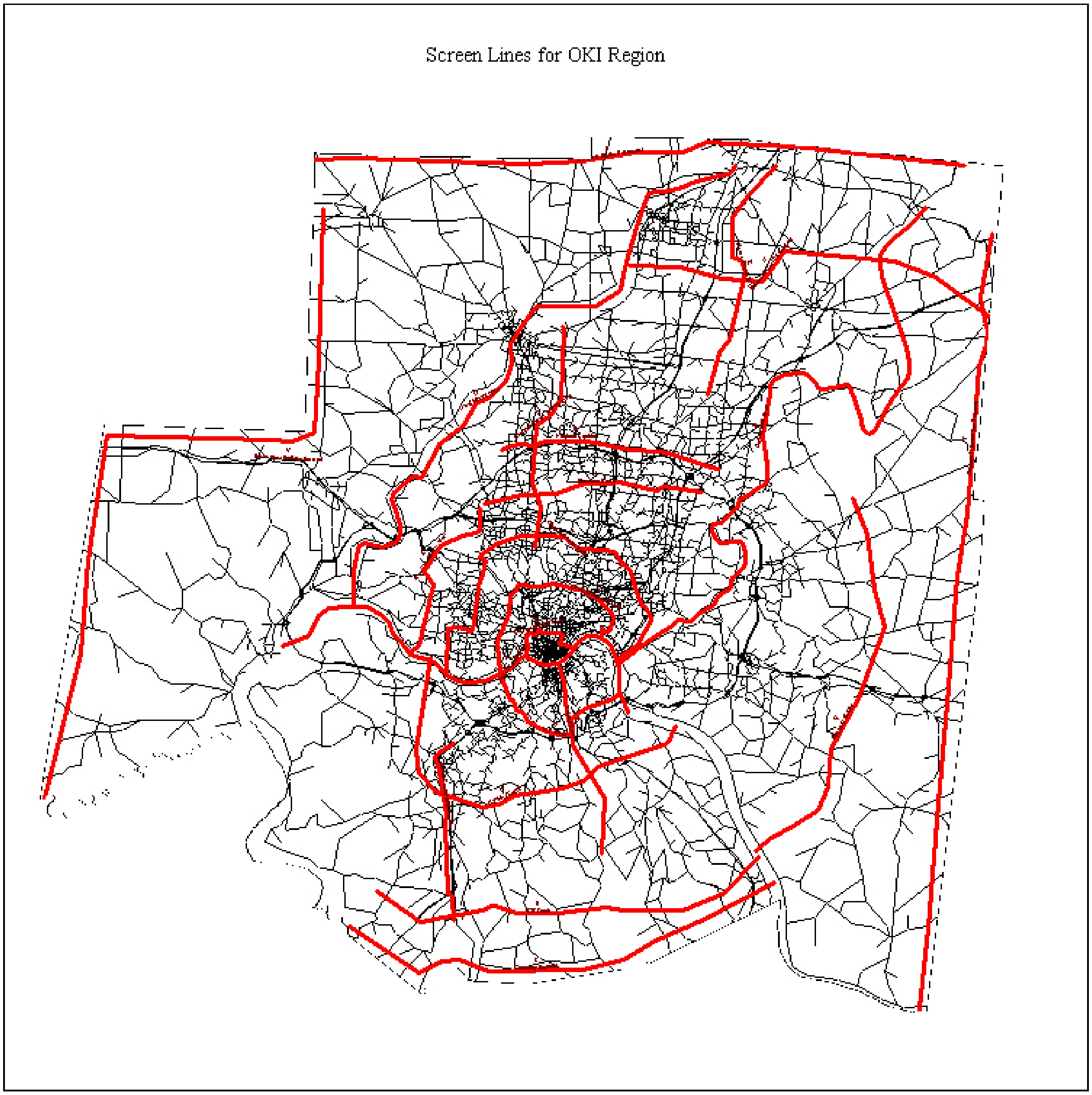


Figure 4.1.4 – Cutline Map for OKI Region

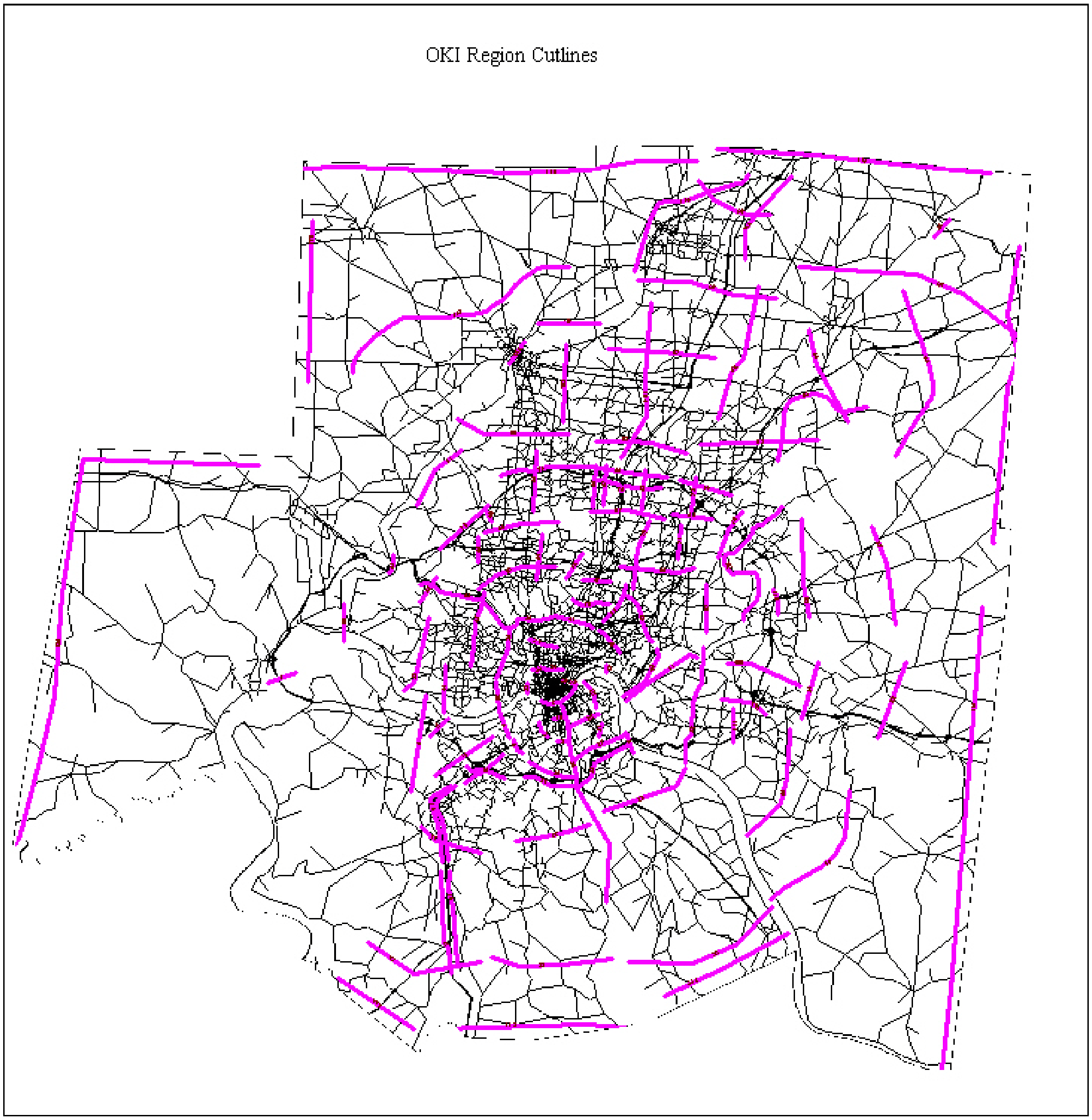


Figure 4.1.5 – Year 2000 Screenline Comparison for the OKI Region

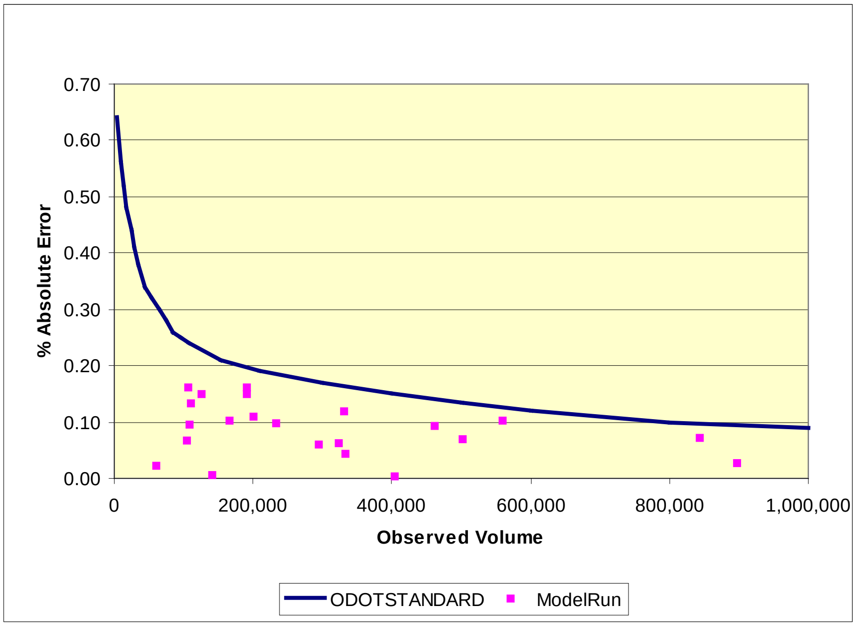


Table 4.1.24 – Year 2000 Screen line comparison for the OKI Region

Screenline	ObsVolume	PredictVolume	Error%
A Ohio River Bridges	405,599	406,503	0.22
B Little Miami River	331,341	370,003	11.67
C Greater Miami River	324,844	304,717	-6.20
D Licking River	142,699	142,022	-0.47
E KY South	125,904	107,202	-14.85
F KY Mid South	334,551	319,958	-4.36
G KY North	192,658	161,669	-16.08
H Cincinnati CBD Loop	503,307	468,908	-6.83
I City of Cincinnati Loop	844,883	784,221	-7.18
J Cincinnati Outer Loop	898,978	876,537	-2.50
K Hamilton County West	191,044	162,705	-14.83
L Hamilton County North	462,436	504,618	9.12
M Northern Corridor	560,602	617,598	10.17
N Warren/Butler N/S Corridor	202,398	224,478	10.91
O Hamilton/ Butler E/W Corridor	294,650	312,260	5.98
P Boone County E/W Corridor	233,252	210,886	-9.59
Q Clermont County	106,499	113,590	6.66
R Warren County E/W	109,643	120,078	9.52
S KY External	110,502	95,903	-13.21
T Clermont/ Warren East External	107,646	124,848	15.98
U Warren N/ Butler N External	167,100	150,159	-10.14
V Butler W /Indiana External	60,656	59,377	-2.11

Figure 4.1.6 displays the comparison of the estimation errors at cutlines level with ODOT maximum allowable errors, and the figure show most of the dots representing errors are under the curve. However, several dots are slightly above the curve. Table 4.1.25 presents the error for each cutline. A simple statistical analysis was performed for the errors listed on the Table 4.1.25, and the results show that the mean absolute error is 11.11 percent, and the maximum absolute error is 33.21 percent, and the minimum absolute error is 0.09 percent. A few factors cause the errors over the curve. Several cutlines across roadways in complicated configurations without most updated traffic counts, and several cutlines are at outlying area with large zones and less local roads on the network. All of these factors will affect the accuracies of model estimation, and more discussion about the causes will be made at the next section about Root Mean Square Comparison.

Figure 4.1.6 – Year 2000 Cutline Comparison for the OKI Region

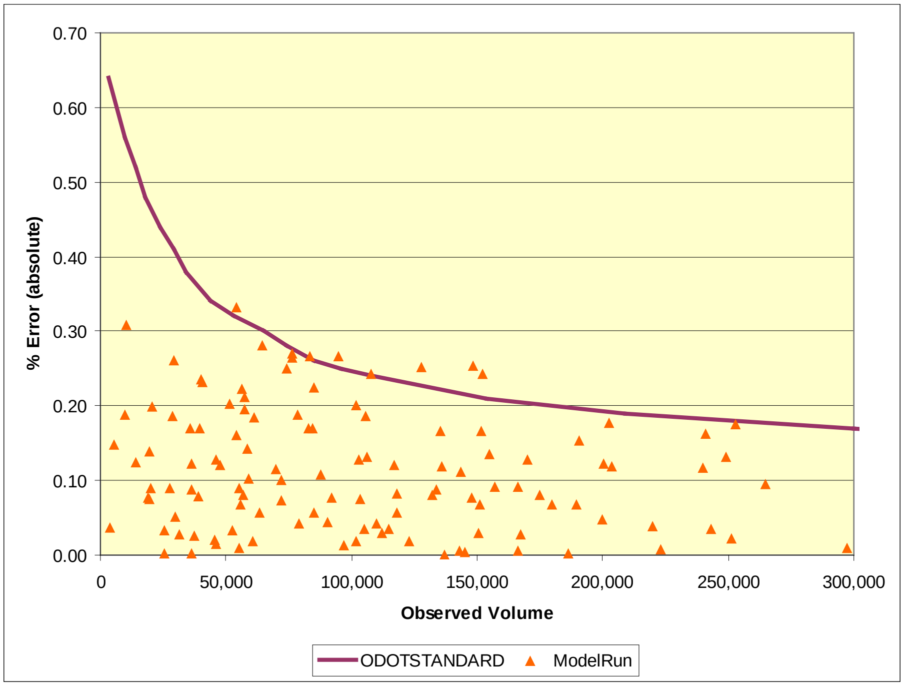


Table 4.1.25 – Year 2000 Cutline Comparison for the OKI Region

Cutline Number	CUTLINE NAME	Observed Volume	Estimated Volume	% Error
1	OHIO RIVER WEST	36,400	32,896	-9.63
2	OHIO RIVER CENTRAL	297,199	294,398	-0.94
3	OHIO RIVER EAST	72,000	79,209	10.01
4	VILLA HILLS	10,303	7,122	-30.87
5	AIRPORT	83,102	69,004	-16.96
6	AIRPORT BEYOND	103,052	89,941	-12.72
7	DEVOU	151,549	176,625	16.55
8	COVINGTON	25,500	25,454	-0.18
9	FT. WRIGHT	166,100	167,068	0.58
10	THOMAS MOORE	219,648	228,144	3.87
11	FLORENCE SOUTH	150,447	146,035	-2.93
12	BOONE COUNTY SOUTH	101,602	81,236	-20.04
13	I-275 KENTON/BOONE	109,704	105,039	-4.25
14	BOONE COUNTY CENTRAL	174,699	160,706	-8.01
15	I-275 ERLANGER	148,352	110,883	-25.26
16	FLORENCE	106,304	92,267	-13.2
17	BOONE COUNTY MID-SW	58,553	50,180	-14.3
18	BOONE COUNTY MID-SE	27,399	24,936	-8.99
19	COVINGTON NORTH	35,552	41,586	16.97
20	COVINGTON SOUTH	64,401	46,287	-28.13
21	TAYLOR MILL	60,501	59,418	-1.79
22	KENTON COUNTY MID-SOUTH	25,451	24,593	-3.37
23	KENTON MID-SOUTH	4,000	3,856	-3.6
24	LICKING RIVER	142,699	142,022	-0.47
25	SOUTH NEWPORT	133,900	122,172	-8.76
26	BELLEVUE	28,851	23,495	-18.56
27	I-471 NORTH	117,954	108,260	-8.22
28	I-471 SOUTH	97,101	98,399	1.34
29	CAMPBELL MID-SOUTH	55,601	59,389	6.81
30	CAMPBELL SOUTH	20,302	22,110	8.91
31	SOUTHGATE	19,600	22,303	13.79
32	CBD WEST	54,403	72,472	33.21
33	I-75 CUMMINSVILLE	203,553	179,313	-11.91
34	CBD NORTH	51,501	41,082	-20.23
35	ST BERNARD SOUTH	154,849	133,993	-13.47
36	CBD EAST	39,001	42,048	7.81
37	I-75 CLIFTON	239,948	212,026	-11.64
38	PRICE HILL	45,597	44,715	-1.93
39	QUEEN CITY	186,349	185,867	-0.26
40	NORTHSIDE/MT AIRY	78,588	93,318	18.74
41	ST BERNARD SOUTH	252,999	208,692	-17.51
42	HYDE PARK	240,902	201,786	-16.24
43	COLUMBIA PKWY	40,448	49,843	23.23
44	DELHI	39,600	32,885	-16.96

Table 4.1.25 – Year 2000 Cutline Comparison for the OKI Region (Continued)

Cutline Number	CUTLINE NAME	Observed Volume	Estimated Volume	% Error
45	I-74/GLENWAY	179,994	167,755	-6.8
46	MONFORT / WINTON	145,343	145,880	0.37
47	MILL CREEK NORTH	199,946	209,607	4.83
48	I-71 HYDE PARK	249,048	216,221	-13.18
49	EASTSIDE NEAR	85,047	104,189	22.51
50	SOUTH CENTRAL	243,402	234,831	-3.52
51	INDIAN HILL	14,245	16,005	12.36
52	EASTSIDE FAR	166,443	181,729	9.18
53	HAMILTON COUNTY WEST	56,349	43,823	-22.23
54	I-74	94,800	69,581	-26.6
55	CROSS COUNTY WEST	39,895	49,301	23.58
56	COLERAIN CORRIDOR NORTH	103,294	111,078	7.54
57	I-75 NORTH HAMILTON COUNTY	189,343	202,106	6.74
58	I-71 PFEIFFER	169,799	191,434	12.74
59	GREAT MIAMI RIVER S. HAMILTON	19,095	17,633	-7.66
60	GREAT MIAMI RIVER I-74	90,400	86,509	-4.3
61	GREAT MIAMI BLUE ROCK	37,297	36,324	-2.61
62	I-74 FEEDERS	114,653	110,728	-3.42
63	I-275 / SPRINGDALE	92,000	98,979	7.59
64	GALBRAITH WEST	87,597	97,032	10.77
65	I-275 CENTRAL HAMILTON CO.	136,951	137,074	0.09
66	NORTH CORRIDOR FAR WEST	190,749	219,859	15.26
67	NORTH CORRIDOR WEST	200,197	224,608	12.19
68	NORTH CORRIDOR EAST	147,850	159,262	7.72
69	NORTH CORRIDOR NORTH	251,503	257,133	2.24
70	NORTH CORRIDOR SOUTH	264,848	289,781	9.41
71	BLUE ASH	84,548	98,880	16.95
72	HAMILTON COUNTY NE.	167,250	162,705	-2.72
73	I-275 NORTHEAST	117,099	131,172	12.02
74	FOREST PARK NORTH	152,000	188,926	24.29
75	COLERAIN NORTH HAM. COUNTY	118,149	124,906	5.72
76	NORWOOD LATERAL	223,047	221,414	-0.73
77	I-71 NORTH HAMILTON COUNTY	157,099	171,539	9.19
78	CENTER HILL	79,248	82,634	4.27
79	READING	83,145	105,316	26.67
80	LANGDON FARM	112,055	108,719	-2.98
81	LITTLE MIAMI RIVER (NEWTOWN)	76,595	96,834	26.42
82	LITTLE MIAMI (LOVELAND)	151,051	161,210	6.73
83	LITTLE MIAMI RIVER (S. WARREN)	45,898	46,533	1.38
84	LITTLE MIAMI (CENTRAL WARREN CO.	47,847	53,609	12.04
85	LITTLE MIAMI RIVER (N. WARREN CO.)	9,950	11,817	18.76
86	LEBANON SOUTH	74,150	92,623	24.91

Table 4.1.25 – Year 2000 Cutline Comparison for the OKI Region (Continued)

Cutline Number	CUTLINE NAME	Observed Volume	Estimated Volume	% Error
87	CLERMONT NE.	20,500	24,569	19.85
88	CLERMONT EAST CENTRAL	56,901	52,351	-8
89	CLERMONT SE	29,098	36,670	26.02
90	CLERMONT SOUTH	57,397	68,548	19.43
91	CLERMONT CENTRAL	63,400	66,944	5.59
92	CLERMONT NORTH	55,250	60,230	9.01
93	WARREN SOUTHWEST	127,998	160,177	25.14
94	NORTHWEST WARREN	58,997	65,018	10.21
95	MIDDLETOWN NORTH	123,149	125,365	1.8
96	MIDDLETOWN SOUTH	143,401	159,460	11.2
97	N/S BUTLER CO.	107,749	133,910	24.28
98	I-75/ALLEN	202,392	238,319	17.75
99	CITY OF HAMILTON! (SOUTH)	132,100	142,655	7.99
100	GREAT MIAMI RIVER NORTH	76,301	55,682	-27.02
101	GR. MIAMI RIVER (N. BUTLER CO.)	29,751	31,270	5.11
102	CITY OF HAMILTON! EAST	70,102	78,154	11.49
103	GREAT MIAMI RIVER (HAMILTON!)	72,000	77,299	7.36
104	CENTRAL N/S BUTLER	105,642	85,969	-18.62
105	SR-63/TYLERSVILLE	57,348	69,520	21.22
106	SR-73/SR-122	52,295	50,558	-3.32
107	MILLVILLE/HAMILTON! NORTH	36,251	39,425	8.76
108	ANDERSON/UNION TWP.	105,098	101,453	-3.47
109	EASTGATE NORTH	85,099	80,278	-5.67
110	I-275/SR-28	135,351	157,853	16.62
111	I-275/BEECHMONT	101,700	103,629	1.9
112	BOONE EXTERNAL	36,450	32,015	-12.17
113	KENTON EXTERNAL	54,403	45,701	-16
114	CAMPBELL EXTERNAL	19,649	18,187	-7.44
115	CLERMONT EXTERNAL	46,251	52,131	12.71
116	WARREN EAST EXTERNAL	61,395	72,717	18.44
117	WARREN NORTH EXTERNAL	135,953	119,887	-11.82
118	BUTLER NORTH EXTERNAL	31,147	30,272	-2.81
119	BUTLER WEST EXTERNAL	5,196	4,430	-14.74
120	DEARBORN EXTERNAL	55,460	54,947	-0.92

4.1.4.3 Percentage Root Mean Square

Root Mean Square is another method to check the discrepancies between the observed and estimated traffic volumes. When screenline analysis checks the total volume passing through a corridor, the percent RMSE examines the error of each link for the volume groups. The formula of the RMSE is

$$RMSE = SQRT(\Sigma_L (GC - VA)^2 / N\text{-}1)$$

GC = Ground count on link L
VA=Volume assigned to link L
L = Set of all links
N=Total links

ODOT defined the volume groups and the allowable percent RMSE error with a curve, and all the volume group errors from model run should be below the ODOT curve. Figure 4.1.7 and Figure 4.1.8 display the RMSE comparison for the consolidated region and OKI region, and Figure 4.1.9 is a comparison using only links with actual counts (links with estimated counts are excluded). Table 4.1.26 – Table 4.1.28 present the RMSE summaries.

Figure 4.1.7 – Year 2000 RMSE Comparison for OKI/MVRPC Region

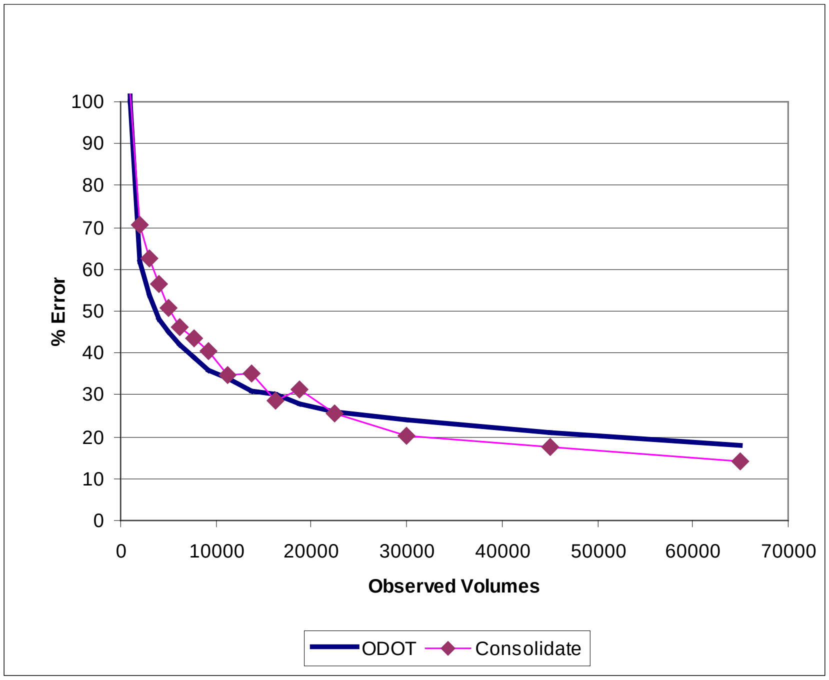


Figure 4.1.8 – Year 2000 RMSE Comparison for the OKI Region

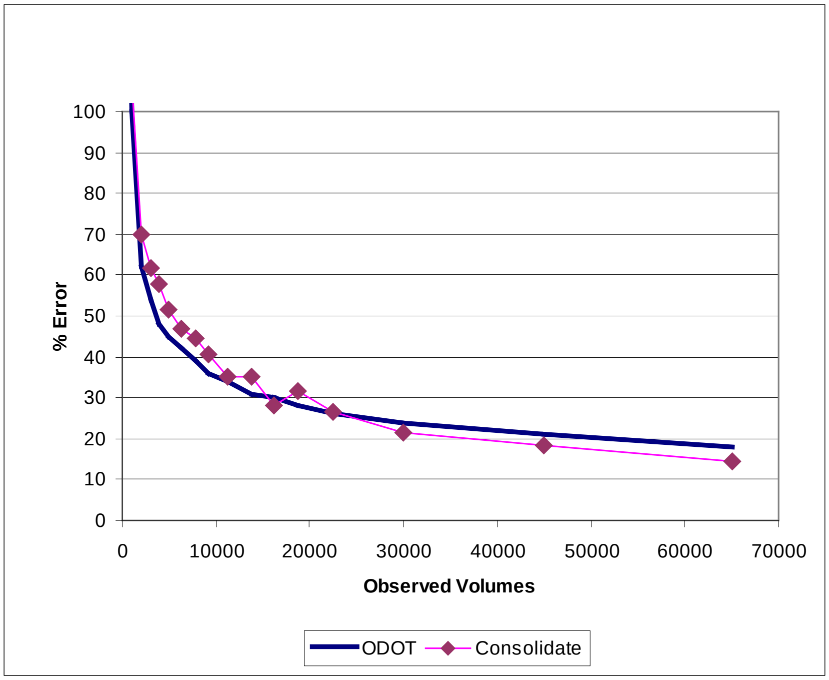


Figure 4.1.9 – Year 2000 RMSE comparison for the OKI/MVRPC Region Using Only Links with Actual Counts

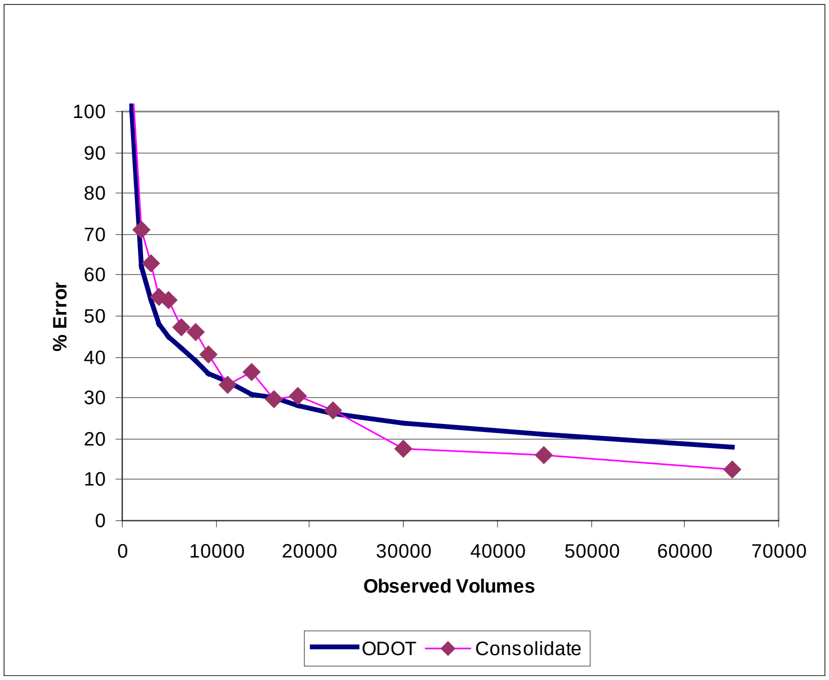


Table 4.1.26 – RMSE Summaries for OKI/MVRPC Region

		LINKS WITH ASSIGNMENT-GROUND COUNT DIFFERENCE														PERCENT RMSE		
VOLUME RANGES		RANGE OF DIFFERENCE													TOTAL	Allowable	Model	DIFF.
LOWER	UPPER	-30k	-20k	-15k	-10k	-5k	-2k	+-1999	2k	5k	10k	15k	20k	+30 k		MAX. (1)	(2)	(2-1)
0	500	0	0	0	0	0	0	628	7	0	0	0	0	0	635	200	153.7	-46.30
500	1500	0	0	0	0	0	0	1943	103	4	0	0	0	0	2050	100	101.9	1.90
1500	2500	0	0	0	0	0	41	1692	152	10	1	0	0	0	1896	62	70.8	8.80
2500	3500	0	0	0	0	0	240	1348	200	16	3	0	0	0	1807	54	62.5	8.50
3500	4500	0	0	0	0	0	358	933	146	35	0	3	0	0	1475	48	56.5	8.50
4500	5500	0	0	0	0	6	349	734	181	39	0	1	0	0	1310	45	50.6	5.60
5500	7000	0	0	0	0	32	447	842	271	57	8	0	0	0	1657	42	46.1	4.10
7000	8500	0	0	0	0	65	358	644	200	92	9	0	0	0	1368	39	43.4	4.40
8500	10000	0	0	0	0	68	200	351	139	63	4	1	0	0	826	36	40.3	4.30
10000	12500	0	0	0	4	114	221	507	242	83	13	0	0	0	1184	34	34.7	0.70
12500	15000	0	0	0	6	43	115	185	104	64	9	6	0	0	532	31	35	4.00
15000	17500	0	0	0	8	37	82	146	49	46	7	0	0	0	375	30	28.6	-1.40
17500	20000	0	0	0	6	31	36	75	37	34	10	2	2	0	233	28	31.3	3.30
20000	25000	0	0	0	10	22	51	41	67	32	8	0	0	0	231	26	25.6	-0.40
25000	35000	0	1	3	17	28	40	55	40	54	2	0	0	0	240	24	20.2	-3.80
35000	55000	0	8	5	15	32	46	48	70	39	13	2	2	0	280	21	17.6	-3.40
55000	75000	0	12	19	18	48	46	42	22	33	38	0	0	0	278	18	14.3	-3.70
TOTAL		0	21	27	84	526	2630	10214	2030	701	125	15	4	0	16377			

Table 4.1.27 – RMSE Summaries for OKI Region

		LINKS WITH ASSIGNMENT-GROUND COUNT DIFFERENCE														PERCENT RMSE		
VOLUME RANGES		RANGE OF DIFFERENCE													TOTAL	Allowable	Model	DIFF.
LOWER	UPPER	-30k	-20k	-15k	-10k	-5k	-2k	+-1999	2k	5k	10k	15k	20k	+30 k		MAX. (1)	(2)	(2-1)
0	500	0	0	0	0	0	0	370	7	0	0	0	0	0	377	200	172.7	-27.30
500	1500	0	0	0	0	0	0	1324	83	3	0	0	0	0	1410	100	107	7.00
1500	2500	0	0	0	0	0	31	1309	115	7	1	0	0	0	1463	62	69.9	7.90
2500	3500	0	0	0	0	0	198	1053	153	11	1	0	0	0	1416	54	61.7	7.70
3500	4500	0	0	0	0	0	289	727	115	32	0	3	0	0	1166	48	57.9	9.90
4500	5500	0	0	0	0	6	292	621	157	36	0	1	0	0	1113	45	51.7	6.70
5500	7000	0	0	0	0	27	370	696	241	52	8	0	0	0	1394	42	47	5.00
7000	8500	0	0	0	0	52	289	533	182	88	9	0	0	0	1153	39	44.4	5.40
8500	10000	0	0	0	0	55	156	301	115	56	4	1	0	0	688	36	40.6	4.60
10000	12500	0	0	0	4	93	187	437	214	80	12	0	0	0	1027	34	35.1	1.10
12500	15000	0	0	0	4	35	99	143	94	57	8	5	0	0	445	31	35.2	4.20
15000	17500	0	0	0	5	33	73	128	40	42	7	0	0	0	328	30	28.3	-1.70
17500	20000	0	0	0	5	27	30	70	37	34	10	2	2	0	217	28	31.5	3.50
20000	25000	0	0	0	10	19	44	35	63	28	8	0	0	0	207	26	26.4	0.40
25000	35000	0	1	3	17	25	27	45	35	50	2	0	0	0	205	24	21.4	-2.60
35000	55000	0	8	5	15	24	37	40	64	38	13	2	2	0	248	21	18.3	-2.70
55000	75000	0	12	19	17	46	45	37	21	33	38	0	0	0	268	18	14.4	-3.60
TOTAL		0	21	27	77	442	2167	7869	1736	647	121	14	4	0	13125			

Table 4.1.28 – RMSE Summaries for OKI Region Using Links Only with Actual Counts

		LINKS WITH ASSIGNMENT-GROUND COUNT DIFFERENCE														PERCENT RMSE		
VOLUME RANGES		RANGE OF DIFFERENCE													TOTAL	Allowable	Model	DIFF.
LOWER	UPPER	-30k	-20k	-15k	-10k	-5k	-2k	+-1999	2k	5k	10k	15k	20k	+30k		MAX. (1)	(2)	(2-1)
0	500	0	0	0	0	0	0	261	6	0	0	0	0	0	267	200	184.3	-15.70
500	1500	0	0	0	0	0	0	694	51	1	0	0	0	0	746	100	109.4	9.40
1500	2500	0	0	0	0	0	12	659	65	5	1	0	0	0	742	62	71.2	9.20
2500	3500	0	0	0	0	0	95	470	67	9	1	0	0	0	642	54	62.7	8.70
3500	4500	0	0	0	0	0	152	360	60	19	0	0	0	0	591	48	54.5	6.50
4500	5500	0	0	0	0	2	141	294	90	21	0	1	0	0	549	45	54.1	9.10
5500	7000	0	0	0	0	13	178	376	152	37	3	0	0	0	759	42	47.3	5.30
7000	8500	0	0	0	0	41	149	286	87	51	5	0	0	0	619	39	46	7.00
8500	10000	0	0	0	0	35	90	179	68	43	0	0	0	0	415	36	40.5	4.50
10000	12500	0	0	0	1	41	110	250	94	50	4	0	0	0	550	34	33.3	-0.70
12500	15000	0	0	0	3	21	49	84	65	38	7	2	0	0	269	31	36.2	5.20
15000	17500	0	0	0	3	25	45	69	19	27	3	0	0	0	191	30	29.5	-0.50
17500	20000	0	0	0	4	10	24	57	15	12	7	1	2	0	132	28	30.5	2.50
20000	25000	0	0	0	7	8	32	11	23	10	2	0	0	0	93	26	26.9	0.90
25000	35000	0	0	1	1	6	8	11	17	17	0	0	0	0	61	24	17.7	-6.30
35000	55000	0	1	2	9	15	20	16	32	13	3	0	0	0	111	21	16	-5.00
55000	75000	0	1	1	0	10	10	7	2	17	12	0	0	0	60	18	12.4	-5.60
TOTAL		0	2	4	28	227	1115	4084	913	370	48	4	2	0	6797			

The patterns on Figure 4.1.6 to Figure 4.1.8 are very similar: the errors on links with heavy traffic (volume > 20,000) are under the ODOT curve, and the errors on links with light volumes are on or above the ODOT curve, but quite close.

Both RMSE charts and cutline comparison show the estimation errors are a little too high for low volume link groups. There are many reasons for discrepancies between observed and estimated traffic volume. As mentioned before, all major routes from interstate down to some collector are included in the network, but not all the minor/local routes. So, those that are in the network may represent two or more existing streets. The actual ground count is for only the particular route which is modeled. In this situation, the ground count would be underrepresented and the links exhibits an apparent over assignment. This situation should be taken into consideration in validity analysis.

Zone size and centroid connection also make differences. If a land use represented by a particular traffic zone has only one point of ingress and egress to the actual road network, then the modeling is not difficult. However, when a traffic zone is large and has more than one activity center within the zone with many access points to the roadway system serving these centers, the model may not be able to produce accurate results. For large zone with multi centroid connectors, the portion of trips sent to the different centroid connectors may not be properly simulated. Many times one centroid connector will have many trips while the others will have few. This can and often does cause an over concentration of trips at the point of loading.

Relating to zone size, “localizing” or “jumping” is a loading problem. On the actual roadway system as we know, traffic load at many places form arterial down to local roads. Limit access highways are not as much a problem in terms of large spikes of volumes. The zones which experience the most problems of this nature are those with a heavy influence in one direction such as suburb zones with high numbers of households which produce many trips which are attracted to the CBD or other employment centers. Links adjacent to these zones tend to experience more traffic than is reasonable causing a “localized” problem. Also, zones near routes with high speeds and capacity show an unbalanced loading. For example, zone with four centroid connections near an interstate highway that produces and attracts a high volume of zonal trips has a tendency to incorrectly send the majority of the trips onto the centroid nearest the interstate highway instead of onto the other centroid connectors that connect to adjacent arterials and collectors. This series of links represent the minimum time path for many trips because in general the interstate speeds are higher and trips are sent to other zones via these routes. This can lead to an assignment that is very high on one side and very low on the other side. In reality zonal trip generation is often spread throughout a zone or along a zone’s perimeter. Thus a large jump in the traffic count is not as common in the observed. In the end, trips will end up on the interstate but how they get there may be skewed.

Careful subdivision of zones and coding of centroid connector distances can alleviate some of problems mentioned above. Comparing to older versions (model 5X and earlier), the latest model increases zone numbers and has smaller zones (zones increased from 1003 to 1608 in OKI area). The centroid connections were also examined and edited. Subdivision of zones further is under consideration. The concern is the ability to forecast the socioeconomic data for smaller areas and their reliability. There is a limit of what can be done for a model designed for regional planning use.

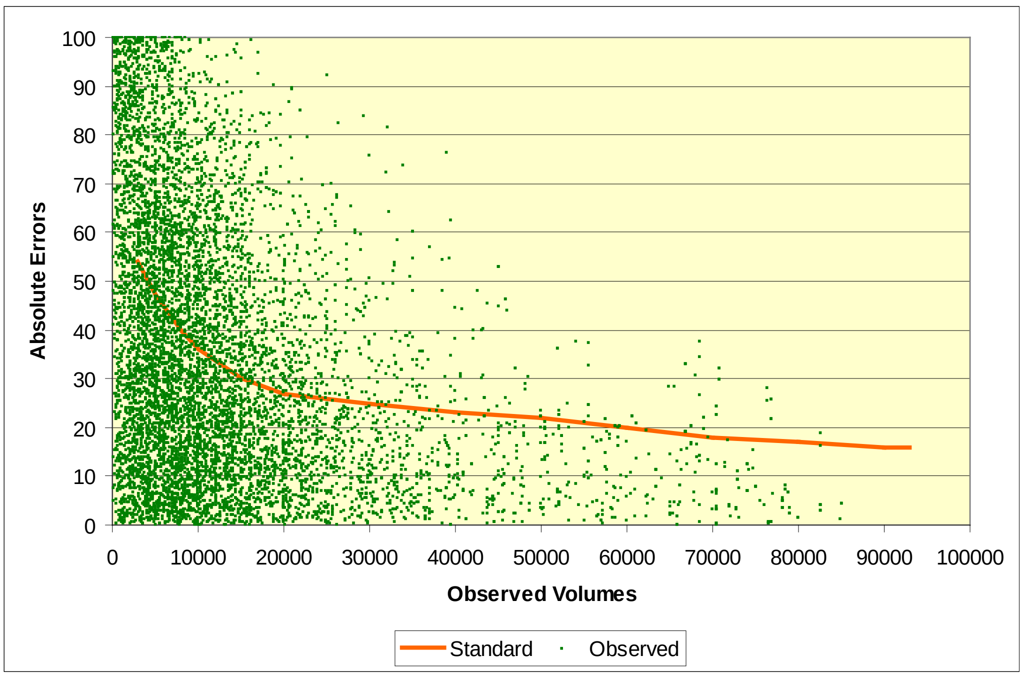
Another difficulty encountered in the assignment procedure is that when arterials and freeways are close to each other and serving the same general traffic flow, more often than not, the freeway gets over assigned and the arterial is under. This is because freeways have higher free flow speeds and higher capacity. Some of this problem is taken care of by using the weighted time/distance as impedance for determining paths for trips. Additional efforts are made to redistribute trips by modifying speeds on freeway, arterials or both, but only to the extent that they remain reasonable and as much as possible representing the speeds on the roadway themselves.

Some causes of problems could be traced up to trip generation phase. Areas with large amounts of commercial activity are in general not simulated well within the model. Attempts are made to correct this through the use of special add-on trips to zonal attractions where these areas occur. Zones with large regional shopping centers coupled with strip commercial centers and a number of fast-food restaurants are normally under assigned trips compared to observed traffic counts even with the add-on trips. Additional evaluation of add-on trips will be performed.

4.1.4.4 Scatter Plots and Regression Plots

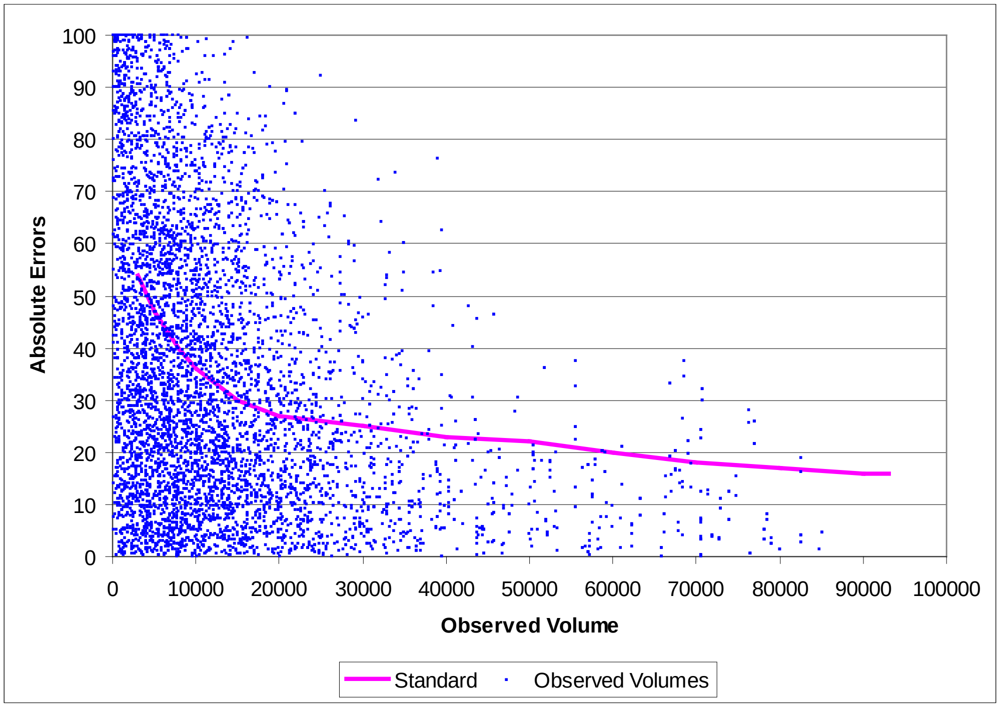
In addition to the methods mentioned above, a curve recommended by NCHRP Report 255[3] defines "Maximum desirable error for link volumes", and is another useful tool for highway assignment validation. While RMSE checks the link group estimation error, this curve measures volume and count disparities of individual link. Two scatter plots were created to compare the individual link estimation errors with the curve. The comparison in Figure 4.1.10 includes all links (with actual or estimated counts) and in Figure 4.1.11 includes only links with an actual count. Both charts demonstrate similar patterns and further prove that the assignments are at satisfactory level for links with large volumes, but not at that level for links with small volumes.

Figure 4.1.10 – Year 2000 Individual Link Estimation Errors for the OKI/MVRPC Region (include All Links with an Actual or Estimated Traffic Count)



[3] Page 41, National Cooperative Highway Research Program Report 255 "Highway Traffic Data For Urbanized Area Project Planning and Design", Transportation Research Board, December 1982

Figure 4.1.11 – Year 2000 Individual Link Estimation Errors for OKI/MVRPC Region (Include Only Links with an Actual Count)



Another useful tool for the validation is a regression plot that compares observed and estimated volumes, and calculates R^2 (Coefficient of Determination). Based on "Model validation and Reasonableness Checking Manual", the data points on the regression plots should be close to the 45^o line and the R^2 should be greater than 0.88. Figure 4.1.12 is the regression plot including the estimated counts, and Figure 4.1.13 uses actual counts only. Both charts show good correlation of observed and estimated volume, and both have R^2 that equal to 0.88. So, this test shows the assignment performance is at acceptable level.

Figure 4.1.12 – Year 2000 Observed Volume vs. Estimated Volume for OKI/MVRPC Region (include All Links with an Actual or Estimated Count)

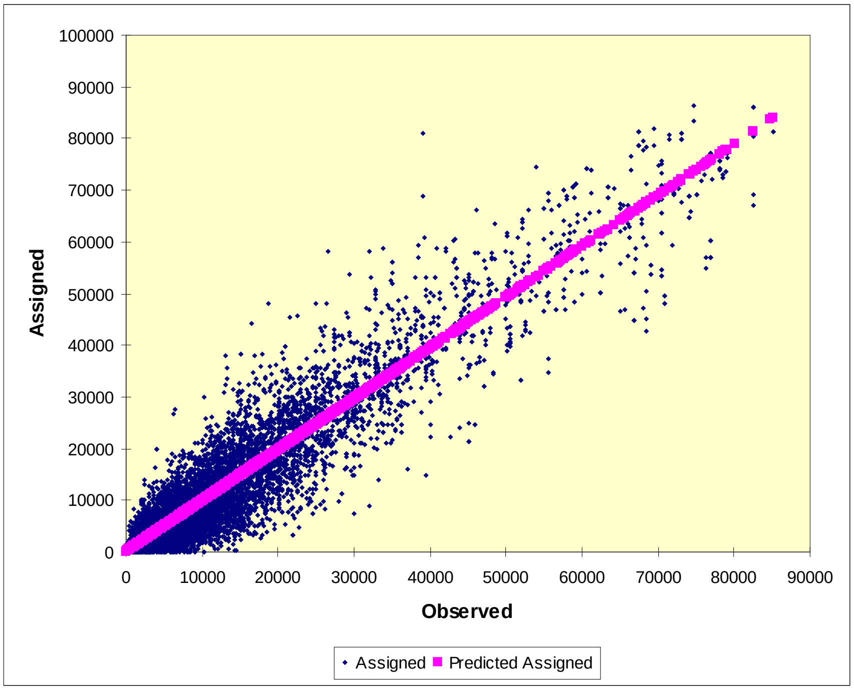
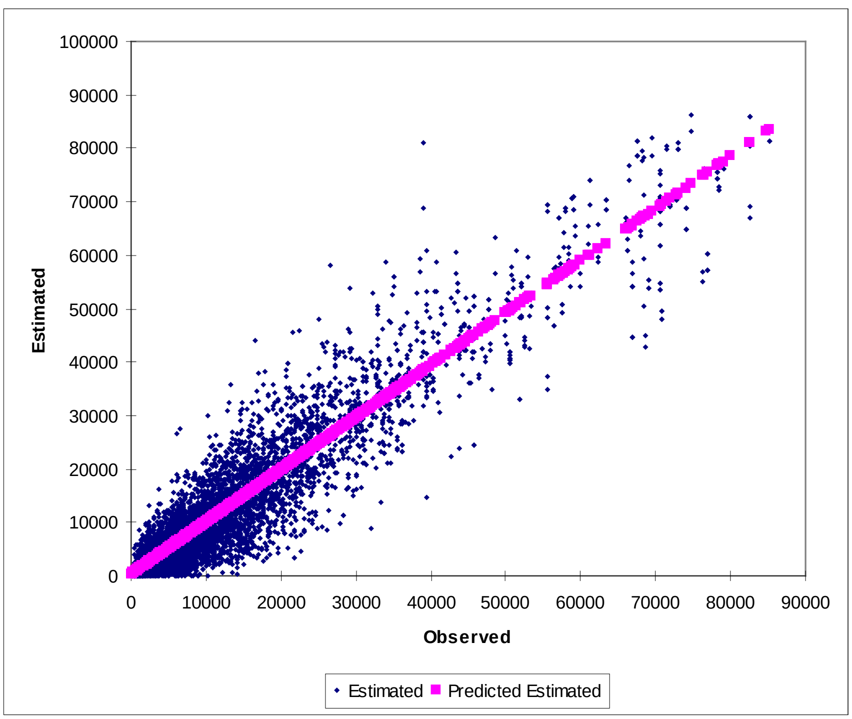


Figure 4.1.13 – Year 2000 Observed Volume vs. Estimated Volume for OKI/MVRPC Region (include only links with an Actual Count)



4.1.5 Transit Assignments

The transit assignment consists of two all-or-nothing daily assignments: peak period and off peak period. Transit trips from the home based and non home based purposes are added to the airport and King's Island trips prior to assignment. This section validates transit ridership against OKI year 2000 observed data.

For the purpose of the validation, student trips were not included in the assignment. For forecasting purposes these trips will be included in the transit boarding totals.

The observed transit data used to compare to the transit assignment are 2000 figures obtained from the transit operators METRO of Ohio and TANK of Kentucky. The average weekday ridership of 50 bus routes was grouped into seven corridors of METRO and two corridors of TANK for the convenience of the validation. Figure 4.1.14 displays the corridors. The crosstown corridor overlaps with other corridors (in yellow), but the volumes were tabulated separately from the others.

Figure 4.1.14 – Year 2000 Transit Corridors

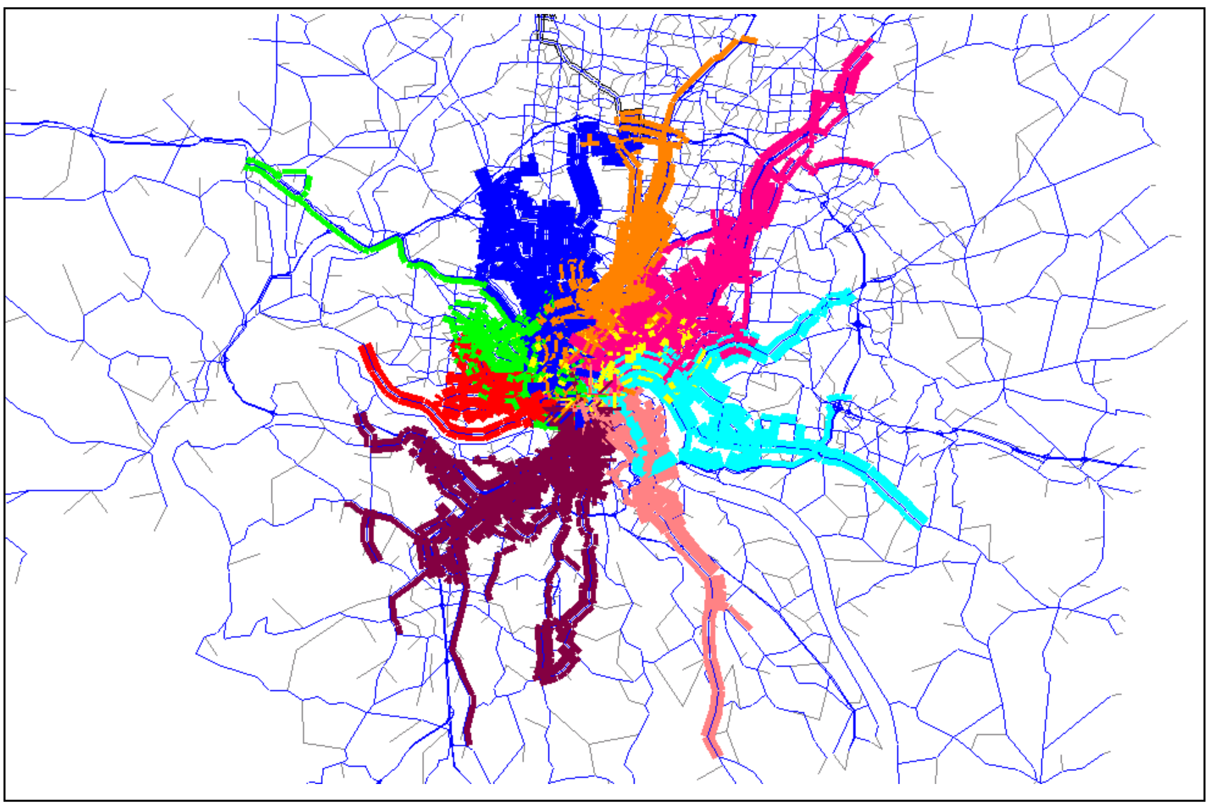


Table 4.1.29 and Table 4.1.30 show the comparison of modeled and observed daily transit ridership by corridors and by routes. The overall METRO ridership is about 13.62 percent over estimated, and TANK ridership is about 13.83 percent over estimated. This discrepancy may due

to the possible overestimation of transit trips in modal choice model. The model (which was calibrated using 1995 data) estimates 3.52% of home based work trips using transit, while the year 2000 census journey to work data indicates 2.90 % of the work trips in OKI region using transit. The discrepancies by corridors and routes are relatively large. Additional checks on transit network and path finding parameters will be performed. Efforts were already made to check the appropriateness of the network and path finding parameters. As mentioned in Chapter 3, the transit network was updated based on the 2000 data provided by the transit companies, and the alignments and attributes of transit lines were checked and edited. Missing lines were added, wrong alignments were corrected, and headways, bus runs and average travel times were recalculated. Furthermore, the auxiliary links such as sidewalk walk connectors and automobile (drive) connectors were checked and edited, and the bus stations, bus transfers are also checked. The transit modeling is technically complicated and the improvements in duplicating the observed data are very challenging. The effort to improve the transit loading will continue.

Table 4.1.29 – Year 2000 Observed and Estimated Transit Ridership Comparison (by Corridor) for OKI Region

CORRIDOR	Predicted Ridership	Observed Ridership	Difference (P-O)	Percentage Difference
1. Price Hill	4412	2558	1854	72.48%
2. Western Hills	16960	12260	4700	38.34%
3. Colerain / Winton	15506	11044	4462	40.40%
4. Reading / Vine	18441	21273	-2832	-13.31%
5. Montgomery / Madison	19534	12884	6650	51.61%
6. Eastern	3255	3079	176	5.72%
7. Crosstown	11227	15526	-4299	-27.69%
METRO TOTAL	**89335**	**78624**	**10711**	**13.62%**
8. Kenton County	10616	10456	160	1.53%
9. Campbell County	5280	3362	1918	57.05%
TANK TOTAL	15896	13818	2078	15.04%
METRO & TANK TOTAL	**105231**	**92442**	**12789**	**13.83%**

Table 4.1.30 – Year 2000 Observed and Estimated Transit Ridership Comparison (by Route) for OKI Region

RTCODE	COMP	ROUTE#	CORRIDOR	OBSERVED	PREDICTED	% DIFF.(P-O)
1_1	1	1	7	935	690	-26%
1_3	1	3	5	370	117	-68%
1_4	1	4	5	6751	11414	69%
1_6	1	6	2	1994	5918	197%
1_10	1	10	1	1011	502	-50%
1_11	1	11	5	4554	6922	52%
1_16	1	16	4	881	330	-63%
1_17	1	17	3	7035	8509	21%
1_18	1	18	3	850	966	14%
1_19	1	19	3	1026	2557	149%
1_20	1	20	3	1234	2361	91%
1_21	1	21	2	2791	1286	-54%
1_22	1	22	3	149	793	432%
1_23	1	23	4	469	253	-46%
1_24	1	24	6	1192	2405	102%
1_25	1	25	5	99	1	-99%
1_26	1	26	6	62	115	85%
1_27	1	27	2	2154	1144	-47%
1_28	1	28	7	1401	1022	-27%
1_29	1	29	6	30	8	-73%
1_30	1	30	6	428	84	-80%
1_31	1	31	7	3271	3757	15%
1_32	1	32	1	1285	2811	119%
1_33	1	33	2	4458	8035	80%
1_39	1	39	2	228	427	87%
1_40	1	40	2	350	87	-75%
1_42	1	42	4	464	80	-83%
1_43	1	43	4	10782	8171	-24%
1_46	1	46	4	3863	2088	-46%
1_49	1	49	7	2208	646	-71%
1_50	1	50	1	35	952	2620%
1_51	1	51	7	1517	3342	120%
1_52	1	52	2	285	63	-78%
1_53	1	53	7	995	74	-93%
1_56	1	56	5	263	379	44%
1_62	1	62	4	278	440	58%
1_64	1	64	7	4829	1344	-72%
1_70	1	70	6	144	15	-90%
1_71	1	71	5	685	616	-10%
1_74	1	74	3	750	320	-57%
1_75	1	75	6	673	423	-37%
1_77	1	77	1	227	147	-35%
1_78	1	78	4	4536	7079	56%
1_79	1	79	7	370	352	-5%

1_80	1	80	5	162	85	-48%
1_81	1	81	6	268	72	-73%
1_82	1	82	6	282	133	-53%
2_1	2	1	8	2826	3018	7%
2_2	2	2	8	801	1406	76%
2_3	2	3	8	473	283	-40%
2_4	2	4	8	108	169	56%
2_5	2	5	8	562	117	-79%
2_7	2	7	8	1370	915	-33%
2_8	2	8	8	700	360	-49%
2_9	2	9	8	380	335	-12%
2_11	2	11	9	487	775	59%
2_12	2	12	9	881	922	5%
2_16	2	16	9	443	1261	185%
2_17	2	17	8	385	91	-76%
2_18	2	18	8	140	6	-96%
2_19	2	19	8	164	42	-74%
2_20	2	20	9	89	94	6%
2_22	2	22	8	125	48	-62%
2_23	2	23	9	198	260	31%
2_24	2	24	9	305	304	0%
2_25	2	25	9	708	1065	50%
2_26	2	26	9	173	372	115%
2_27	2	27	9	78	227	191%
2_28	2	28	8	131	0	-100%
2_29	2	29	8	188	46	-76%
2_30	2	30	8	129	51	-60%
2_31	2	31	8	85	144	69%
2_32	2	32	8	172	46	-73%
2_33	2	33	8	191	551	188%
2_34	2	34	8	0	104	0%
2_35	2	35	8	29	210	624%
2_SOUTHBANK	2	SB	8	1497	2674	79%
3_GREEN	3	GREEN	11	275	224	-19%
3_GOLD	3	GOLD	11	228	337	48%
3_RED	3	RED	11	147	786	435%
3_BLUE	3	BLUE	11	255	386	51%
4_2	4	2	10	125	686	449%
4_4	4	4	10	125	81	-35%
4_5	4	5	10	125	86	-31%
4_6	4	6	10	125	2372	1798%
4_9	4	9	10	125	593	374%
4_10	4	10	10	125	52	-58%
4_11	4	11	10	125	100	-20%
	QCM (1)			78624	89335	
	TANK (2)			13818	15896	
	CITY OF HAMILTON (3)			905	1733	
	Butler County Transit (4)			875	3970	
	OKI REGION			94222	110934	

4.1.6 Validation Summary

The validation analysis has tested the travel demand model performance at all aspects including trip generation, trip distribution, modal choice, highway assignment and transit assignment. The validation has proved that the model performs well at trip generation, and the trip rates calculated using model outputs match observed data quite well. The trip distribution validation also show good results, the trip lengths are reasonable, and the trip flow interchange simulates similar pattern as census data. However, the non home based intrazonal trips are a little too large, and need further study. The model also does reasonably well at modal choice, and the mode splits are close to the 1995 surveyed percentages. However, year 2000 census data indicates that the transit share is lower in year 2000 for work trips.

Highway assignment is a focus of the validation, and estimation errors of assigned volumes and counts are tested against ODOT criteria and other widely used TRB and FHWA standards. VMT validation tests the assignment systemwide and show very good match of estimated and observed volumes. Screenlines and cutlines measure the model performance at corridor level and show good results at screenline comparison, and not at satisfactory level at a few cutline locations. The RMSE checks estimation errors of link groups, and demonstrates that the model performs slightly below the desired accuracy for low volume links. The individual link error checking gives same conclusion as RMSE. Transit assignment has been validated against year 2000 observed ridership, overall the ridership is about 36 percent overestimated and the discrepancies are significant at corridor and route levels. The distribution of transit trips among the transit routes is not simulated well. Additional analysis on modal choice, path finding and transit network is needed.

In general the model quality is good, and suitable for regional analysis and long range planning. But the effort to improve the quality of the model will continue. The quality of current model is better than the previous versions overall, it needs fine tuning and to meet the industry's acknowledged standards better. Some "shortcuts" exist for model improvements. For example, modifying speeds or capacity not based on actual data can improve model performance, but will skew the forecasting results. It is felt that knowing the model's shortcomings before undertaking a planning study is far superior to "masking" the model's problems during the validation process. The efforts to identify errors in input data and methodology will continue. The trip data will be analyzed to examine the changes in trip making behavior.