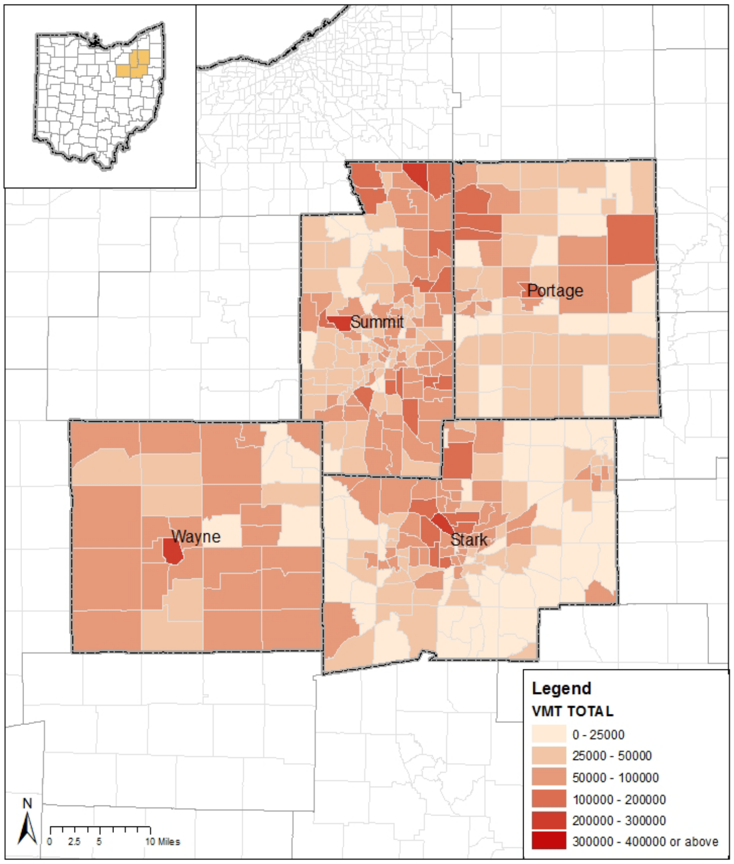
Linking Land Use and Travel in Ohio: Incorporating Vehicle Choice and Decline Components



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16. Abstract		

This study adds two new components to the Regional Land Use Allocation Decision Analysis Tool, which was developed for ODOT in 2013. This tool uses information on infrastructure availability (accessibility, sewer, water services), current land-use policies where available, and environmental constraints to allocate regional and county forecasts of population and employment to 40 acre cells in each metropolitan region of Ohio. This information is then used in subsequent transportation models to estimate the number of auto trips, trip distances and the resulting VMT. This study adds two critical components to this model: vehicle choice and a better understanding of the impacts of declines in population and employment. The outputs of the revised land-allocation tool provide population and employment distribution to forecast auto trips, vehicle type distribution and trip distances at the TAZ level for each future scenario.

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1. INTRODUCTION

The connections between land-use, transportation infrastructure, socio-demographics and travel behavior have been the focus of several studies in the literature (Badoe and Miller 2000; Ewing et al. 2011; Miller et al. 2004; Waddell 2011). Several urban challenges related to energy consumption, environmental quality and economic viability result from these connections. The major challenges include traffic congestion, greenhouse gas (GHG) emissions, air pollution and fuel consumption (Badoe and Miller 2000; Ewing et al. 2011; Stead 1999). Auto dependency and the resulting increasing vehicle miles travelled are key contributors to these urban issues. These issues have been challenging policy makers and planners along with the changing demographics and economic conditions and rising costs of energy.

In recent decades, metropolitan regions around the world have been devoting their efforts in developing alternative growth policies and plans to mitigate the consequences of urban problems related to energy consumption, global warming, environmental quality and economic viability. It is important to understand the relationships between land-use, transportation infrastructure, socio-demographics and travel behavior, and how these might be impacted by future land use, transportation and energy policies to mitigate these issues.

According to the 2001 National Household Transportation Survey (NHTS), private vehicle trips account for 80% of all trips nationwide (Pucher and Renne 2003). The carbon footprint of daily travel for an individual or a household is based on the types of vehicles that household owns, the fuel efficiency, and the number of miles traveled. Therefore, the number and types of vehicles a household owns are important determinants of the resulting travel patterns. Although there are many technological innovations with the potential to reduce transportation emissions from passenger vehicles, several researchers agree that those technological innovations alone will not be enough to reach targeted reductions in emissions, as the projected increase in vehicle miles traveled will outpace the advances in fuel economy and lower carbon fuels (Ewing et al. 2008; Rajan 2006; Schipper 2011). Therefore it is crucial to understand the links between the land-use, transportation policies, individual/household travel behavior and vehicle choice to reduce GHG emissions and shape the travel patterns in the future.

The land-use, vehicle choice and travel behavior models provided as a result of this research enable the decision makers make informed decisions regarding the future land-use policies and transportation investments.

2. OBJECTIVES & PROJECT SCOPE

In the previous project funded by ODOT, the PIs developed a *Regional Land-use Allocation Decision Analysis Model*, which would enable decision makers quantify the impacts population and employment distribution and the resulting VMT. This model includes two main components: Land Allocation Component and Transportation Component. The model can forecast the changes in VMT under changing land-use decisions and transportation policies. The model uses information concerning infrastructure availability (accessibility, sewer, water services), current land-use policies where available, and environmental constraints to allocate regional and county forecasts of population and employment to 40 acre cells in each metropolitan region of Ohio. The outputs of the land-allocation model inform the subsequent transportation models in terms of population and employment distribution to forecast auto trips and trip distances for each future scenario. These forecasting models estimate the number of auto trips and the associated distances as a function of household characteristics, population and employment distribution aggregated to the TAZ (Traffic Analysis Zone) level.

This study adds two critical components to this *Regional Land-use Allocation Decision Analysis Tool*: vehicle choice and a better understanding of the impacts of declines in population and employment. Adding a vehicle choice component will enable the decisions makers predict the impacts of land-use and socioeconomic changes on households' vehicle holdings. Vehicle type distribution models are developed to forecast the changes in vehicle fleet based on changing socio-economics and land-use characteristics. The outputs of the land-allocation model provide population and employment distribution to forecast vehicle type distribution, auto trips and trip distances at the TAZ level.

3. LAND ALLOCATION COMPONENT: Improving the Land Use Change Forecast

3.1. Project Goals

In our previous research project, *Linking Land Use, Transformation and Travel Behavior in Ohio* (Akar et al. 2013), we linked a land allocation model based on forecasts of population and employment with a model of travel behavior. One of the problems we faced in that work is that portions of many Ohio metropolitan areas are declining in population while other parts of the same metropolitan regions are growing. We employed an empirical forecast based on the extent of the growth or decline of subareas between 1990 and 2000 to represent those changes. However, those indicators used rather arbitrary breakpoints to represent the changes and did not offer any further insights into the underlying causes of the changes.

The goal of this part of the project is to create a more robust model of growth and decline that can be integrated into the land allocation and travel models. We begin with a discussion of our general approach and its relationship with the literature. We then describe the available input data, the analytical approaches we used to test various models, and the final model results.

3.2. General Approach

The land allocation model uses a probabilistic framework to choose subareas that are most likely to grow or decline based on historical trends. Since consistent historical data on land use are not available, population change is used as a proxy for these probabilities. The key question then becomes best to model population change at sub-metropolitan area scale.

Both inter- and intra-regional migration play a pivotal role in population changes for the small areas (Klosterman 1990; Tayman 1996). Such forecasts consider the interactions among socioeconomic, environmental, and housing, and local infrastructure conditions (Chi 2010; Smith 2001; Wilson 2005).

Studies have found a diverse set of causes and conditions for population movement. Economic opportunities are an important set of factors in migration. People are willing to move to a new location where there is an influx of capital, higher wages, or potential development areas in anticipation of a better quality of life (Egdell and McQuaid 2011; Headey 2009; Shafik 1994; Wu and Yao 2003). Conversely, higher unemployment rates and housing cost burdens have been linked to negative changes in population and land use (Alexiadis et al. 2013; Kirk and Laub 2010; Matsukawa 1991). According to Wilson (1987), poverty rates have dramatically increased in Chicago since deindustrialization and suburbanization. This has resulted in inner city neighborhoods populated by lower-skilled African Americans. Eggers and Massey also found that the decline of manufacturing jobs has resulted in people moving toward areas with job opportunities (Eggers and Massey 1991).

Historical trend in the area's population size is an important factor to predict to future unless some of areas experience unprecedentedly dramatic demographic changes (Hobbs and Stoops 2002).

The availability and quality of housing also impacts neighborhood level migration. Adding new housing units generally results in neighborhood population growth (Ellen 2008; Rosenthal 2008). Hobbs and Stoops (2002) also found that newer, more affordable housing opportunities induce substantial population growth. In contrast, old housing units are more likely to influence neighborhood decline and physical deterioration. Since neighborhood decline can be a result of filtering process, affluent families move out to newer housing while poor families fill in their vacancy (Galster 1991; Rosenthal 2008; Temkin and Rohe 1996).

Indices of quality of life or local amenities have also been found to influence growth. These include recreation opportunities, social and public service availability, and the quality of the public schools (DeLuca and Dayton 2009; Jordan et al. 2012; Krupka 2009; Rickman and Rickman 2011). These impacts often occur at the neighborhood level, differentiating different neighborhoods based on their proximity and accessibility to a variety of amenities. Several authors have also found that the physical condition of the neighborhood including the presence of vacant and abandoned property and the condition of the local physical infrastructure influence population and land use change (Chi 2012; Gutiérrez et al. 1998)

Using data from the several sources, we apply these observations to examine the influence of regional economic conditions and local economic, quality of life, and physical conditions on the rate of neighborhood growth and decline between 1990 and 2000. These indicators are used to build a set of probabilities for growth and decline that are used to model a variety of future scenarios for the area and their possible impacts on transportation and other services.

3.3. Input Data

The primary data used in this study is the Neighborhood Change Database (NCDB) normalized by Geolytics[1]. It includes population and housing census data at the census tract level for metropolitan areas in Ohio[2]. Tract boundaries have changed over time. This dataset provides tract level census data for 1990, 2000, and 2010 normalized to 2010 boundaries. Employment data is used as the number of employees at place of work from Census Transportation Planning Products (CTPP) [3].

We modeled the changes in population between 1990 and 2000. Original number of census tracts is 2,956 but we used 2,435 census tracts representing 11 metropolitan areas in Ohio after excluding non-metro tracts. We did not use data for the remaining rural areas in Ohio as these had small populations and little change in their demographics over this period.

For the geographic boundaries of the metropolitan areas in Ohio, we used the primary metropolitan statistical areas of the US, which include 12 metropolitan areas in Ohio but we excluded Postsmouth metropolitan statistical area. The unit of analysis is at the census tract level. The areas used in the study are shown in Figure 1.

[1] www.geolytics.com
[2] Our thanks to the Ohio State University Center for Urban and Regional Analysis for allowing us to use these data under their license.
[3] www.fhwa.dot.gov

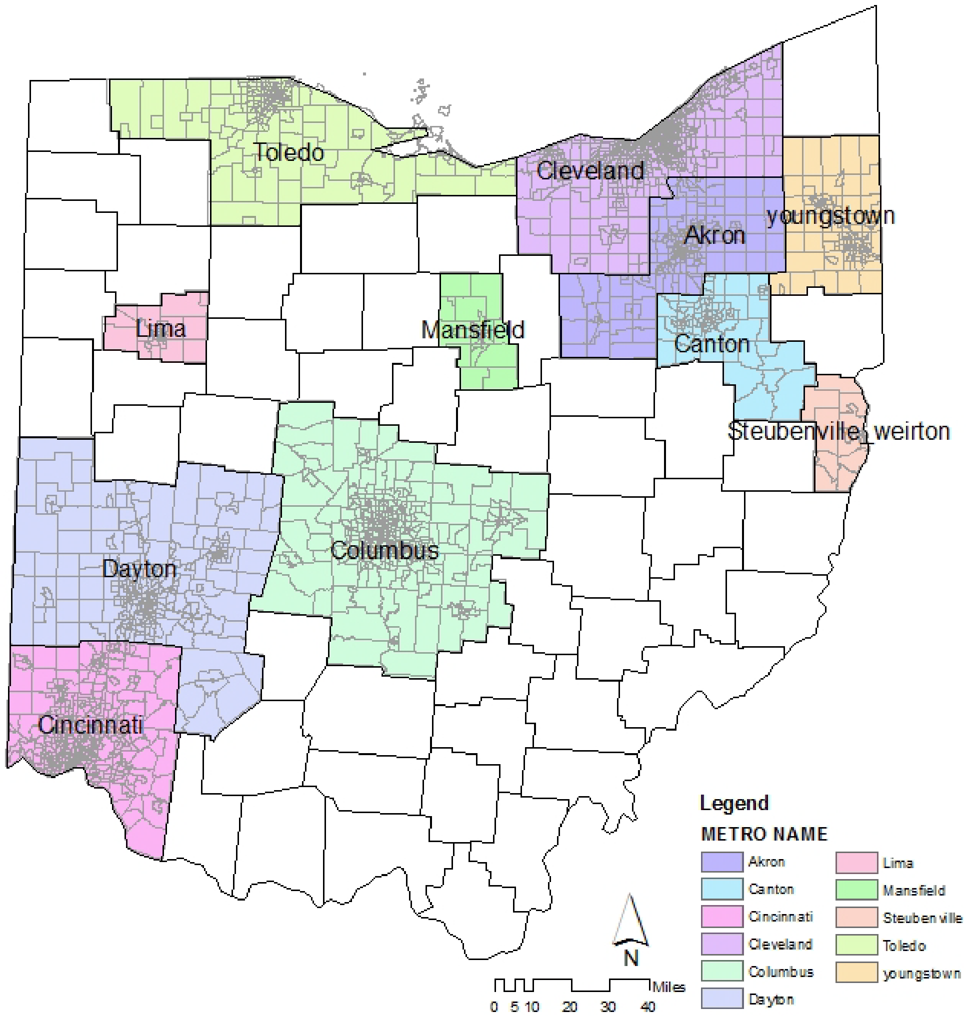

Figure 1: Metropolitan Areas in Ohio

3.3.1. Dependent variable

A number of previous studies have modeled the percentage change in population as a function of a number of socioeconomic and physical variables (Chi 2011). Thus we first tried to explain population percentage changes from 1990 to 2000 as a dependent variable using both linear and nonlinear functions of the available independent variables. These models turned out to be very weak. A summary of those attempts is given in APPENDIX A.

We next tried a series of models using the absolute change in tract population as the dependent variable. Figure 2 shows the distribution of those changes in the target tracts. As shown in Table 1, the largest proportion of tracts had little or no change in population while a significant number of tracts either declined or increased in population over the period.

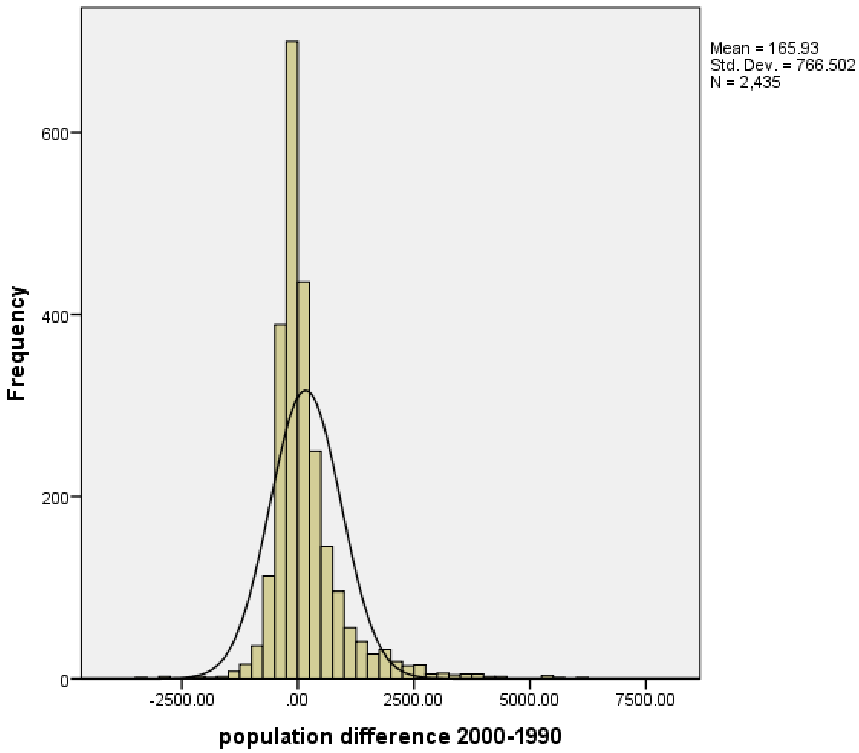

Figure 2: Distribution of the Number of Tracts in Population Changes from 1990 to 2000

From Table 1, 52.2% census tracts in 11 metropolitan areas experienced decrease in population size. Above all, 44.7% was on the decrease in population between -1 and -499. On the contrary, 27.9% among population growth census tracts revealed population increasing from 1 to 500.

Table 1: Frequency of Population Changes between 1990 and 2000

Population changes	The number of census tracts	Percent
Lowest to -1500	8	0.3
-1499 to -1000	24	1.0
-999 to -500	150	6.2
-499 to -1	1088	44.7
0	7	0.3
1 to 500	680	27.9
501 to 1000	240	9.9
1001 to 1500	98	4.0
1501 to highest	140	5.7
Total	2435	100.0

3.3.2. Target Explanatory variables

Based on the literature, population change is driven by a number of demographic, socio-economic, physical, and environmental factors. With the available data we selected the potential explanatory variables as shown in Table 2.

Table 2: Potential Explanatory Variables

Categories	Description
Demographic characteristics	% of female headed families and subfamilies with own children, % of married couples with own children, % of African-American population, base year population, % of 65+ population, % of foreign born population, 1990 % of persons 16+ years old who are working within their county of residence, % of young professional rate (25-40 yr), ethnic groups
Neighborhood characteristics	% of new housing units built within 5 yrs, % of old housing units built over 50 yrs ago, % of renter occupied housing units,% of vacant housing units, % of households moved in 5 yr, % of households receiving public assistance
Socio-economic characteristics	Number of jobs by place of work, Median housing price, median gross rent, median household income, education level, % of total persons below the poverty level last year, occupied housing units with no car access, % of adults age 25+ with a bachelor's degree or more, Job availability, JOB-POP index, % of industrial jobs, % of retail jobs, Job availability within 15 min commute distance, % of unemployed workers, % of employment within their own county
Physical characteristics	The number of intersection junctions, distance to transit, distance to parks and recreation areas, distance to major roads, distance to school, commute time, population density, employment density, land use, open space
Other conditions	School performance index, distance to CBD, distance to local markets, , distance or number of foreclosures, potential development, housing policy, crime rates, attractiveness, availability of social public service, livability

All of the possible independent variables were available or could be calculated from existing data with the exception of those in the "Other Conditions" category. We explored several possible sources of data for those categories but could not identify consistent measures that could apply across the entire state. Thus, those variables were dropped from further consideration.

Since many of these independent variables are related, we used correlation analysis to remove covariant variables. We excluded the highly correlated variables with correlations above 0.7 and below -0.7 to avoid multicollinearity problems. For example, workers with higher levels of education earn more income than workers with less education. In this way, we eliminated a number of the variables to arrive at a subset for further analysis. These are discussed below.

3.4. Approach to Modeling

Several different statistical methods were used to model the relationships between population changes and the set of potential independent variables. These included linear regression, non-linear regression, and several different logit model formulations.

The model with the best fit was the linear regression model which was chosen to integrate into the land use allocation framework. The final version of that model is discussed in the next section. APPENDIX A has the results of several of the other model formulations.

3.5. Final Model and Interpretation

After excluding the highly correlated variables, a stepwise regression was run using twenty potential independent variables. That analysis yielded eleven significant explanatory variables. Table 3 describes the final explanatory variables in the linear regression model. Dummy variables for the 11 metropolitan regions were used in the model but the final model excluded insignificant dummy variables. Table 4 shows the correlations among the independent variables.

Table 3: Final Explanatory Variable Dataset Used in the Model

Characteristics	Variables	Description
Demographic	POP9	1990 Total population
	OLD1990	1990 % of persons who are 65+ years old
	BLK1990	1990 % of African American population
Economic activity	UNEMPRT1990	1990 % of persons 16+ years old who are in the civilian labor force and unemployed
	WRCNT1990	1990 % of persons 16+ years old who are working within their county of residence
	JP9_15	Job-Pop index within 15 min neighbors
Housing and neighborhood	Bltyr9_5	1990 % Total housing units built within 5 yrs or less
	Bltyr9	1990 % Total housing units built above 50 yrs
	Vac9	1990 % Total vacant housing units
	MRTVal9	1990 Index for each metropolitans of Median gross rent of spec. renter-occ. housing units paying cash rent index
Accessibility	Junctions	The number of intersections
Regional Dummies	Canton	1 if the tract i is in the Canton
	Cleveland	1 if the tract i is in the Cleveland
	Dayton	1 if the tract i is in the Dayton
	Steubenville	1 if the tract i is in the Steubenville
	Toledo	1 if the tract i is in the Toledo
	Youngstown	1 if the tract i is in the Youngstown

Table 4: Correlations among the Independent Variables

	Pop9	Inter	Blt5	Blt50	Blk	Vac	JP-15	UEM	WR	OLD
Pop9	1.00									
Intersections	0.31	1.00								
Bltyr9_5	-0.04	0.32	1.00							
Bltyr9	-0.15	-0.19	-0.42	1.00						
BLK1990	-0.14	-0.29	-0.23	0.26	1.00					
Vac9	-0.19	-0.02	-0.02	0.36	0.42	1.00				
JP_15	-0.05	-0.40	-0.09	-0.01	0.24	0.02	1.00			
UNEMP1990	-0.15	-0.19	-0.30	0.46	0.68	0.56	0.10	1.00		
WRCN1990	-0.01	-0.36	-0.32	0.23	0.31	0.15	0.43	0.24	1.00	
OLD1990	-0.05	-0.16	-0.33	0.06	-0.02	-0.03	0.08	-0.02	0.24	1.00

Table 5 shows descriptive statistics for the dependent and independent variables. The mean population is about 3,602 and the maximum is 8,941 within one tract in 1990. The average change of the population between years is 165 but it might be close together due to higher kurtosis and the ranges of the distribution of it. The percentage of new housing ranges from 0 to about 67.0 % in the year of 1990. The distribution of the new housing might be concentrated in some certain areas since the kurtosis of the new housing is about 6.8. Besides, mean of new housing percentage is about 25% while the mean of old housing is about 7.2%. About 80% of workers reside in their county.

Table 5: Descriptive Statistics of the Dataset

(N=2,435)	Min	Max	Mean Statistic	Mean Std. Error	Std. Deviation	Kurtosis
Population changes1990-2000	-3299	6065.0	165.93	15.53	766.50	9.63
Total population	0	894	3602.62	28.57	1410.18	-.12
The number of intersections	6	1078.0	221.55	3.25	160.51	3.25
% of total housing units built within 5 yrs	0	66.9	7.15	.20	10.08	6.78
% of total housing units built over 50 yrs	0	92.2	24.96	.45	22.54	-.23
% of African American population	0	100.0	14.15	.53	26.37	3.48
% of vacant housing units	0	64.3	6.09	.11	5.47	28.31
Job-Pop index within15 min neighbors	0	96.9	60.02	.45	22.60	.87
% of unemployed workers	0	63.9	7.27	.12	6.25	12.45
% of workers within their county of residence	0	100.0	78.73	.41	20.69	1.09
% of old population	0	50.0	12.89	.12	5.98	2.84

The job population index measures the job and population balance for 15 minute distance neighborhoods. The index varies from zero to one and the value of 1.00 means that there is one job for each person within 15 minute neighborhoods. The value of 0 indicates that the neighborhood is exclusively for the residential area or workplace.

In statistics, kurtosis is interpreted as a measurement of the peakedness of the distribution. Based on the descriptive statistics and kurtosis values, vacant housing, unemployment and old housing may be concentrated at certain areas.

Table 6 shows the results of the final regression. The signs of the relationships are in expected directions and confirm many of the analyses found in the literature. New housing units have a positive effect on population growth. This is expected as new housing units imply new or infill development trends. The number of intersections also has a positive influence. This variable is a proxy for accessibility. Areas with higher accessibility should also be candidates for development and therefore have a positive effect on population growth. Job-Pop index shows that the more balanced job and population areas have more possibility of population growth.

Table 6: Coefficients of the Regression Model[a]

Model	Unstandardized Coefficients		Standardized Coefficients		
	Beta	t	Beta	t	Sig
(Constant)	440.509	75.848		5.808	.000
1990 Total population	-.137	.009	-.251	-15.428	.000
The number of intersections	1.689	.093	.354	18.227	.000
% of total housing units built within 5yrs	26.852	1.452	.353	18.495	.000
% of total housing units built over 50 yrs	-1.293	.628	-.038	-2.059	.040
% of African American population	-2.504	.621	-.086	-4.029	.000
% of vacant housing units	-8.036	2.662	-.057	-3.019	.003
JOB-POP index within15 min neighbors	2.618	0.605	.077	0.043	.000
% of unemployed workers	-7.726	2.945	-.063	-2.624	.009
% of workers within their county of residence	-3.083	.673	-.083	-4.578	.000
% of old population	-4.999	2.122	-.039	-2.355	.019
Dummy-Canton[b]	-185.217	62.946	-.046	-2.942	.003
Dummy-Cleveland	86.263	29.539	.049	2.920	.004
Dummy-Dayton	-181.386	37.094	-.077	-4.890	.000
Dummy-Steubenville_weirton	-539.737	119.857	-.068	-4.503	.000
Dummy-Toledo	-94.676	43.990	-.035	-2.152	.031
Dummy-Youngstown	-124.052	54.715	-.036	-2.267	.023
No. of Obs	2435				
R^2	0.480				
SE of Estimate	554.594				

a. Dependent Variable: population difference 2000-1990

b. Base case: Columbus, Cincinnati, Mansfield, Akron, and Lima

The analysis also identified a number of factors that are indicators of tracts where decline is more likely. In general, declining tracts have an aging housing stock, and larger percentages of vacant housing units. The population tends to have higher proportions of minority groups, elderly and unemployed people which are all correlated with low income population.

The 1990 population was also used in the model to control for tracts with vastly different total populations but with the same amount of population change during the 1990-2000 periods.

Metropolitan dummy variables capture the regional differences which are not controlled for by the other independent variables. Canton, Dayton, Steubenville and Youngstown have lost population while the Cleveland area has increased in population relative to the population change in the Columbus, Akron, Cincinnati, Lima, and Mansfield metropolitan areas.

Overall the model is quite strong with an R-square value of 0.48. Looking at the standardized coefficients, new housing is the most influential variable in predicting population change. If the percentage of new housing grows by 1 unit then population change is 26.86 people.

The model was tested to ensure that the estimates are not biased by multicollinearity. The variance inflation factors (VIF) in the model represent that multicollinearity is not a problem.

3.6.Testing Model Accuracy

Several tests were done to test the model from the perspective of using the predicted changes to guide the assignment of growth and decline in the land allocation model. First, we divided the tracts into nine groups based on their actual population change between 1990 and 2000. Table 7 shows the distribution of the tracts with respect to this division into relatively arbitrary groups. Most of the tracts are in the range of -1 to +1; there are a few very large declines while there are more tracts with large amounts of growth.

Table 7: Distribution of the Census Tract Population Changes 1990-2000

Groups	N	Mean	Minimum	Maximum	Std. Deviation
-4	8	-2271.75	-3299	-1549	638.76
-3	24	-1188.92	-1452	-1011	147.02
-2	150	-663.93	-989	-500	134.82
-1	1088	-207.17	-499	-1	128.82
0	7	0.00	0	0	0.00
1	680	203.70	1	500	147.63
2	240	723.13	502	998	141.11
3	98	1219.37	1002	1500	149.04
4	140	2458.35	1506	6065	920.31
Total	2435	165.93	-3299	6065	766.50

We then used the regression model to predict the population change for the tracts and placed the predictions into the same groups. Those results are shown in Table 8. The values in red show the correctly predicted number of tracts. The model did a reasonable job of placing tracts into the correct groups. The majority of errors appear in the central groups between -1 and 1. That means the majority of errors in using the model for prediction will be in lower magnitudes. About 48.9% as 1191 among 2435 tracts is predicted correctly. Around 20.0% of the growth areas and 28.9% of the decline areas are predicted correctly. There are 1158 tracts in observed growth areas while 1330 tracts belong in predicted growth areas.

Table 8: Observed vs Predicted 2000 forecasts based on 1990 data

		Predicted Population Change from Regression							
		-3	-2	-1	1	2	3	4	Total
Actual Change Groups	-4	1	2	2	2	1	0	0	8
	-3	0	11	9	1	2	0	1	24
	-2	0	48	78	19	5	0	0	150
	-1	0	73	655	317	38	5	0	1088
	0	0	0	2	5	0	0	0	7
	1	0	9	192	329	115	26	9	680
	2	0	0	18	86	99	28	9	240
	3	0	0	3	27	39	20	9	98
	4	0	0	2	18	32	48	40	140
Total		1	143	961	804	331	127	68	2435

We then applied the model using the year 2000 data to make a forecast of the tract level population change for 2010. We then used the same approach to compare the actual and predicted population change. The descriptive statistics for the 2000-2010 population changes are shown in Table 9.

Table 9: Distribution of the Population Changes 2000-2010

Groups	N	Mean	Minimum	Maximum	Std. Deviation
-4	46	-2293.87	-5578	-1514	853.67
-3	64	-1206.91	-1492	-1003	154.41
-2	250	-680.44	-995	-500	133.82
-1	1209	-208.82	-499	-2	128.47
0	2	0.00	0	0	0.00
1	488	181.08	1	497	141.51
2	145	732.20	506	993	149.28
3	84	1227.33	1024	1484	131.63
4	147	3172.23	1506	11941	1700.12
Total	2435	65.14	-5578	11941	1050.89

Table 10 shows the actual versus predicted values for 2010 in the same way they were shown for the 1990-2000 groupings. Compared to population changes from 1990-2000, population growth tracts are decreased 12.8% points from 47.7% to 34.7% while population decline tracts are increased.

Table 10: Observed vs Predicted 2010 forecasts based on 1990 coefficients

		Predicted Population Change from Regression						Total
		-2	-1	1	2	3	4	
Actual Change Groups	-4	8	11	19	6	2	0	46
	-3	25	22	13	2	2	0	64
	-2	42	167	35	5	0	1	250
	-1	25	660	438	74	10	2	1209
	0	0	0	2	0	0	0	2
	1	3	120	244	99	20	2	488
	2	0	17	61	52	12	3	145
	3	0	8	33	24	11	8	84
	4	0	2	23	43	41	38	147
Total		103	1007	868	305	98	54	2435

About 43.0 % as 1047 among 2435 tracts is predicted correctly including 14.2% from the growth areas and 28.8% from the decline areas. 864 tracts belong to the observed growth areas while 1325 tracts belong in predicted growth areas.

4. TRANSPORTATION COMPONENT: Vehicle Choice

Datasets from different sources were assembled for this part of the project. The trip rate models are based on the Ohio Statewide Model (OSM) outputs using the population and employment data for the year 2000. The following two household travel surveys are used for calculating trip distances and the distribution of vehicle types.

- 2009-2010 Cincinnati Household Travel Survey
- 2012-2013 Cleveland Household Travel Survey

These two surveys include information on the location of each household's residence, individual and household characteristics as well as the origins and destinations of each trip (geo-coded), which enable the researchers identify spatial characteristics.

In addition to two household travel surveys, several land-use and transportation system related variables were calculated using the data acquired from the Southwest Ohio Regional Transit Authority (SORTA), the Greater Cleveland Regional Transit Authority (RTA), Mid-Ohio Regional Planning Commission (MORPC), Ohio Department of Transportation (ODOT), 2000 and 2010 Census, Census Transportation Planning Products (CTPP) and 2006-2010 American Community Survey (ACS) 5-year estimates.

In this study, the unit of analysis was chosen as the TAZ level. Most of the TAZs are smaller in size, which better allows for capturing variations in land-use and built environment characteristics. Table 11 and Figure 3 present the distribution of Ohio's TAZs. Around 35% of TAZs locate in the three biggest metropolitans areas of Ohio (Columbus, Cincinnati and Cleveland).

Table 11: Distribution of TAZs

	N	Percent
Akron	234	6.39
Canton	146	3.99
Cincinnati	430	11.75
Cleveland	454	12.40
Columbus	403	11.01
Dayton	425	11.61
Lima	51	1.39
Mansfield	58	1.58
Steubenville-Weirton	60	1.64
Toledo	253	6.91
Youngstown	178	4.86
Non-metropolitan areas	968	26.45
Total	3,660	100

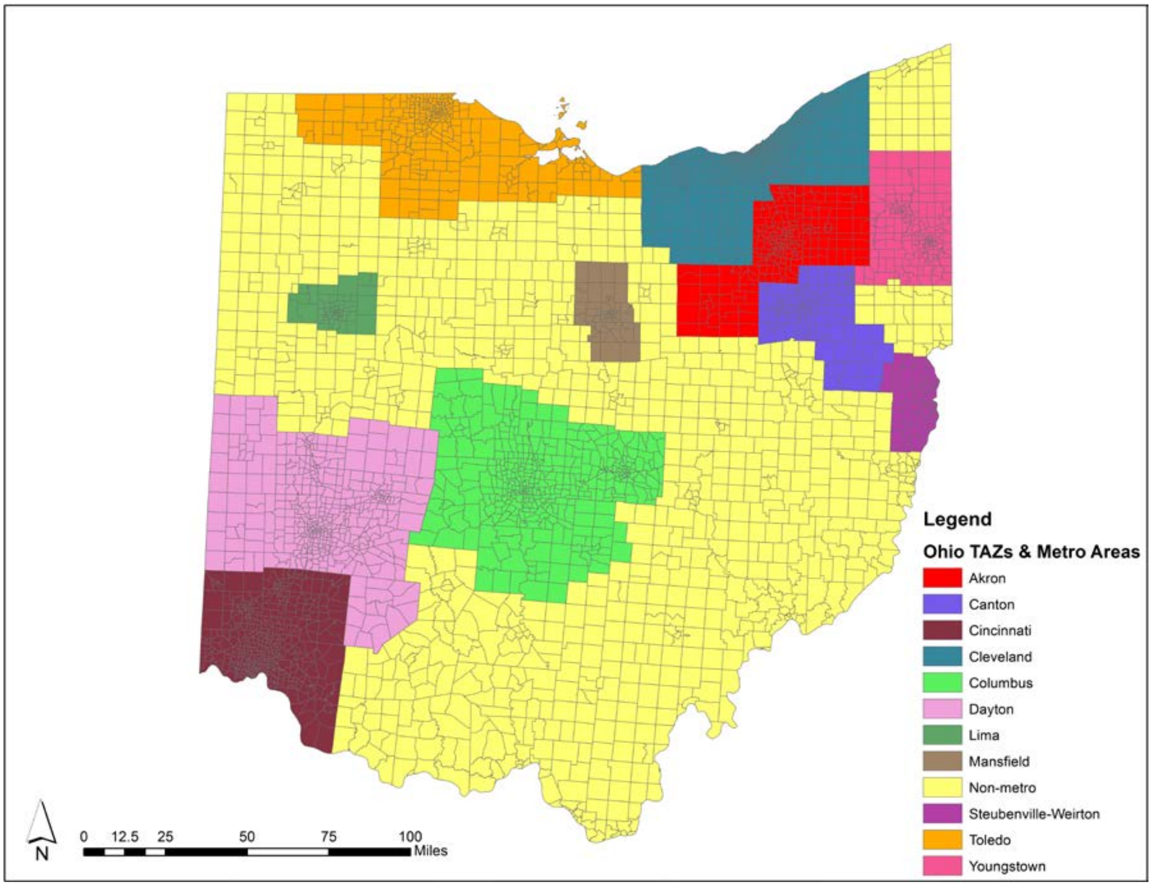

Figure 3: Distribution of TAZs and Metropolitan Areas

4.1. Descriptive Statistics

4.1.1. Employment, Population & Household

The trip rate models are based on the Ohio Statewide Model (OSM) (Model runs completed by MORPC) using the data for the year 2000. The dependent variable, trip rate at the TAZ level, is taken from the OSM outputs. The dependent variables for vehicle distribution models and the trip distance model use the 2009-2010 Cincinnati Household Travel Survey and 2012-2013 Cleveland Household Travel Survey. The explanatory variables use 2010 census and 2006-2010 ACS data. Table 12 and Table 13 present the average number of jobs, population and households and corresponding densities at the TAZ level across the state for 2000. Table 14 and Table 15 present the same types of variables for 2010. Since most explanatory data are not readily available at the TAZ level, we calculated them using two approaches.

The first approach is applied to employment data. Data on number of jobs, households and population at each TAZ are readily available through ODOT for the year 2000. Since we were uncertain[4] about the accuracy of the original number of jobs in the 2000 TAZ shape-file, by

[4] ODOT provides these numbers with the TAZ shape-file directly and is not certain about the data source.

using tract level data we recalculated employment data by considering the distribution patterns of employment values along with the statewide TAZ data from ODOT. First, census tract and TAZ shape-files of Ohio were spatially overlaid using ArcGIS. Then, based on the proportional area of overlaid polygon over the TAZ area and the corresponding employment values at the TAZ level, we calculated the number of employment for each overlaid polygon. The calculated results of overlaid polygons were aggregated if falling into the same tract to get the total number of employment for each tract. Then we derived the ratios by dividing the number of employment for each overlaid polygon by each tract employment number. Using the calculated ratio, we calculated the new number of employment for each overlaid polygon from real census tract data (not the ones aggregated from TAZ). Finally the resulting employments of overlaid polygons were aggregated for each TAZ.

The second approach is used for population and households. The original data of these two variables are only available at the block level. The proportional area of each overlaid polygon (between TAZ and block shape-files) over corresponding block area was calculated to obtain the proportional number of population/household from the corresponding block. The results were aggregated for each TAZ.

Table 12: Total Employment, Population and Households at the TAZ level (2000)

	Employment		Population		Households		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	1635.0	2011.7	3447.1	2144.5	1344.9	857.9	234
Canton	1229.2	1653.0	2787.5	1973.6	1092.1	803.1	146
Cincinnati	1793.4	2699.2	3520.7	2284.4	1375.9	903.7	430
Cleveland	2302.6	2920.4	4683.6	3044.7	1854.9	1210.2	454
Columbus	2098.3	3784.8	3922.6	4039.8	1551.0	1679.4	403
Dayton	1256.6	1977.9	2649.0	2113.5	1050.4	874.4	425
Lima	1062.1	1226.0	2126.9	1328.4	796.9	543.2	51
Mansfield	1029.3	1351.0	2222.1	1578.4	854.2	670.0	58
Steubenville-Weirton	428.0	889.0	1231.2	1012.9	506.8	443.0	60
Toledo	1524.8	1994.6	3098.8	2281.8	1218.0	907.5	253
Youngstown	1138.8	1466.7	2709.4	2145.5	1075.5	900.5	178
Non-metropolitan areas	785.4	1471.2	2247.6	1790.4	854.7	715.1	968
Total	1433.5	2370.1	3091.2	2597.9	1209.5	1054.7	3660

Table 13: Densities (/sq. mile) of employment, population and households across TAZs (2000)

	Employment Density		Population Density		Households Density		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	974.6	2461.5	1647.4	1987.6	667.5	819.8	234
Canton	813.1	1720.2	1329.8	1648.1	529.9	660.6	146
Cincinnati	3046.4	20715.6	2337.9	2329.3	978.7	1050.3	430
Cleveland	2628.6	10567.6	3413.3	3355.2	1391.0	1377.7	454
Columbus	2034.2	15877.2	1495.3	2102.4	614.6	859.6	403
Dayton	922.7	2634.4	1333.1	1838.2	545.3	760.1	425
Lima	957.4	2380.2	1168.4	1553.1	456.4	619.5	51
Mansfield	883.3	2378.6	1187.9	1626.9	438.5	634.1	58
Steubenville-Weirton	294.7	814.7	495.4	952.3	211.0	418.8	60
Toledo	971.9	3196.3	1607.5	2065.6	646.1	828.3	253
Youngstown	804.5	2025.4	1277.4	1404.4	510.7	564.6	178
Non-metropolitan areas	135.4	428.3	252.6	566.4	100.5	232.6	968
Total	1284.2	9764.1	1459.2	2191.9	595.2	910.4	3660

Table 14: Total Employment, Population and Households at the TAZ level (2010)

	Employment		Population		Households		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	1628.0	1990.5	3495.3	2213.1	1400.5	898.8	234
Canton	1177.5	1646.7	2770.1	2182.9	1112.8	893.0	146
Cincinnati	1829.7	2394.4	3674.9	2556.2	1444.2	975.6	430
Cleveland	2223.6	2664.2	4572.8	3152.0	1881.5	1300.9	454
Columbus	2247.6	3818.3	4470.7	4589.2	1763.5	1857.9	403
Dayton	1181.8	1801.4	2623.4	2264.6	1062.8	952.0	425
Lima	1055.9	1208.5	2085.0	1432.2	796.5	567.9	51
Mansfield	938.1	1188.1	2147.0	1577.7	843.8	673.4	58
Steubenville-Weirton	436.1	863.6	1161.6	1044.5	485.1	463.1	60
Toledo	1463.3	1865.8	3119.7	2273.3	1260.7	934.9	253
Youngstown	1013.2	1283.1	2520.9	2111.6	1036.7	915.6	178
Non-metropolitan areas	761.8	1412.0	2273.7	2020.9	880.7	798.9	968
Total	1415.2	2262.7	3151.6	2825.0	1257.5	1146.9	3660

Table 15: Densities (/sq. mile) of employment, population and households across TAZs (2010)

	Employment Density		Population Density		Households Density		
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	946.4	2374.0	1588.2	1799.1	656.7	764.1	234
Canton	761.6	1649.5	1242.1	1527.2	503.6	621.7	146
Cincinnati	2640.0	13780.7	2302.0	2298.4	972.5	1083.5	430
Cleveland	2353.6	7929.3	3151.6	3019.5	1336.4	1359.4	454
Columbus	1950.8	14267.4	1580.0	2099.8	649.9	875.2	403
Dayton	835.3	2448.7	1249.5	1663.8	520.0	694.0	425
Lima	892.3	2234.1	1108.4	1507.4	432.7	582.9	51
Mansfield	793.8	2198.8	996.7	1384.3	405.6	575.9	58
Steubenville-Weirton	266.6	703.9	506.4	940.1	202.1	390.3	60
Toledo	895.9	2873.4	1523.9	1880.0	624.3	765.7	253
Youngstown	693.7	1810.0	1097.5	1192.2	452.1	498.3	178
Non-metropolitan areas	133.0	435.0	264.5	604.1	106.2	244.7	968
Total	1165.0	7439.0	1399.7	2045.7	583.1	890.7	3660

4.1.2. Socio-Demographics

Relevant socio-demographic values at the TAZ level for 2010 presented by Table 16 were calculated from the smallest available spatial levels using the same approach as for population and households explained in previous sub-section. Median age of housing unit, median household income, percentage of population (over 25 years old) with at least bachelor degree and median value of owner-occupied housing unit were derived from 2006-2010 ACS 5-year estimates at the block group level. Average household size, percentages of white population, families with children, female population, single-parent households and households with one or more people 60 years and over are originally available at the 2010 census block level.

Table 16: TAZ Characteristics (2010)

		Median age of housing unit	Median Income	% of family w/children	% of female	average HH size	% of single-parent HH	% of HH with 60+	N
Akron	Mean	41.4	55255.8	41.2	51.0	2.2	8.4	35.2	234
	S.D	13.0	20449.3	6.5	2.3	0.5	4.8	7.5	
Canton	Mean	46.8	46720.0	39.4	50.9	2.2	8.6	38.8	146
	S.D	11.5	14892.6	6.6	2.1	0.4	5.2	6.1	
Cincinnati	Mean	40.6	60858.6	43.5	50.6	2.1	9.9	32.4	430
	S.D	17.2	28558.3	9.8	5.0	0.6	7.8	9.4	
Cleveland	Mean	48.2	55223.3	41.9	51.3	2.1	10.2	35.9	454
	S.D	16.1	28124.5	9.5	5.5	0.6	7.6	10.3	
Columbus	Mean	35.2	60946.1	43.6	50.2	2.2	8.9	31.3	403
	S.D	14.8	23609.7	9.7	4.1	0.5	5.0	9.1	
Dayton	Mean	45.3	53605.6	39.4	50.5	2.2	8.8	37.3	425
	S.D	13.7	18966.0	8.0	3.3	0.5	5.4	8.9	
Lima	Mean	47.0	48930.7	41.1	49.3	2.2	9.8	37.0	51
	S.D	12.4	18358.7	7.7	5.1	0.5	6.1	7.6	
Mansfield	Mean	45.7	48910.1	40.1	49.4	2.2	9.4	37.9	58
	S.D	13.8	15623.6	6.5	7.4	0.5	5.1	6.9	
Steubenville-Weirton	Mean	49.1	39650.4	35.0	50.9	2.1	7.0	41.6	60
	S.D	9.1	9577.4	5.2	2.5	0.4	3.4	6.7	
Toledo	Mean	45.3	53137.7	42.0	50.6	2.1	9.7	34.4	253
	S.D	14.8	19574.0	7.8	2.6	0.5	5.9	7.4	
Youngstown	Mean	46.9	43356.6	38.1	51.0	2.1	9.7	40.5	178
	S.D	12.5	15827.9	8.4	5.1	0.5	6.6	7.9	
Non-metro	Mean	40.7	46325.1	39.8	49.8	2.4	7.8	37.0	968
	S.D	11.3	10564.3	5.1	2.8	0.3	2.9	4.7	
Total	Mean	42.8	52472.8	41.0	50.5	2.2	8.9	35.8	3660
	S.D	14.4	21118.7	8.0	4.0	0.5	5.6	8.3	

4.1.3. Employment by Category

The land allocation model allocates employment in 4 categories: retail, industrial, office and other. The data from both 2000 and 2010 CTPP have 14 subgroups, and these subgroups are reorganized into four categories to match the land allocation model's outputs. Subgroups of these employment categories are summarized in Table 17. The following tables, Table 18 and Table 19, Table 20 and Table 21, report the distribution of employment number and densities in these 4 categories across the state at the TAZ level for 2000 and 2010 respectively.

Table 17: Employment categories

Industry Code (2000/2010)	Industry	Land Allocation Model
02	Agriculture, Forestry, Fishing and Hunting	other
03	Construction	industrial
04	Manufacturing	industrial
05	Wholesale Trade	industrial
06	Retail Trade	retail
07	Transportation and Warehousing	industrial
08	Information	office
09	Finance and Insurance	office
10	Professional, Scientific, and Technical Services	office
11	Educational Services	office
12	Arts, Entertainment, and Recreation	retail
13	Other Services (except Public Administration)	retail
14	Public Administration	other
15	Armed forces industry	other

Table 18: Number of Jobs in Retail, Industry, Office and Other at TAZ level (2000)

	Retail jobs		Industry jobs		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	400.2	515.8	602.9	868.2	234
Canton	314.6	563.6	454.4	713.9	146
Cincinnati	419.2	669.0	600.9	1002.8	430
Cleveland	518.5	671.1	779.9	1165.9	454
Columbus	516.0	865.3	587.8	1052.9	403
Dayton	287.1	456.9	436.9	891.0	425
Lima	265.9	497.1	392.7	565.3	51
Mansfield	255.5	390.5	411.1	641.2	58
Steubenville-Weirton	109.8	255.8	136.1	291.5	60
Toledo	372.3	551.7	571.5	948.3	253
Youngstown	303.8	511.8	406.2	741.4	178
Non-metropolitan areas	185.8	391.0	301.8	620.4	968
Total	341.1	584.1	492.8	892.8	3660

	Office jobs		Other jobs		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	564.5	1102.5	67.2	229.1	234
Canton	409.8	807.9	50.2	196.5	146
Cincinnati	710.8	1855.0	62.4	346.4	430
Cleveland	913.5	1828.1	90.5	350.3	454
Columbus	857.3	2096.1	137.1	727.1	403
Dayton	442.7	940.1	89.7	725.6	425
Lima	340.1	563.6	63.2	202.5	51
Mansfield	297.9	495.6	64.7	231.0	58
Steubenville-Weirton	164.1	420.1	17.9	71.1	60
Toledo	534.2	1076.0	46.7	87.3	253
Youngstown	379.4	657.3	49.1	136.0	178
Non-metropolitan areas	244.3	613.6	53.4	120.6	968
Total	527.2	1333.6	72.3	400.9	3660

Table 19: Retail, industrial, office and other employment densities at the TAZ level (2000)

	Retail density		Industry density		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	223.5	407.7	288.1	605.1	234
Canton	162.0	326.1	291.9	680.3	146
Cincinnati	544.9	2830.6	797.6	4101.4	430
Cleveland	547.9	3217.8	702.9	2261.9	454
Columbus	369.7	2196.7	370.3	1912.9	403
Dayton	185.1	478.8	294.5	821.0	425
Lima	216.3	507.5	272.8	567.8	51
Mansfield	173.8	364.3	340.6	933.4	58
Steubenville-Weirton	71.3	198.8	81.5	275.8	60
Toledo	213.7	488.5	291.2	734.7	253
Youngstown	176.9	379.5	272.8	691.5	178
Non-metropolitan areas	34.5	118.2	45.1	139.2	968
Total	254.4	1692.0	341.8	1810.6	3660

	Office density		Other density		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	415.1	1521.3	47.8	319.5	234
Canton	319.4	943.0	39.6	318.5	146
Cincinnati	1637.4	16314.3	66.3	654.0	430
Cleveland	1240.3	6115.8	137.4	1224.3	454
Columbus	1046.2	8556.2	247.9	3953.4	403
Dayton	367.0	1497.0	76.0	857.2	425
Lima	419.1	1394.5	49.1	233.6	51
Mansfield	287.3	916.6	81.5	524.8	58
Steubenville-Weirton	127.6	377.4	14.3	68.8	60
Toledo	450.4	2242.3	16.5	47.8	253
Youngstown	308.7	1087.6	45.9	291.2	178
Non-metropolitan areas	48.4	197.0	7.2	32.3	968
Total	614.7	6714.1	73.1	1436.5	3660

Table 20: Number of Jobs in Retail, Industry, Office and Other at TAZ level (2010)

	Retail jobs		Industry jobs		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	398.2	511.5	530.2	801.9	234
Canton	317.6	600.6	360.8	530.8	146
Cincinnati	445.6	641.3	536.0	834.5	430
Cleveland	515.0	638.5	647.5	960.5	454
Columbus	551.7	862.9	542.3	931.4	403
Dayton	280.7	446.4	340.1	633.9	425
Lima	260.0	525.0	337.3	434.8	51
Mansfield	243.5	361.7	319.0	482.0	58
Steubenville-Weirton	129.0	341.6	120.7	195.3	60
Toledo	382.5	558.5	468.8	693.6	253
Youngstown	281.3	470.4	290.1	443.1	178
Non-metropolitan areas	188.1	395.5	257.5	510.9	968
Total	347.2	577.7	417.1	727.5	3660

	Office jobs		Other jobs		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	637.0	1178.4	62.4	169.4	234
Canton	455.8	916.8	43.1	149.6	146
Cincinnati	786.2	1657.5	61.7	298.3	430
Cleveland	967.9	1749.4	93.2	344.6	454
Columbus	1015.7	2296.9	137.9	718.9	403
Dayton	477.4	979.7	83.4	616.5	425
Lima	400.7	620.1	57.7	140.7	51
Mansfield	323.7	596.6	51.8	167.2	58
Steubenville-Weirton	171.8	429.4	14.6	48.1	60
Toledo	563.9	1073.9	47.9	88.0	253
Youngstown	396.6	686.4	45.0	123.8	178
Non-metropolitan areas	267.5	662.1	48.6	102.9	968
Total	581.2	1350.4	69.6	366.6	3660

Table 21: Retail, industrial, office and other employment densities at the TAZ level (2010)

	Retail density		Industry density		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	209.3	374.5	246.4	491.3	234
Canton	158.4	323.1	225.0	522.2	146
Cincinnati	534.1	2577.6	607.8	2659.3	430
Cleveland	483.9	2505.4	527.6	1364.7	454
Columbus	333.2	1553.2	303.0	1485.5	403
Dayton	178.3	464.9	202.6	532.2	425
Lima	160.5	299.4	225.5	488.5	51
Mansfield	123.2	230.1	241.4	594.4	58
Steubenville-Weirton	79.5	248.5	51.6	109.9	60
Toledo	215.2	520.2	224.5	493.8	253
Youngstown	154.2	331.7	177.7	369.9	178
Non-metropolitan areas	34.5	120.9	38.9	127.1	968
Total	236.9	1386.2	260.7	1198.2	3660

	Office density		Other density		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	449.2	1598.9	41.4	244.2	234
Canton	346.6	1047.9	31.6	238.6	146
Cincinnati	1436.5	10391.2	61.5	541.5	430
Cleveland	1192.6	4956.2	149.4	1252.9	454
Columbus	1066.9	7995.3	247.6	3958.7	403
Dayton	381.9	1532.0	72.3	818.0	425
Lima	463.1	1476.1	43.0	215.7	51
Mansfield	360.9	1217.8	68.1	457.1	58
Steubenville-Weirton	125.7	368.8	9.6	43.9	60
Toledo	438.8	2043.3	17.3	52.1	253
Youngstown	319.8	1173.7	41.8	256.5	178
Non-metropolitan areas	53.2	211.2	6.2	26.8	968
Total	595.3	4885.9	72.0	1430.8	3660

4.1.4. Transit

To account for transit availability in all models, we calculated the number of transit stops within 0.5 mile of each TAZ centroid. A dummy variable as transit proximity was created, 1 if there is at least one transit stop within this 0.5-mile buffer or there is at least one transit stop within the TAZ but not within the 0.5-mile buffer. The following table, Table 22, presents the average number of transit stops at the TAZ level.

Table 22: Number of Transit Stops at the TAZ level

	Mean	Std. Dev.	N
Akron	6.7	12.4	234
Canton	0.0	0.0	146
Cincinnati	10.3	20.6	430
Cleveland	17.3	24.7	454
Columbus	5.0	12.2	403
Dayton	5.2	12.0	425
Lima	0.0	0.0	51
Mansfield	0.0	0.0	58
Steubenville-Weirton	0.0	0.0	60
Toledo	6.2	11.5	253
Youngstown	0.0	0.0	178
Non-metropolitan areas	0.0	0.0	968
Total	5.4	14.7	3660

4.1.5. Auto Trips (2000)

In order to estimate trip rate model, we acquired the outputs (trip ends at the TAZ level) of the Ohio Statewide Model (OSM) through MORPC. The model was run using 2000 data. The OSM is an integrated economic, land-use, and travel demand forecasting model. This model was developed by the ODOT Modeling & Forecasting Section to serve as an important tool for large multi-region corridor studies, system-wide congestion analysis, and traffic forecasting in the rural areas of the state not covered by urban MPO models.

The OSM is made up of multiple components covering residents, visitors, and freight travels. Among them, a Personal Travel (PT) model forecasts the person movements arising from the population within the model area engaging in spatially-separated activities, based on the concept of tours. A tour is defined as a sequence of activities that begins and ends at the same location: home (home-based tours) or work (work-based tours). In the PT model, personal travel is classified into short distance travel (SDT) and long distance travel (LDT). SDT includes all work tours, regardless of tour length, and all non-work tours to destinations within 50 miles of the home location. The following table, Table 23, reports the trip ends at the TAZ level for year 2000.

Table 23: Number of Auto Trips in Vehicles and Persons (2000)

	Auto Trips (autos)		Auto Trips (persons)		
	Mean	Std. Dev.	Mean	Std. Dev.	N
Akron	16683.8	13036.5	21988.5	16871.5	234
Canton	13636.2	13252.2	18025.6	17391.3	146
Cincinnati	16947.8	13004.1	22509.8	17077.4	430
Cleveland	23692.0	17130.4	31197.0	22412.9	454
Columbus	20079.2	23042.4	26323.9	30063.4	403
Dayton	13215.3	13142.5	17373.1	17087.9	425
Lima	11535.9	10327.2	15225.1	13578.2	51
Mansfield	11204.4	10335.3	14761.6	13601.9	58
Steubenville-Weirton	5914.5	7446.7	7923.8	9980.8	60
Toledo	17041.7	15943.1	22383.8	20710.8	253
Youngstown	14223.6	14188.0	18784.5	18587.8	178
Non-metropolitan areas	10721.8	14605.9	14239.1	19114.0	968
Total	15426.8	16122.7	20357.9	21062.2	3660

*Source: Ohio Statewide Model (Model runs completed by MORPC)

4.1.6. Vehicle Types

Based on the experimental outputs of the 2010 Motor Vehicle Emission Simulator (MOVES) of Environmental Protection Agency (U.S. EPA 2010), 8-year was selected as the break-point for vehicle vintage. 2013 is the base year in our case. Thus, any vehicle produced after 2005 (including 2005) was defined as a new vehicle. The vehicles from the Household Travel Surveys (Greater Cincinnati and Greater Cleveland) were categorized into new passenger cars, old passenger cars, new passenger trucks and old passenger trucks. The numbers of vehicles by these four types at the TAZ level were calculated using the survey weights attached to households. Since Cincinnati data only have survey weights for the 2051 completed households, the households with corresponding vehicle observations were dropped if there is no survey weight for them. The distributions and descriptive statistics of four vehicle types are presented in Table 24 and Table 25. However, the vehicle age distribution in MOVES is not changed over time since the new vehicle purchase rate stays pretty constant and there is no good way to determine if cars will have a longer lifespan in the future. Therefore, we only categorize vehicles into passenger cars and passenger trucks in the final vehicle distribution model.

Table 24: Distribution of Four Vehicle Types

Vehicle	Frequency		Percentage (Raw)		Percentage (Weighted)	
Type	Cincinnati	Cleveland	Cincinnati	Cleveland	Cincinnati	Cleveland
New Car	711	2,072	20.76%	30.90%	20.89%	31.14%
Old Car	1,215	1,991	35.47%	29.69%	34.45%	28.60%
New Truck	572	1,412	16.70%	21.06%	16.97%	22.60%
Old Truck	927	1,231	27.07%	18.36%	27.69%	17.65%
Total	3,425	6,706	100%	100%	100%	100%

Table 25: Percentages of Vehicles by Type at TAZ level

Vehicle Type	Cincinnati		Cleveland		Total	
	Mean	Std. Dev	Mean	Std. Dev	Mean	Std. Dev
New Car	22.01	25.48	29.50	18.59	26.16	22.23
Old Car	36.23	28.90	31.20	21.70	33.44	25.28
New Truck	14.76	19.66	20.20	17.29	17.77	18.57
Old Truck	27.00	25.65	19.10	17.32	22.63	21.78
Obs.	339		421		760	

4.1.7. Trip Distance

Overall average trip distances at the TAZ level were calculated using the Household Travel Surveys from Cincinnati and Cleveland. Travel distances are directly available for all trips from the surveys. The mean values of these distances and also number of trips for both trip production and trip attraction were calculated at the TAZ level, using the survey weights attached to households. Then we calculated overall average trip distances using the equation as followed:

$$\frac{N^p \times DIST^p + N^A \times DIST^A}{(N^p + N^A)}$$

Where N^p and N^A represent the numbers of trip produced and attracted respectively, $DIST^p$ and $DIST^A$ represent the average trip distances for trips produced and attracted respectively. As shown in Table 26, the overall average trip distance for two metropolitan areas (Cincinnati and Cleveland) is 6.3 miles.

Table 26: Average Trip Distance at TAZ level (miles)

	Mean	Std. Dev.	N
Cincinnati	6.61	2.41	428
Cleveland	6.07	2.08	453
Total	6.33	2.26	881

*Exclude trips below 0.1 miles or over 50 miles

4.2. Seasonal differences in Vehicle-use

We analyzed the seasonal differences in vehicle-use across different vehicle types and vintage. Based on the statistical analysis, we conclude that differences across seasons are not statistically significant. Table 27 and Table 28 show the mean vehicle use per day (in miles) across different seasons and t-test results for differences across winter and summer seasons.

Only Cincinnati dataset has information on odometer readings on different days for each vehicle. In Cleveland dataset, there is no information about how and when each vehicle was used during the survey period. In Cincinnati dataset, outlier observations (150 out of 2905) were excluded (some odometer readings result in over 1,000 miles for 2-3 days). We tried to identify which vehicle was used for each trip if the mode of that trip was private vehicle. The trip-based data do not have information about vehicle usage. Although the vehicle dataset provides the primary driver number, some drivers are the primary drivers for more than one vehicle. In Cincinnati dataset, we found that among 7.6% of (262 out of 3427) vehicles, one person is the primary driver for more than one vehicle. In Cleveland dataset, the problematic records are 18.22% of (1242 out of 6818). This leads to the problem of linking vehicle usage to trips. We considered 4 vehicle types for the seasonal analysis: new cars, old cars, new trucks, old trucks. We observed that new vehicles are used more, but this is true for all seasons. The only statistically significant difference is observed for old trucks.

Table 27: Vehicle Use (miles per day) across seasons

Vehicle Type		Season			
		Winter	Spring	Summer	Fall
New car	Mean	33.31	38.73	33.18	30.21
	Std.Dev	26.53	26.44	22.54	21.34
Old car	Mean	25.92	28.43	27.43	27.03
	Std.Dev	20.43	21.13	20.69	20.78
New truck	Mean	33.64	31.14	34.64	33.14
	Std.Dev	23.45	21.34	24.38	24.66
Old truck	Mean	23.93	29.35	33.72	28.52
	Std.Dev	20.03	20.00	28.73	24.18

Table 28: Results of t-tests across winter and summer

Vehicle Type	Season	Obs.	Mean	S.D.	t-stat
New car	Summer	141	33.18	22.54	-0.048
	Winter	233	33.31	26.53	
Old car	Summer	98	27.43	20.69	0.551
	Winter	129	25.92	20.43	
New truck	Summer	102	34.64	24.38	0.342
	Winter	192	33.64	23.45	
Old truck	Summer	71	33.72	28.73	2.701
	Winter	110	23.93	20.03	

4.3. Trip Rate Model

For the auto-trip rate regression models, the vehicle trip ends are regressed with the number of households and number of jobs in 2 employment categories, retail and all other (industrial, office and other). These employment categories are based on the categories used by the land-allocation model. Subgroups of these employment categories are summarized in Table 17. Three groups of different trip rate models were estimated. These are summarized in Table 29.

Table 29: Trip Rate Models

Model No.	Type	Dependent Variable	Independent Variable	Data Used	Unit of Obs.	Notes
1	OLS*	# of trips produced, attracted and total trip generation	• Land-use (TAZ) • Public transit proximity (TAZ centroid)	Ohio Statewide Model	SWTAZ	• The explanatory power is high. • Some land-use variables are significant.
2	OLS	Weighted # of trips produced, attracted and total trip generation, by vehicle type	• Land-use (TAZ) • Public transit proximity (TAZ centroid)	Cleveland	SWTAZ	• The explanatory power is high. • Some land-use variables are significant. • The significance of land-use variables varies by vehicle types.
3	SUR**	First equation: The # of trip production, attraction and generation from Ohio Statewide Model (OSM); Subsequent equations: The weighted % of trips (production, attraction and generation) by vehicle type	• Land-use (TAZ) • Public transit proximity (TAZ centroid)	Cleveland	SWTAZ	• The explanatory power is high. • Most land-use variables are significant.

* OLS: Ordinary Least Squares Regression Model
** SUR: Seemingly Unrelated Regression Model

By comparing the results, we decided to estimate total trip generation using the Ordinary Least Squares (OLS) for the 2000 Ohio Statewide Model outputs. We estimated two separate models:

one for metropolitan TAZs and one for nonmetropolitan TAZs. Daily vehicle trip ends at the TAZ level are based on the Ohio Statewide Model outputs: vehicle trip ends at the TAZ level for year 2000. We used year 2000 values for the model estimation. OLS estimation was used to analyze the links between number of households, number of jobs and transit availability on auto trip rates. The functional form for the regression model and the variables of interest are described below and in Table 30.

$$\begin{aligned} Y = \; & \beta_1 * (\text{number of households}) + \\ & \beta_2 * (\text{number of retail jobs}) + \\ & \beta_3 * (\text{number of all other jobs}) + \\ & \beta_4 * (\text{number of retail jobs x transit availability}) + \\ & \beta_5 * (\text{number of all other jobs x transit availability}) + \end{aligned}$$

The dependent variable Y represents the trip ends at the TAZ level. The intercept of the regression is forced to zero, as TAZs with no employment and households should not generate any vehicle trips for the model purposes. To account for transit availability and how it affects the number of auto trips, interaction terms were introduced. The number of jobs in retail and all other categories were multiplied by the transit availability binary variable, which takes a value of 1 if there is a transit stop within 0.5 mile radius of the TAZ centroid or one TAZ has at least one transit stop but not within the 0.5-mile buffer, and 0 (zero) otherwise.

Table 30: Variable definitions for Auto Trip Rates at the TAZ level

Variable name	Explanation	Source
Households	Num. of households at TAZ	2000 Census
Retail jobs	Num. of retail jobs at TAZ	2000 CTPP
All other jobs	Number of all other jobs (industrial + office + other) at TAZ	2000 CTPP
Retail jobs X transit	Interaction variable	These interaction variables are calculated based on employment data and transit availability
All other jobs X transit	Interaction variable	

The model coefficients were estimated separately for metropolitan TAZs and nonmetropolitan TAZs. Table 31 presents the descriptive statistics for the estimation samples. There are in average 1337 households, 397 retail and 1270 non-retail jobs in metropolitan TAZs. The model results for two types of areas are reported in Table 32 and Table 33. In the model for metropolitan areas, increasing one household would bring around 9 auto trip ends while holding all else equal. One more retail job could increase about 12 auto trips. The interactive terms between employment variables and transit availability decrease the number of auto trip ends. As there is no transit stop in nonmetropolitan areas, the model corresponding to these TAZs did not include the transit interaction variables. The observed and estimated auto trip ends are graphically shown in Figure 4 and Figure 5.

Table 31: Descriptive Statistics of the Estimation Sample - Auto Trip Rate Models

Metropolitan TAZs		
	Mean	Std. Dev.
Number of households	1337.19	1125.72
Number of retail jobs	396.94	630.31
Number of all other jobs	1269.61	2177.07
Transit availability (binary variable)	0.37	0.48
Sample size	2692	
Nonmetropolitan TAZs		
	Mean	Std. Dev.
Number of households	854.73	715.12
Number of retail jobs	185.80	391.03
Number of all other jobs	599.64	1134.73
Sample size	968	

Table 32: Trip Rate Model: Metropolitan Areas

Dependent variable= Number of auto trip ends		
	Coefficient	t stat.
Households	8.796341	126.36
Retail employment	11.7857	36.22
All Other employment	1.699776	14.67
Retail X transit availability	-2.678459	-7.14
All other X transit availability	-.5044022	-3.95
Number of observations	2692	
R^2	0.9594	
Adjusted R^2	0.9593	

Table 33: Trip Rate Model: Non-metropolitan Areas

Dependent variable= Number of auto trip ends		
	Coefficient	t stat.
Households	7.970681	40.47
Retail employment	14.44557	23.93
All Other employment	3.029331	13.87
Number of observations	968	
R^2	0.9481	
Adjusted R^2	0.9480	

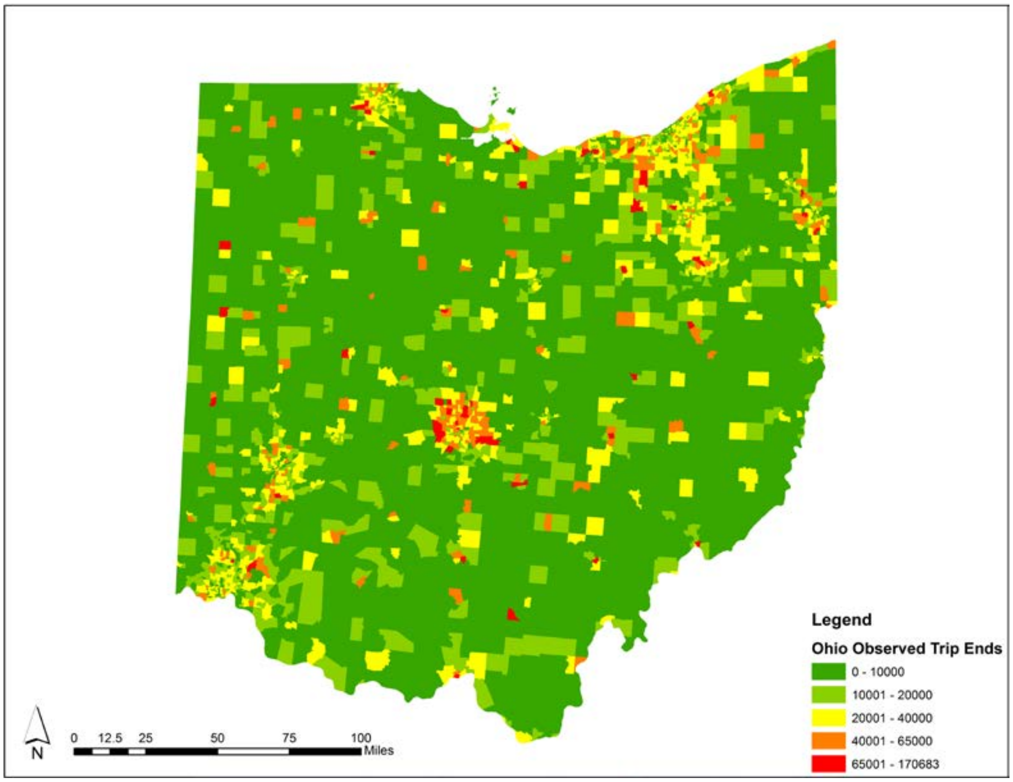

Figure 4: Observed Trip Ends

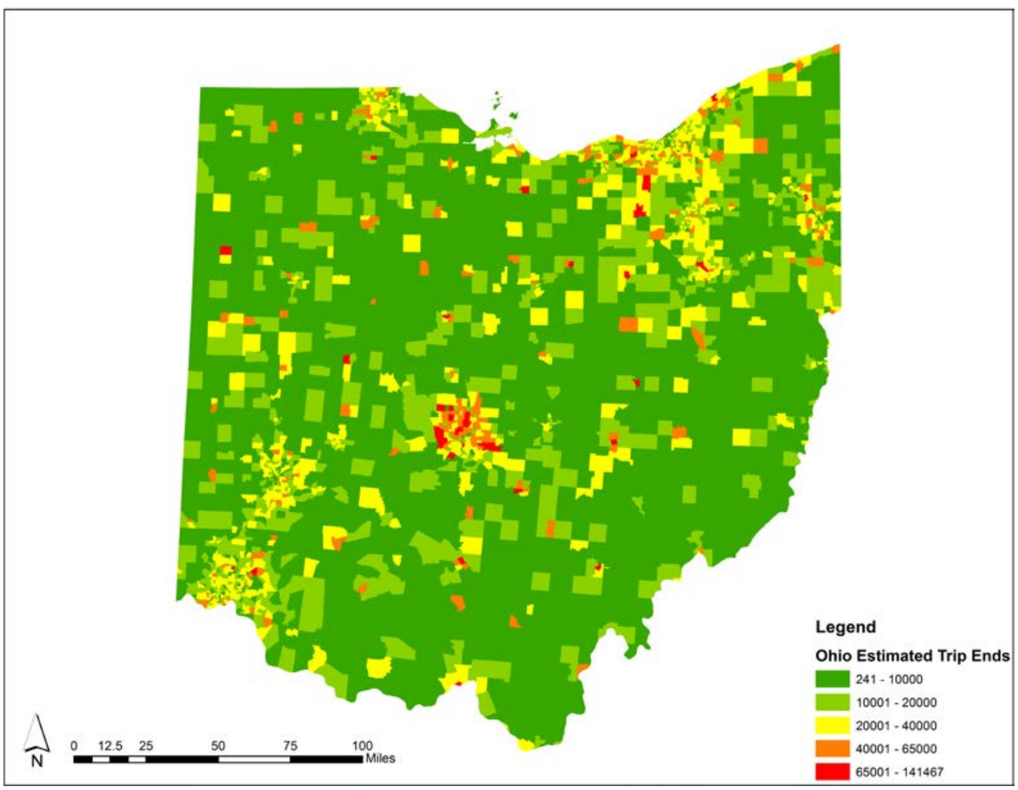

Figure 5: Estimated Trip Ends

4.4. Vehicle Choice Models

For vehicle choice, we estimated discrete vehicle choice models at the vehicle level and OLS regression vehicle distribution models at the TAZ level. These models are summarized in Table 34.

Discrete vehicle choice models were not selected in the end due to low explanatory power. Appendix B2 presents the discrete vehicle choice model results. In the end, vehicle distribution model for the percentage of passenger cars is estimated using OLS at the TAZ level and presented in this section. OLS regression vehicle distribution models for four vehicle types (new car, old car, new truck and old truck) are also estimated and presented in Appendix B4 (Cincinnati and Cleveland) and B5 (Cleveland). In terms of the MOVES application, currently we only use the model for two vehicle types (passenger car and passenger truck). The distribution models for four vehicle types could be used in the future if the vehicle age distribution needs to be changed. The functional form for the regression model used in this study and the variables of interest are described below and in Table 35.

$$
\begin{aligned}
Y = \; & \alpha + \\
& \beta_1 * (\text{household density}) + \\
& \beta_2 * (\text{employment density}) + \\
& \beta_3 * (\text{JOB-HH index within 10 minutes}) + \\
& \beta_4 * (\text{transit availability}) + \\
& \beta_5 * (\text{Household size}) + \\
& \beta_6 * (\text{\% single-parent household}) + \\
& \beta_7 * (\text{\% household w/60+})
\end{aligned}
$$

The dependent variable Y represents the weighted percentage of passenger cars at the TAZ level and α is a constant. Socio-demographic variables were calculated based on 2010 Census data and 2006-2010 ACS 5-year estimates and converted to TAZ level as discussed in descriptive statistics section.

Table 34: Vehicle Choice Models

Model No.	Type	Dependent Variable	Independent Variable	Data Used	Unit of Obs.	Notes
1	Binary Logit	Car VS. Truck	• Socio-demographics (Individual & Household) • Land-use (TAZ) • Public transit proximity (Residence location)	Cincinnati & Cleveland	Vehicle	• Explanatory power is very low. • Most density variables are not significant.
2	MNL*	New car, old car, new truck, old truck	• Socio-demographics (Individual & Household) • Land-use (TAZ) • Public transit proximity (Residence location)	Cincinnati & Cleveland	Vehicle	• Explanatory power is very low. • Some land-use variables are not significant.
3	MNL	Car, SUV, pickup truck, van	• Socio-demographics (Individual & Household) • Land-use (TAZ) • Public transit proximity (Residence location)	Cincinnati & Cleveland	Vehicle	• Explanatory power is low. • Some land-use variables are not significant.
4	OLS**	Weighted % of vehicle types: Car & truck	• Socio-demographics (TAZ) • Land-use (TAZ) • Public transit proximity (TAZ centroid)	Cleveland	SWTAZ	• Explanatory power is medium.

5	OLS	Weighted % of vehicle types: New car, old car, new truck, old truck	• Socio-demographics (TAZ) • Land-use (TAZ) • Public transit proximity (TAZ centroid)	Cleveland	SWTAZ	• The models for new car and old car have higher R-squared. • The significant variables vary across four models.
6	SUR***	First equation: total weighted # of vehicles Subsequent equations: weighted % of four vehicle types	• Socio-demographics (TAZ) • Land-use (TAZ)	Cleveland	SWTAZ	• Explanatory power is medium. • The significance of land-use variables depends on vehicle type.

* MNL: Multinomial Logit Model

** OLS: Ordinary Least Squares Regression Model

*** SUR: Seemingly Unrelated Regression Model

Table 35: Variable definitions for Vehicle Distribution Model (% of passenger cars) at the TAZ level

Variable name	Explanation	Source
Household density	Number of households divided by the TAZ area	2010 census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained below.	needs to be calculated
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Household size	Average household size at TAZ	2010 Census
% single-parent household	% of single-parent households at TAZ	2010 Census
% household w/60+	% of households with one or more people 60 years and over	2010 Census

The employment and household densities were calculated based on the number of jobs and households. In addition, an index which measures the job-household balance for each TAZ based on a 10-minute driving time from the TAZ centroid was also calculated based on employment and household data, and included in these models. The total number of jobs and households within a 10-minute driving distance were calculated for each TAZ. The calculation of this index refers to the equation in Ewing et al.'s paper (Ewing et al. 2011). Based on the empirical facts in the study area, the value 0.2 (which was used by Ewing et al. (2011) for the population number), representing a balance of employment and household, was adjusted to 1 to represent a balance between jobs and number of households in this study.

$$JOB\_HH\ index = 1 - \frac{|\,number\ of\ \ jobs - number\ of\ \ households\,|}{(number\ of\ \ jobs + number\ of\ \ households)}$$

The index varies between 0 (zero) and 1. An index value of 1 indicates that there will be one job for each household within a 10-minute driving distance. An index value of 0 (zero) indicates that there are only households or jobs present in a given 10-minute driving distance. As the index value approaches 1, the index represents a more balanced area in terms of households and jobs.

The descriptive statistics for the vehicle distribution estimation sample are summarized in Table 36. We estimated one OLS regression model at the TAZ level for the percentage of passenger cars. Based on the estimation sample, the average Job-Household balance index is 0.85, average household size is 2.2 persons, average percentages of single-parent households and households with seniors (60 years old or over) are 10.2 and 36.4 respectively.

The estimated model for Cleveland is reported in Table 37. This model provides better results as compared to the model using both Cincinnati and Cleveland samples, in terms of explanatory power and significance for explanatory variables. The descriptive statistics and model estimation results for two regions together (Cincinnati and Cleveland) are reported in Appendix B3.

The model results indicate that, increasing household and employment densities increase the percentage of passenger cars. This is reasonable since households residing in TAZs characterized with lower densities (suburban TAZs) have larger vehicles. Consistently, a better balance between jobs and households tends to increase the percentage of passenger cars. Having at least one transit stop (bus stop or rail station) within 0.5 miles of a TAZ centroid or having at least one transit stop within the TAZ increases the percentage of passenger cars. Average household size decreases the percentage of passenger cars, because larger households need larger vehicles to accommodate more family members. TAZs with more single-parent households tend to have higher percentage of passenger cars. Having more households with elderly members also increases the percentage of passenger cars: smaller vehicles may be easier to operate by the elderly members.

Table 36: Descriptive Statistics of the Estimation Sample - Vehicle Distribution Model

	Mean	Std. Dev.
Household density	1416.57	1367.56
Employment density	2022.65	7149.42
JOB_HH	0.85	0.12
Transit availability (binary variable)	0.63	0.48
Household size	2.18	0.52
% single-parent household	10.23	7.30
% household w/60+	36.41	8.86
Sample size	421	

Table 37: Vehicle Distribution Model (Cleveland)

Dependent variable= % of Passenger Car		
	Coefficient	t stat.
Household density	0.0021062	2.39
Employment density	0.0004699	2.97
JOB_HH	11.2936	1.37
Transit availability (binary variable)	5.15057	2.11
Household size	-3.266895	-1.49
% single-parent household	0.4022137	2.50
% household w/60+	0.356791	2.72
Constant	33.93721	3.17
Number of observations	421	
R^2	0.1324	
Adjusted R^2	0.1177	

4.5. Trip Distance Model

Five groups of trip distance models summarized in Table 38 were estimated using OLS regression. The levels of significance for explanatory variables and explanatory power indicate that the overall average trip distance model at the TAZ level is a better choice for this study.

Overall average trip distances at the TAZ level are regressed on household and employment densities, Job-Household balance index, transit availability and four socio-demographic variables at the TAZ level. Table 39 presents their definitions and data sources. The functional form for the trip distance model is defined as:

$$
\begin{aligned}
Ln(Y) = \quad & \alpha + \\
& \beta_1 * \text{(household density)} + \\
& \beta_2 * \text{(retail density)} + \\
& \beta_3 * \text{(industrial density)} + \\
& \beta_4 * \text{(office density)} + \\
& \beta_5 * \text{(other density)} + \\
& \beta_6 * \text{(JOB-HH index within 10 minutes)} + \\
& \beta_7 * \text{(transit availability)} + \\
& \beta_8 * \text{(Housing median value)} + \\
& \beta_9 * \text{(Household income)} + \\
& \beta_{10} * \text{(\% family w/children)} + \\
& \beta_{11} * \text{(\% female)}
\end{aligned}
$$

The dependent variable *Ln(Y)* is the natural log form of overall average trip distance at the TAZ level. The calculation of overall average trip distance has been described in the section for descriptive statistics. The calculations of socio-demographic variables are the same as described in vehicle distribution models.

Table 38: Trip Distance Models

Model No.	Type	Dependent Variable	Independent Variable	Data Used	Unit of Obs.	Notes
1	OLS	Trip distance at Trip level	• Socio-demographics (Individual & Household) • Land-use (TAZ) • Public transit proximity • Vehicle type	Cincinnati & Cleveland	Individual trip	• Most land-use variables are significant, but explanatory power is very low.
2	OLS	Weighted average trip distances for trip produced and attracted	• Land-use (TAZ) • Public transit proximity (TAZ centroid) • Vehicle type distribution	Cleveland	SWTAZ	• Explanatory power is medium. • The significance of land-use variables varies for models of trip produced and attracted. • Retail density is not significant in both models.
3	OLS	Weighted average trip distances by vehicle type for trip produced and attracted	• Land-use (TAZ) • Public transit proximity (TAZ centroid)	Cleveland	SWTAZ	• Explanatory power is medium. • Household density is significant for most models. • Retail density is not significant in all models.
4	OLS	Overall weighted average trip distances	• Land-use (TAZ) • Public transit proximity (TAZ centroid)	Cleveland	SWTAZ	• Explanatory power is medium. • Most density variables are significant.
5	OLS	Overall weighted average trip distances by vehicle type	• Land-use (TAZ) • Public transit proximity (TAZ centroid)	Cleveland	SWTAZ	• Explanatory power is medium. • Most density variables are significant. • The significance of job-household balance index varies by vehicle types.

Table 39: Variable definitions for Trip Distance Model at the TAZ level

Variable name	Explanation	Source
Household density	Number of households divided by the TAZ area	2010 census/ divide by area
Retail density	Number of retail jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
Industrial density	Number of industrial jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
Office density	Number of office jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
Other density	Number of other jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained above.	needs to be calculated
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Housing Median Age	Median age of housing unit at TAZ	2006-2010 ACS 5-year estimate
Household income	Median household income at TAZ	2006-2010 ACS 5-year estimate
% family w/children	% of family with children at TAZ	2010 Census
% female	% of female population at TAZ	2010 Census

The estimation sample for trip distance model includes two regions-Cincinnati and Cleveland. Table 40 presents the descriptive statistics of the trip distance model estimation sample. Based on the estimation sample, the average trip length is 6.3 miles, median age of housing stock is 44.6, median income is $57,945 and average percentages of families with children and female population are 42.7 and 51 respectively. The mean value of Job-Household index calculated based on the year 2010 employment and household numbers is 0.81.

Table 40: Descriptive Statistics of the Estimation Sample – Trip Distance Model

	Mean	Std. Dev.
Overall average trip distance	6.33	2.26
Household density	1163.20	1246.04
Retail density	510.08	2543.66
Industrial density	568.44	2099.33
Office density	1315.77	8080.43
Other density	106.97	976.22
JOB_HH	0.81	0.14
Transit availability (binary variable)	0.55	0.50
Housing Median Age	44.60	17.14
Household income	57945.49	28502.94
% family w/children	42.69	9.74
% female	51.02	5.35
Sample size	881	

The estimated coefficients for the trip distance model are reported in Table 41. The dummy variable to indicate regional effects (Cincinnati and Cleveland) is dropped from the model due to its statistical insignificance. This table also reports the elasticities associated with these variables. For continuous variables (such as household income, employment and household densities) the elasticity effect was calculated at the sample means and indicates the percent change in the dependent variable with respect to a 1% change in the independent variable. For dummy variables, we report the percent change in the dependent variable due to a discrete change (from zero to one) in the dummy variable.

The findings reveal that overall average trip distances are longer for TAZs with lower household and retail employment densities as well as lower Job-Household indexes. A 1% increase in Job-Household index (towards a more balanced job-household distribution) will reduce the trip distance by 0.27%. Having at least one bus stop or rail station within half mile of the TAZ centroid or within the TAZ itself decreases trip distances by 4.08% after controlling for all other variables. All else being equal, a 1% increase in median housing age will lead to a 0.19% decrease in trip distances. An increase of 1% in families with children or female population will reduce average trip distances by 0.16% or 0.32% respectively, all else being equal.

Table 41: Trip Distance Model

Dependent variable= Ln (trip distance)			
	Coefficient	t stat.	Elasticities
Household density	-0.0000648	-6.33	-0.075
Retail density	-7.37e-06	-1.13	-0.004
Industrial density	0.0000252	2.69	0.014
Office density	2.16e-06	1.36	0.003
Other density	0.0000272	2.66	0.003
JOB_HH	-0.328963	-4.69	-0.266
Transit availability (binary variable)	-0.0417006	-1.79	-4.084
Housing Median Age	-0.0041642	-5.46	-0.186
Household income	6.43e-07	1.66	0.037
% family w/children	-0.0037544	-3.61	-0.160
% female	-0.0062844	-3.13	-0.320
Constant	2.766439	22.82	
Number of observations	881		
R^2	0.2988		
Adjusted R^2	0.2899		

5. MODEL IMPLEMENTATION AND EXAMPLES

5.1. Allocation Model Description

The revised land allocation model was implemented in CUBE. The basic operations in the model are the same as the previous version with a few exceptions. The model for the mid-Ohio region was unchanged as there are no forecasts of overall decline for that region. Changes were made to the allocations for the other regions based on the decline statistical model. A flowchart showing the major steps in the model are shown in Figure 6. The major inputs are the grid data for the base year showing the probabilities and weighting schemes for households and jobs, the buildout rate for each land use type, and the control totals for households and jobs for the forecast year.

The major difference in the input data is that for households. In the current version of the model, the household cell probability was calculated from the new regression model for growth and decline. The model projects the population for 2000 from the 1990 base year for the census tracts in each metropolitan region. This projection is then used to calculate the percentage change in population for that tract. That change is then assigned to the cells in each tract and used in the input dataset. The household inputs also include the previous weight of the cell based on an array of infrastructure availability and environmental limitation scores. Those scores have not changed.

With those inputs, the model then calculates the full built numbers of households and jobs should all cells be filled to capacity. Capacity is limited by the assigned land use code which applies a density of development for each cell. The codes and their limitations are the same as those in the previous model and are summarized in Appendix C.

The growth and decline goals are calculated next for each county based on the control total forecast. When we ran the model with the new input data for households, we discovered that a few counties would fall very short of their growth goals. This was because more of the cells in the region were assigned negative or low growth by our forecast, leaving a much larger portion of growth to assign to the growing parts of the region. Given the constraints on density, that growth could not be attained.

There are several possible solutions to this problem. One solution is to reexamine the density limitations in the growth cells and reassign them to higher densities based on any local knowledge or scenarios for higher density development. A second approach is to examine the assignment of decline cells and find subareas that might actually grow instead. We added an optional calculation that implements a version of the first strategy. This routine uses the weighting scores for the cells for households to determine which cells are most “ready” to develop. The amount of household decline forecast for the region is used as a target for increased growth elsewhere. The potential allocated growth is calculated for growth cells by changing their land use code from low to moderate density. Cells are then allocated that growth in the order of their readiness for development until the target growth numbers is reached.

The model then proceeds to allocate decline and growth for both households and jobs and provides outputs of the assigned households and jobs for each cell for the forecast year of 2035.

There are then post processing routines that assign the growth to the appropriate TAZ and then apply the transportation models to project the impacts of the growth and decline by TAZ, county, and region in terms of VMT and trip distance by vehicle type (passenger cars and passenger trucks).

Figure 7 shows the detailed flowchart for the Monte-Carlo allocation of households to the cells. A cell is chosen at random and checked to see whether it has sufficient capacity for additional development. If the cell has a negative score (decline), it follows the right side sequence. At each iteration, checks are made to determine if the decline goal was reached. If not, a random weight is selected and compared to the probability that the grid will decline. If the random weight is larger than the probability, the model goes back to select another grid. If the random weight is less than or equal to the probability, the grid is allocated an increment of household decline.

For growth grids, a similar method is followed. One additional step is added if the grid is allocated an increment of growth. The standardized weighting is used to determine whether there is sufficient infrastructure in place to promote growth. If the score is above 0.3, an increment of growth is allocated. This score recognizes that growth is most likely to occur in places with sufficient infrastructure and fewer environmental constraints. However, we found that if the score was set to 0.5 that the projected growth was never achieved in some counties. For this reason, we set the value lower to recognize that over the long run additional infrastructure can be put in place to allow development to occur.

This is one parameter that can be changed if the model is producing development in places where little or none should occur. The value can be increased to avoid this. In order to reach the growth goal, the zoning density in the cells where growth is desired would then need to be increased to allow the allocation to get closer to the forecast goal.

The model proceeds to allocate household growth and decline until the final goals are approached and the final forecast year is reached. Because of the random processes involved, the patterns from multiple runs using the same data will be similar but will vary somewhat. The resulting household growth and decline and then passed to the transportation models to project vehicle type, VMT, and trip distances for the scenario.

The jobs allocation process was not changed from the previous model. The process is illustrated by Figure 8 and Figure 9. In the first part of the allocation, a random cell is chosen and compared to the goals for the county. In the second part, a path similar to that for households is followed based on whether the grid is a decline or growth grid. This determination was made by calculating historical changes in employment by sector for each of the metropolitan areas. The distribution of change was divided into six categories based on the amount of growth or decline and then coded from -3 to +3. That score is used to assign a probability of growth or decline to each cell that is used in the comparison.

The goals for employment are divided into three sectors – office, retail, and industry – and thus the allocation is made to achieve the goal for each sector for each county in the region. Once the model reaches the forecast year, the data are passed to the transportation model.

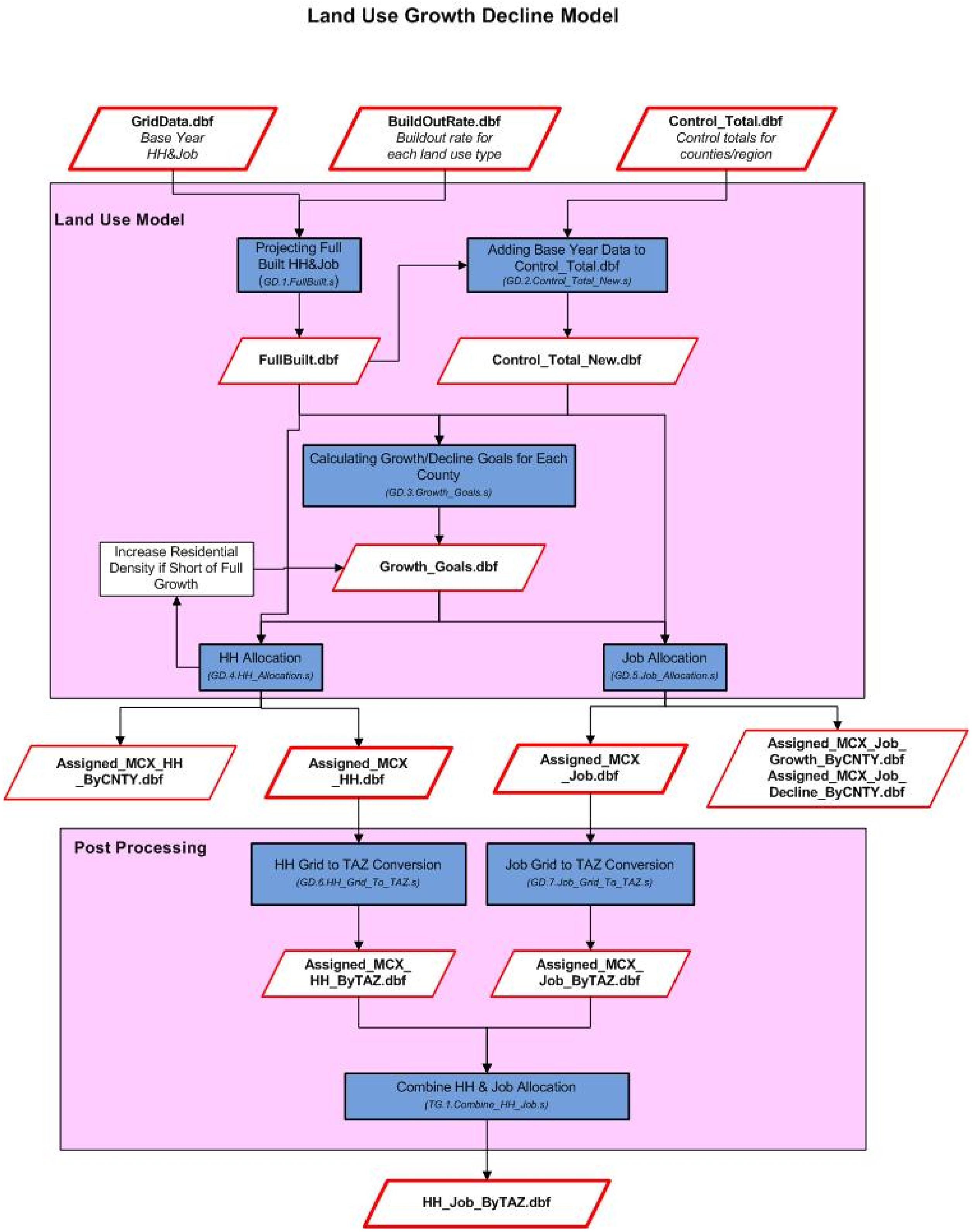

Figure 6: Land Use Growth and Decline Model

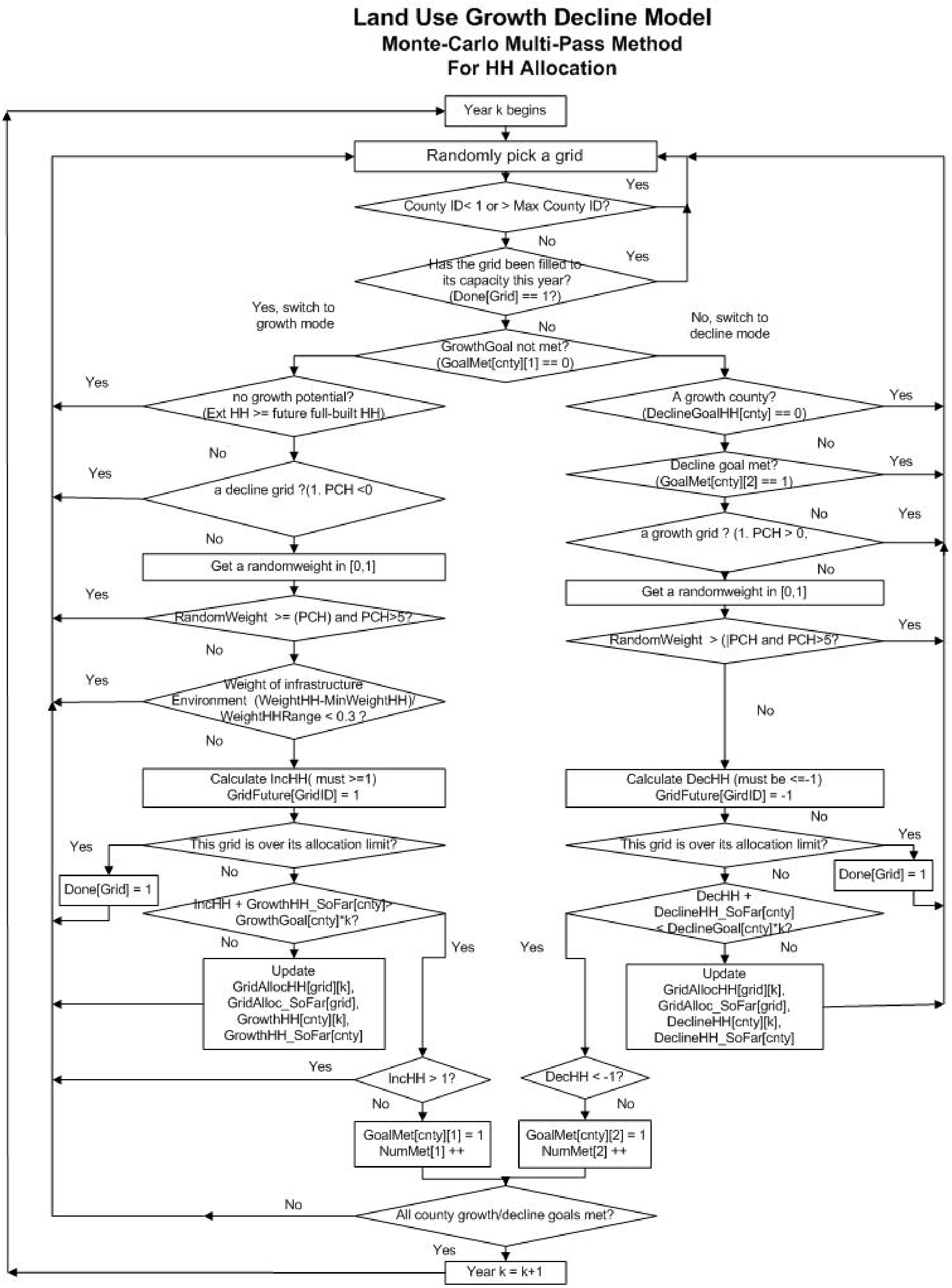

Figure 7: Detailed Monte-Carlo Model Flowchart

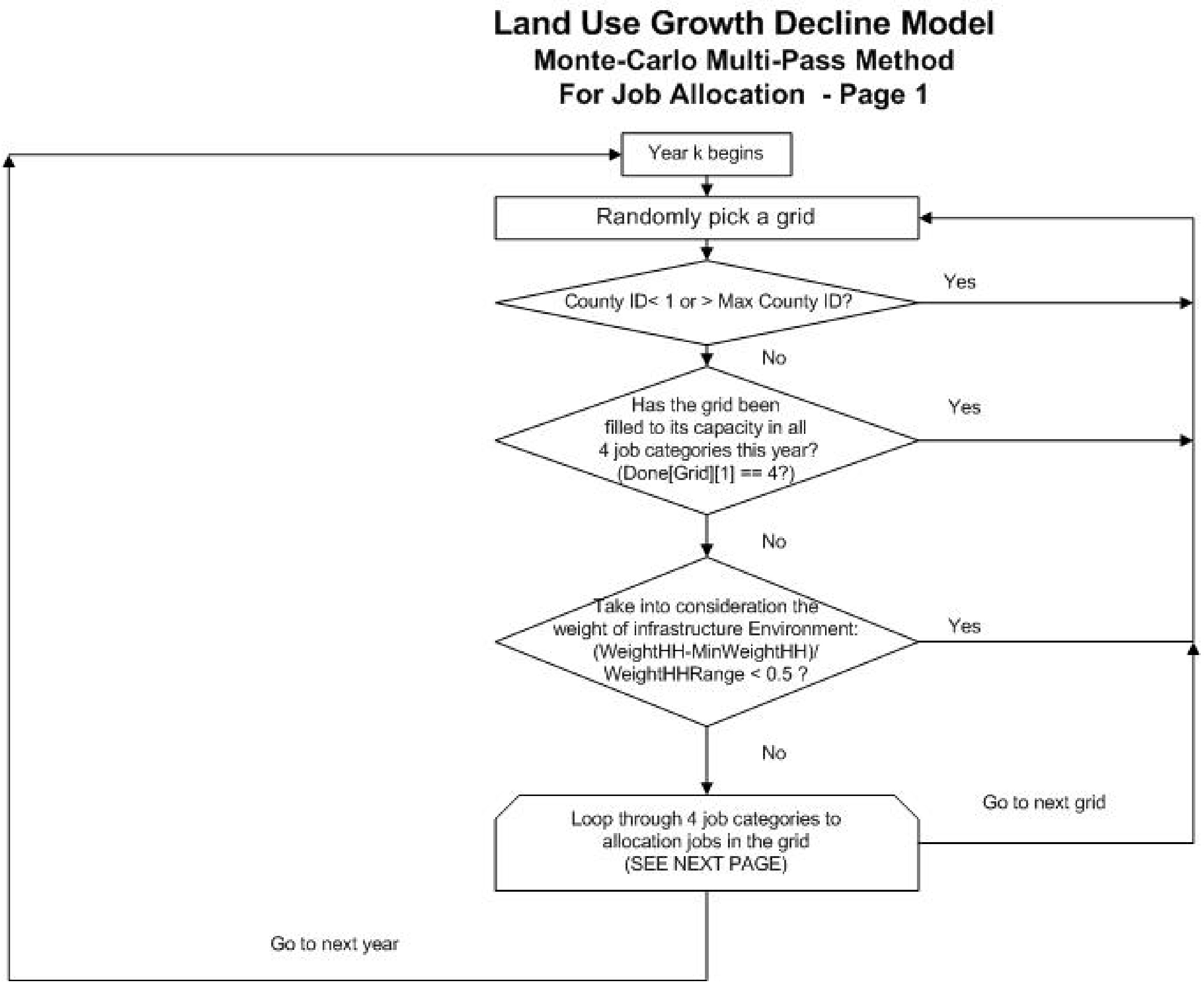

Figure 8: Part 1 of the Jobs Allocation Process

One final optional adjustment was added to the model. When running the model to compare different development scenarios, there are slight differences in the allocated jobs and households between model runs caused by the random allocation processes. When applied to the transportation model, these changes can screen the actual impacts of different development scenarios. The household-job adjustment module (HH/JobAdjustment) was added to resolve this problem. This module sums up the households and jobs, by category for both the reference scenario and the comparison scenario. The ratio of households and jobs between the runs is then used to adjust the comparison scenario forecast of households and jobs to match the reference scenario at the TAZ level. The resultant ADJUSTED_HH_JOB_ByTAZ.dbf file is then used to make the transportation model forecasts. Differences in the outcomes for VMT and trip distance can then be attributed to changes in the distribution of households and jobs across the region rather than any differences in the number of households or jobs.

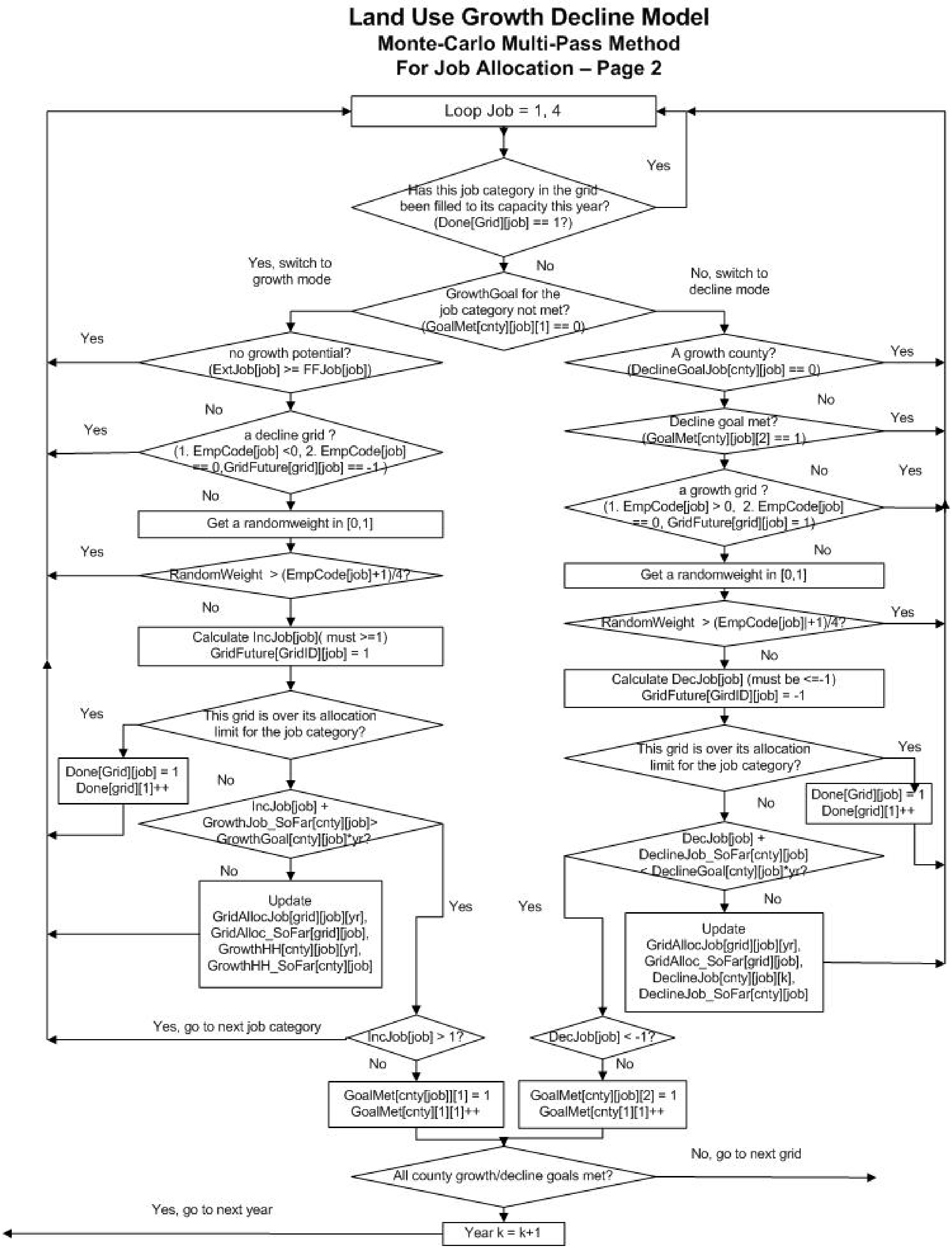

Figure 9: Part 2 of the Jobs Allocation Process

5.2. Scenarios

We ran the model with three scenarios in order to illustrate its use and results. Each of these scenarios is described below followed by a summary of the results

5.2.1. Scenario 1 – Base Case

Our base case scenario assumes that the historical population growth and decline in Ohio's metropolitan areas will continue to follow historical trends. The county household and job forecast control totals that were obtained as part of our previous project are used as control totals in the model. The forecasts are divided by the total number of years to provide an annual control total for each year.

For household allocations, cells are assigned a probability of growth or decline based on the final regression model. For each iteration of the model, cells are selected randomly. Their probability of growth or decline is then compared to a pseudo-randomly generated score. If the cell score is greater than or equal to the randomly generated score, the cell is allocated an increment of growth or decline. Growth is limited by the land use assigned to each cell – with each residential land use having a maximum density. Allocations continue until the growth or decline goal is met for the counties in the region. This is repeated annually until the last period is reached. The allocated growth may not always reach the goals given constraints on the density assigned to the cells in the region.

For jobs, there is a growth goal by major job category. The scores for the cell to accommodate new jobs are standardized and used as the probability for cell job growth. Random cells are selected along with a random score that is compared to the job growth probability. Job growth is then assigned if the cell score is greater than or equal to the randomly selected score. This is repeated until all jobs are allocated. Here again, cell capacities based on the land uses assigned can limit the potential job growth so that the control totals are not always met.

5.2.2. Scenario 2 - Increased Growth in Multi-nodal Central Cities

In scenario 2, we selected tracts that are within five miles of the centroid of each municipality in each region. For all Ohio regions, this includes the predominant central city and all suburban communities. This scenario represents a possible return of population to urban centers and sub-centers but maintains a split between central city and suburban city development. For each of the cells in the selected tracts, the population change probabilities are changed to 0.10 for all cells that were assigned negative numbers (decline) or lower than 10% growth. The control totals for the counties in the region are left the same as in the base case for this scenario.

5.2.3. Scenario 3 - Return to the Central County

Scenario 3 is built to reflect the possibility that people will move back into the central counties of each region due to rising commuting costs and redeveloping central communities. This scenario is implemented by selecting all of the tracts in the central county that are adjacent to tracts where historical growth has occurred. This implies that the positive growth in those subareas will have a positive impact on future growth in adjacent areas. For the cells in those adjacent tracts, the population growth probability is set to 0.10 for all of the cells with negative scores or scores less than 0.10.

Since many of the central counties are forecast to continue declining in population, we altered those forecasts to accommodate this projected growth. This was done by allocating 10% of the growth of the other counties in the region to the central county and decreasing the outlying counties growth forecast accordingly.

5.3.Model Results

5.3.1. Base Case Scenario

The base case scenario simulates the impacts of continuing current trends on land use patterns and their related transportation impacts. The results are summarized in Table 42 to Table 47. The tables show the numbers of households and jobs, by categories that are inputs to the model for the base year 2000. The same information is given for the forecast year 2035. Then, the table shows for both years the forecast in the number of trips, VMT, and trip distance and the differences between the starting and ending year. Also included is the VMT by passenger cars and passenger trucks.

The results reflect the overall population and job forecasts for each of the regions. For the Akron region, a decrease in VMT is projected. Much larger decreases in VMT are forecasted for all other regions where there is an overall decline in jobs and households. The largest decline is in the Cleveland region at -25%. Cincinnati has an 8% decline in VMT while Dayton and Toledo have larger declines in their VMT.

For Columbus, a large increase (over 30%) in VMT is projected reflecting both the increased growth in the region and the continuation of trends for low density urban sprawl.

Example maps showing the forecast of VMT, household density, and job density are provided for both Akron and Columbus. The maps shown as Figure 10 to Figure 15 illustrate the patterns of development and resulting impacts on travel behavior.

The input and output data for each of the runs model runs are provided along with the associated GIS files on the companion DVD for this report. Those files can be used to replicate all of the runs and to create additional maps as needed.

Table 42: Akron Base Case Forecasts

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	462837	490014	27178	5.87
Num_of_Jobs	649671	683115	33443	5.15
Office_Jobs	102797	212871	110073	107.08
Retail_Jobs	157684	81396	-76288	-48.38
Industrial_Jobs	164825	243041	78217	47.45
Other_Jobs	224365	145808	-78558	-35.01
Num_Of_Trips	3223833	3032677	-191155	-5.93
Avg_Trip_Dist	6.34	6.23	-0.11	-1.70
Total_VMT	20440314	18900678	-1539636	-7.53
VMT_CAR	11028399.28	10106258	-922141.15	-8.36
VMT_TRUCK	9411915.12	8794420	-617494.95	-6.56

Table 43: Cincinnati Base Case Forecasts

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	591590	561574	-30016	-5.07
Num_of_Jobs	771145	784542	13397	1.74
Office_Jobs	305653	298744	-6909	-2.26
Retail_Jobs	180256	103831	-76425	-42.40
Industrial_Jobs	258395	283503	25108	9.72
Other_Jobs	26841	97353	70512	262.70
Num_Of_Trips	3895477	3491561	-403916	-10.37
Avg_Trip_Dist	6.17	6.30	0.13	2.10
Total_VMT	24044475	22003195	-2041279	-8.49
VMT_CAR	13463236.26	11761875	-1701361.26	-12.64
VMT_TRUCK	10581238.41	10241320	-339917.98	-3.21

Table 44: Cleveland Base Case Forecasts

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	851240	829967	-21273	-2.50
Num_of_Jobs	1348733	861739	-486994	-36.11
Office_Jobs	232429	281469	49040	21.10
Retail_Jobs	275967	127503	-148463	-53.80
Industrial_Jobs	294575	301546	6970	2.37
Other_Jobs	545762	151221	-394542	-72.29
Num_Of_Trips	5824259	4806652	-1017607	-17.47
Avg_Trip_Dist	6.26	5.66	-0.59	-9.47
Total_VMT	36431232	27219672	-9211560	-25.29
VMT_CAR	22173306.53	15501820	-6671486.72	-30.09
VMT_TRUCK	14257925.60	11717852	-2540073.56	-17.82

Table 45: Dayton Base Case Forecasts

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	359375	364460	5084	1.42
Num_of_Jobs	536781	389587	-147194	-27.42
Office_Jobs	106070	125279	19209	18.11
Retail_Jobs	123112	67322	-55791	-45.32
Industrial_Jobs	105245	127807	22562	21.44
Other_Jobs	202354	69180	-133175	-65.81
Num_Of_Trips	2472116	2167020	-305096	-12.34
Avg_Trip_Dist	6.44	6.01	-0.43	-6.64
Total_VMT	15915697	13025479	-2890219	-18.16
VMT_CAR	8847138.50	7135643	-1711495.57	-19.35
VMT_TRUCK	7068558.71	5889836	-1178722.93	-16.68

Table 46: Columbus Base Case Forecasts

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	815226	1067240	252014	30.91
Num_of_Jobs	976208	1241394	265186	27.17
Office_Jobs	402240	504755	102515	25.49
Retail_Jobs	224301	290315	66014	29.43
Industrial_Jobs	183773	238302	54529	29.67
Other_Jobs	165894	208022	42128	25.40
Num_Of_Trips	5250998	6856706	1605708	30.58
Avg_Trip_Dist	6.34	6.40	0.06	0.89
Total_VMT	33303838	43876445	10572606	31.75
VMT_CAR	17615912.92	22851980	5236066.64	29.72
VMT_TRUCK	15687925.32	21024465	5336539.66	34.02

Table 47: Toledo Base Case Forecasts

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	282067	280790	-1277	-0.45
Num_of_Jobs	427340	313602	-113738	-26.62
Office_Jobs	72165	96699	24534	34.00
Retail_Jobs	106410	49948	-56462	-53.06
Industrial_Jobs	79912	105635	25723	32.19
Other_Jobs	168853	61320	-107533	-63.68
Num_Of_Trips	1999332	1675611	-323721	-16.19
Avg_Trip_Dist	6.19	6.02	-0.17	-2.81
Total_VMT	12383978	10087645	-2296333	-18.54
VMT_CAR	6891065.09	5627842	-1263222.60	-18.33
VMT_TRUCK	5492913.08	4459802	-1033110.83	-18.81

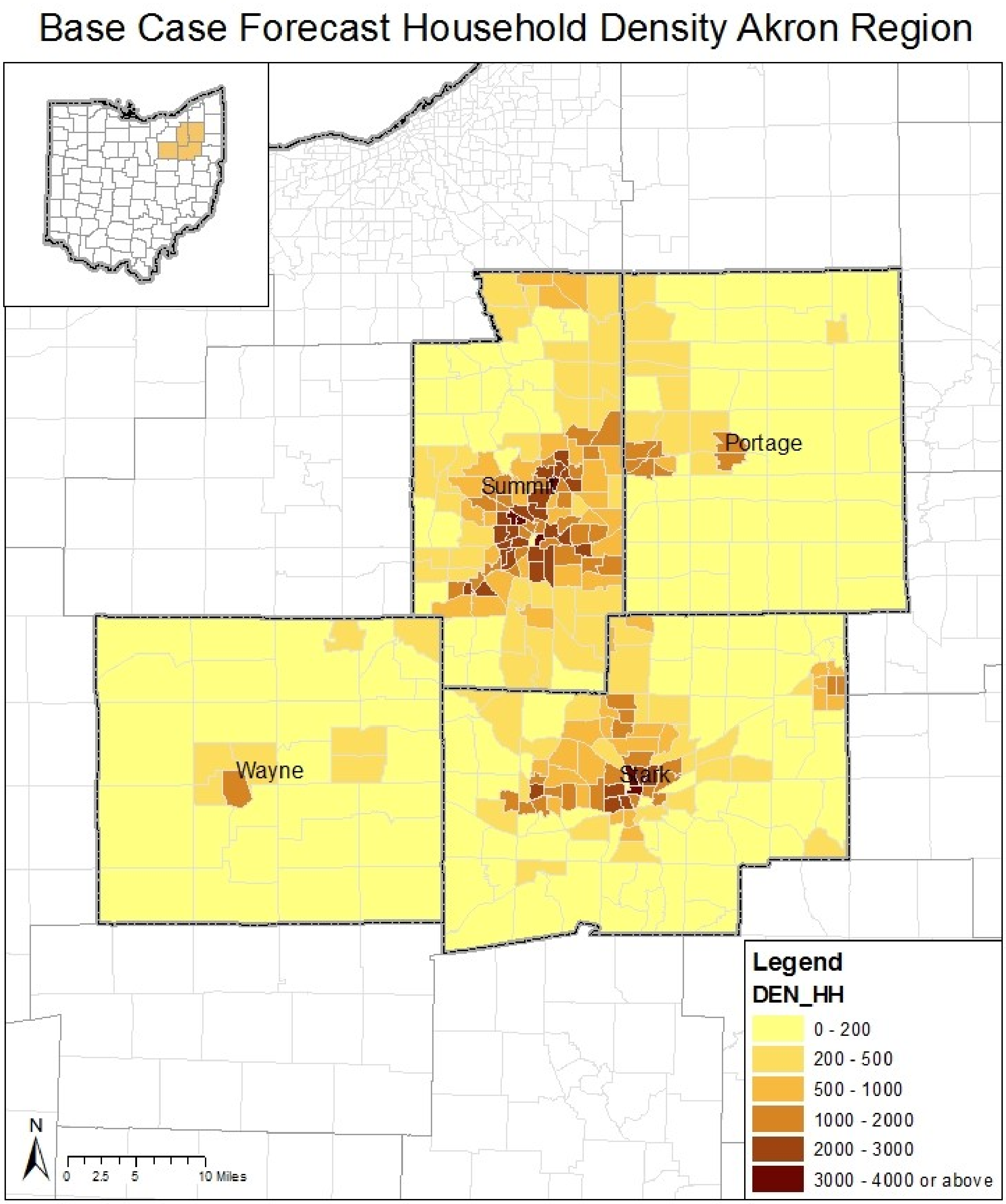

Figure 10: Household Density Base Case Akron

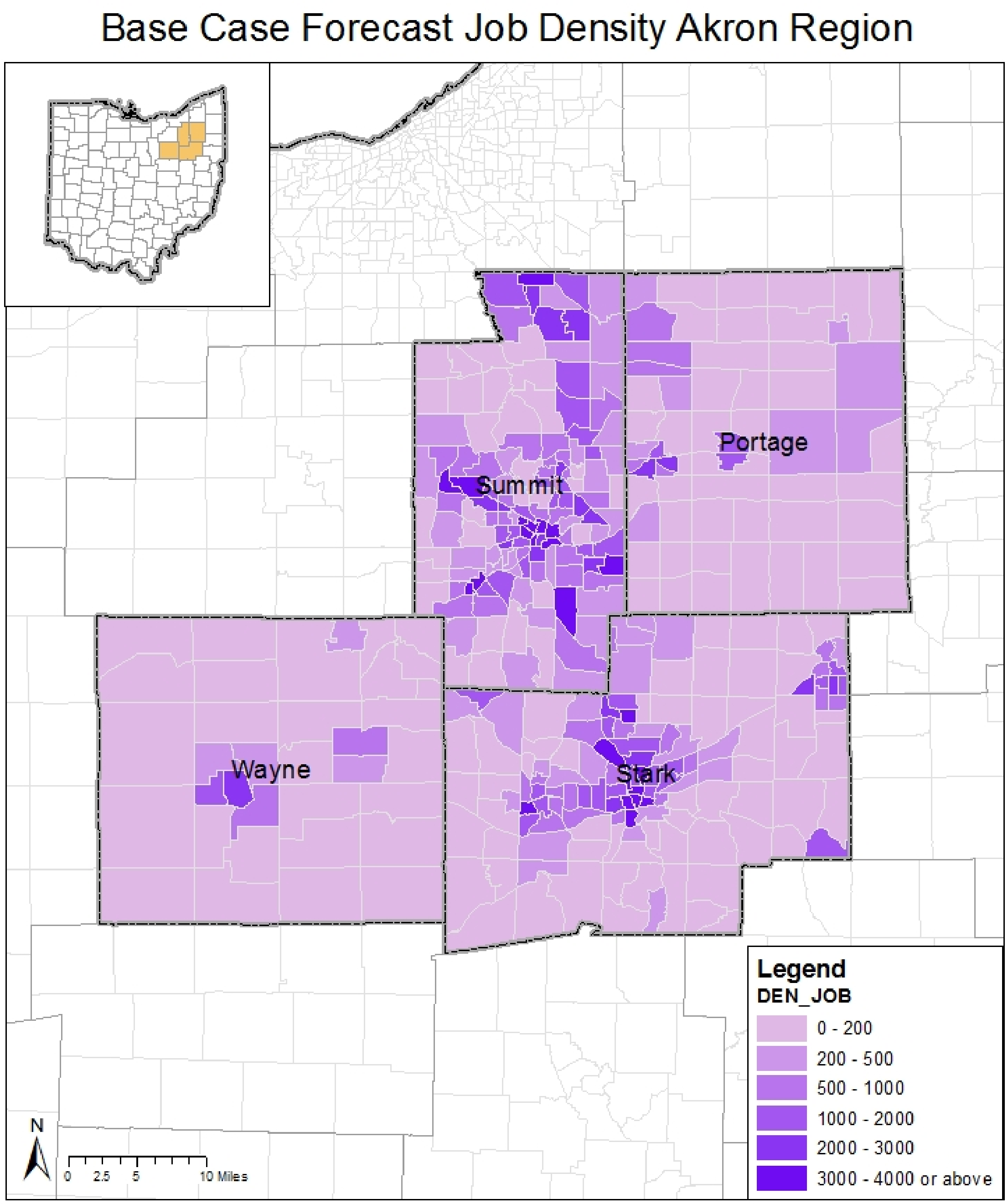

Figure 11: Job Density Base Case Akron

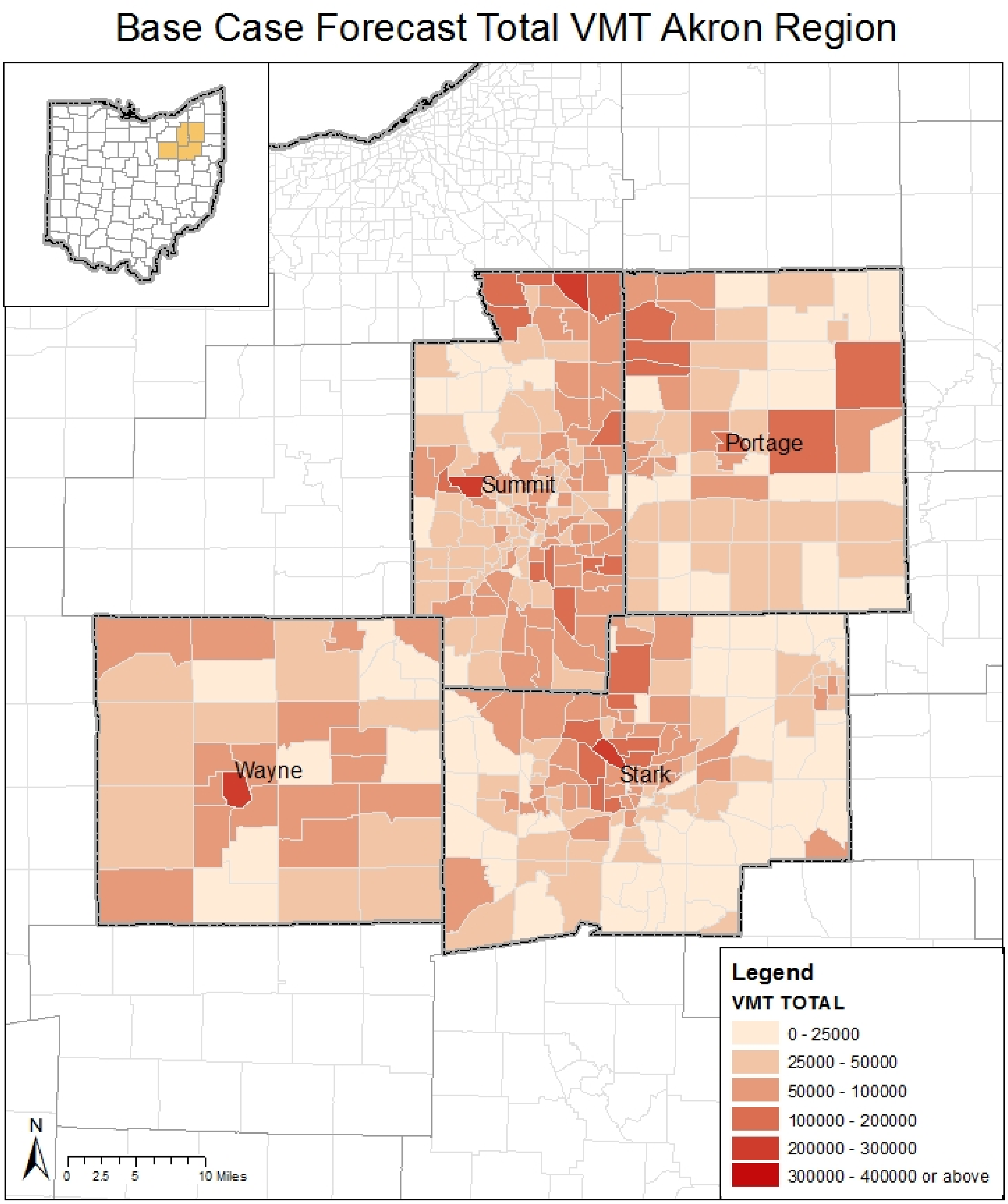

Figure 12: VMT Forecast Base Case Akron

Base Case Forecast Household Density Columbus Region

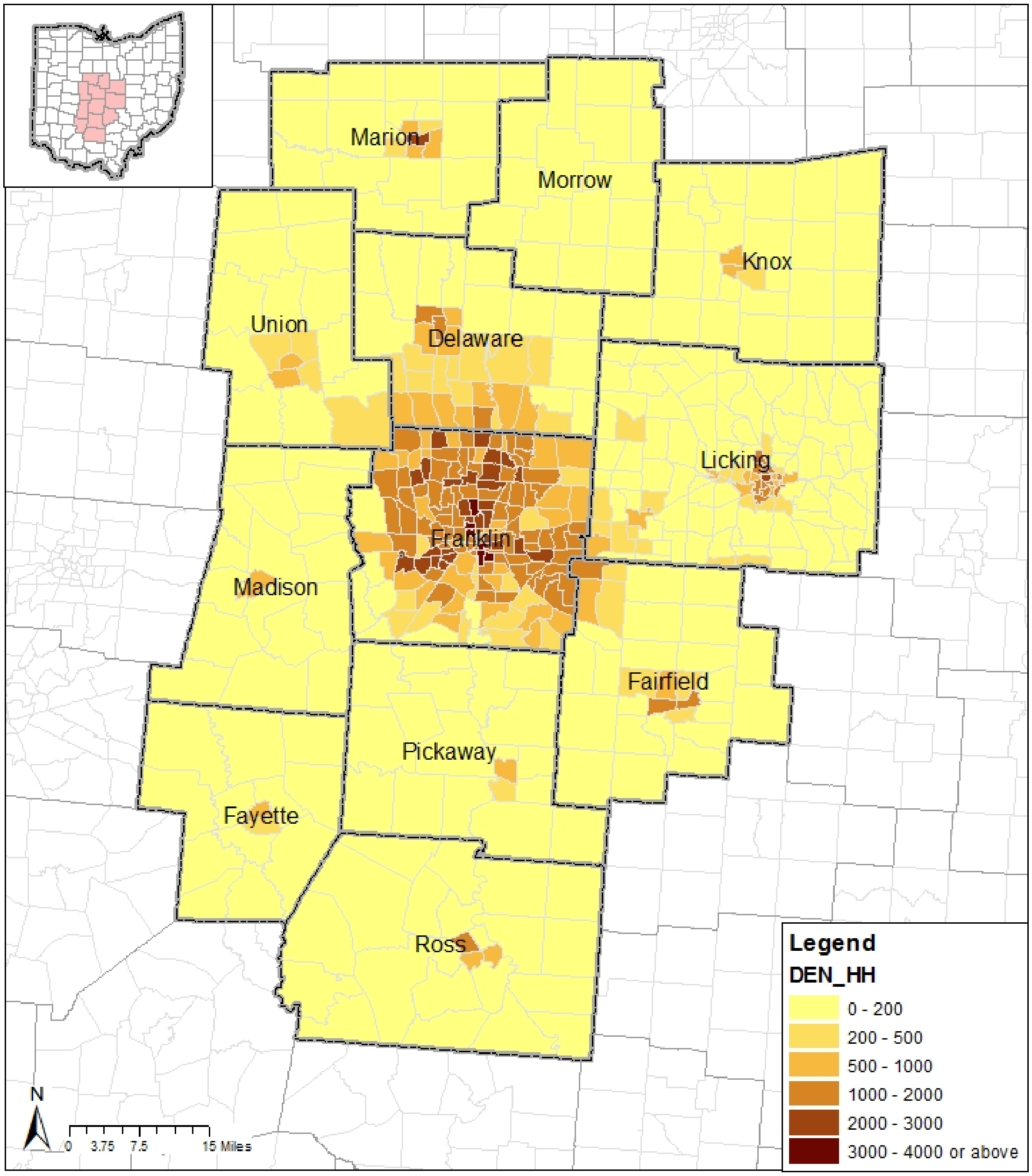

Figure 13: Household Density Base Case Columbus

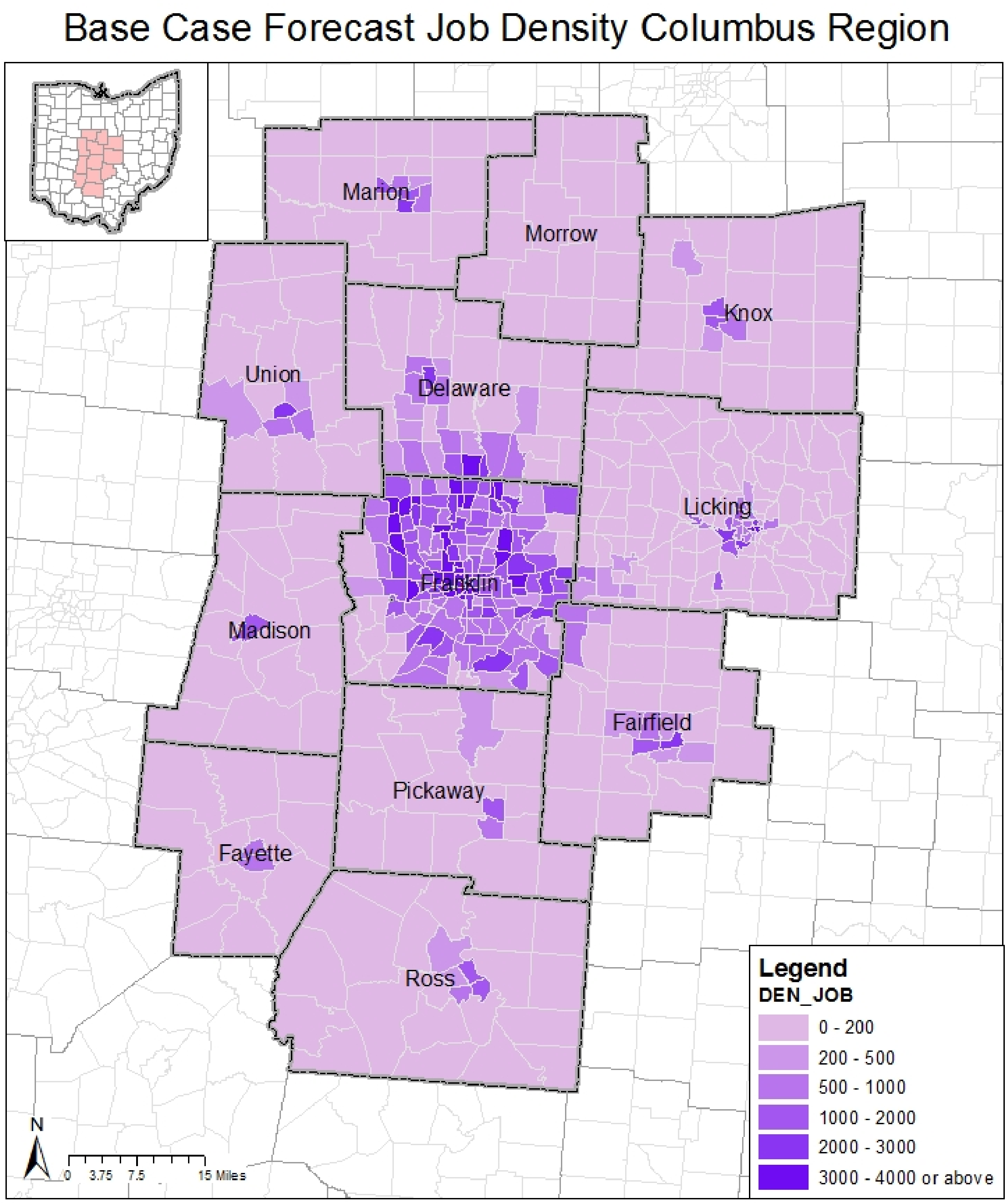

Figure 14: Job Density Base Case Columbus

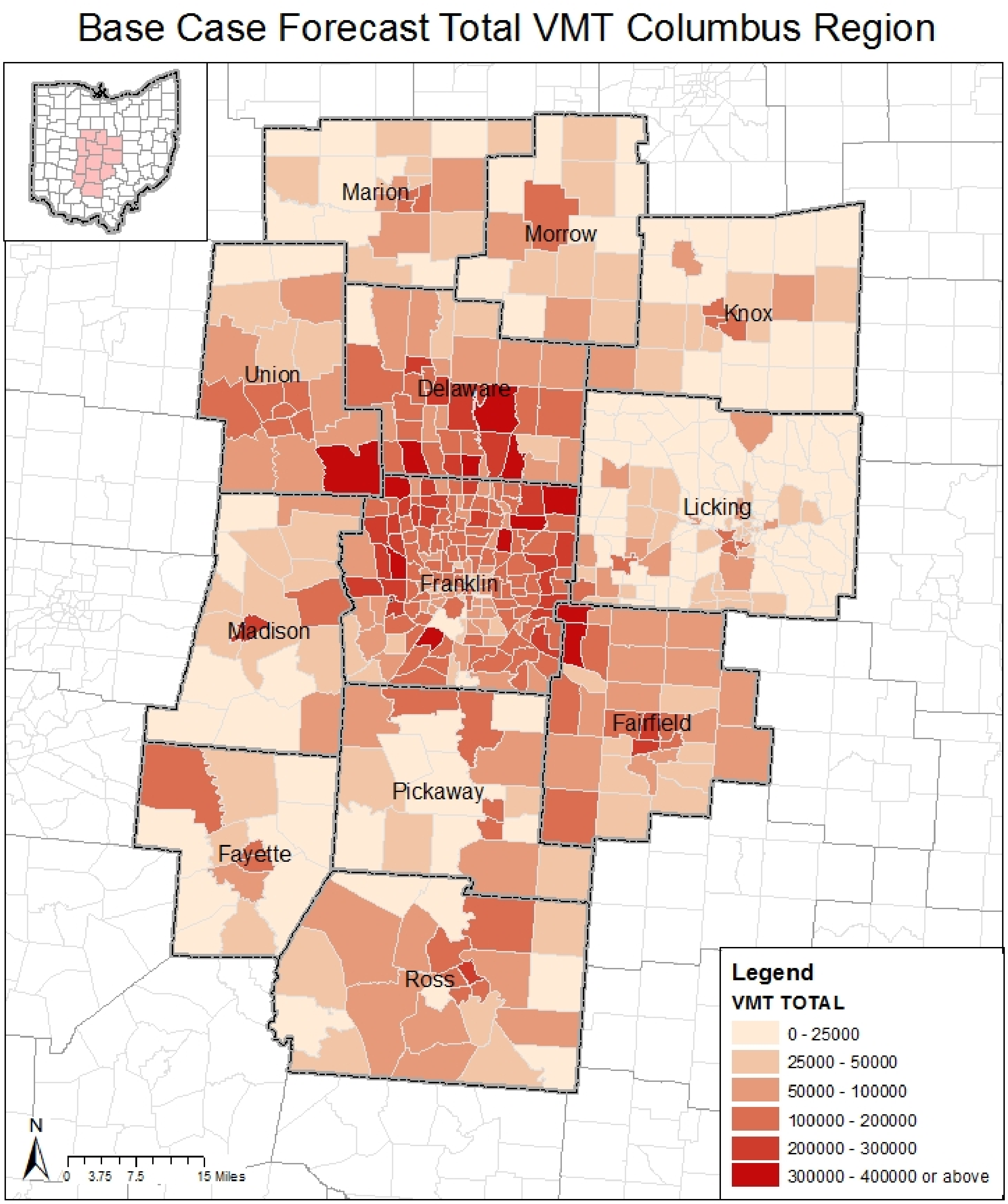

Figure 15: VMT Forecast Base Case Columbus

5.3.2. Increased Growth in Multi-nodal Central Cities

Scenario 2 represents a slight difference from the historical growth patterns. In this scenario, areas close to the centroids of all existing municipalities in the region are changed so that they are more likely to grow. This reflects a current trend of living closer to central business districts but still reflects a trend of growth outside the central cities.

Table 48 shows the Scenario 2 forecasts for Akron. The total VMT only slightly increases under this scenario with respect to the base case. The increase in the total VMT over the base case is only 0.23%. This is expected as the average density of satellite cities in the region is generally lower than the central city. Thus, as more people are allocated to those suburban locations, the average density increases resulting in a higher VMT. The absolute amount is not very large as only 1.1 percent of cells in the region had their probability of development changed from negative to positive values.

Table 48: Scenario 2 Forecasts for Akron

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	462837	490014	27178	5.87
Num_of_Jobs	649671	683115	33444	5.15
Office_Jobs	102797	212871	110073	107.08
Retail_Jobs	157684	81396	-76288	-48.38
Industrial_Jobs	164825	243041	78217	47.45
Other_Jobs	224365	145808	-78558	-35.01
Num_Of_Trips	3223833	3032196	-191637	-5.94
Avg_Trip_Dist	6.34	6.25	-0.09	-1.46
Total_VMT	20440314	18944291	-1496023	-7.32
VMT_CAR	11028399.28	10093504	-934895.49	-8.48
VMT_TRUCK	9411915.12	8850787	-561127.67	-5.96

Table 49 shows the Scenario 2 results for Cincinnati. The results are similar to those for Akron with a slight increase in VMT as development in surrounding centers at lower density takes place.

Table 49: Scenario 2 Forecasts for Cincinnati

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	591590	561574	-30016	-5.07
Num_of_Jobs	771145	783431	12286	1.59
Office_Jobs	305653	298744	-6909	-2.26
Retail_Jobs	180256	103831	-76425	-42.40
Industrial_Jobs	258395	283503	25108	9.72
Other_Jobs	26841	97353	70512	262.70
Num_Of_Trips	3895477	3491314	-404162	-10.38
Avg_Trip_Dist	6.17	6.32	0.14	2.32
Total_VMT	24044475	22048748	-1995727	-8.30
VMT_CAR	13463236.26	11792247	-1670989.36	-12.41
VMT_TRUCK	10581238.41	10256501	-324737.24	-3.07

Changes in the Cleveland region are similar to those for Akron as shown in Table 50. Modifying less than 0.5% of the cells to increase the probability of growth near the center of satellite cities produces a slight increase of 0.13% in VMT as compared with the base case.

Table 50: Scenario 2 Forecasts for Cleveland

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	851240	829967	-21273	-2.50
Num_of_Jobs	1348733	861739	-486994	-36.11
Office_Jobs	232429	281469	49040	21.10
Retail_Jobs	275967	127503	-148463	-53.80
Industrial_Jobs	294575	301546	6970	2.37
Other_Jobs	545762	151221	-394542	-72.29
Num_Of_Trips	5824259	4807030	-1017230	-17.47
Avg_Trip_Dist	6.26	5.67	-0.59	-9.35
Total_VMT	36431232	27255852	-9175380	-25.19
VMT_CAR	22173306.53	15516596	-6656710.83	-30.02
VMT_TRUCK	14257925.60	11739256	-2518669.47	-17.67

The results for the Columbus region for scenario 2 are shown in Table 51. The scenario changed the values for 0.5% of the cells in the region and produced a negligible decrease in VMT.

Table 51: Scenario 2 Forecast for Columbus

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	815226	1067240	252014	30.91
Num_of_Jobs	976208	1241394	265186	27.17
Office_Jobs	402240	504755	102515	25.49
Retail_Jobs	224301	290315	66014	29.43
Industrial_Jobs	183773	238302	54529	29.67
Other_Jobs	165894	208022	42128	25.40
Num_Of_Trips	5250998	6859049	1608051	30.62
Avg_Trip_Dist	6.34	6.39	0.05	0.81
Total_VMT	33303838	43853821	10549983	31.68
VMT_CAR	17615912.92	22856468	5240554.80	29.75
VMT_TRUCK	15687925.32	20997353	5309427.96	33.84

A similar percentage of the cells for Dayton were changed for scenario 2 but produced a very negligible increase in VMT as shown in Table 52. This may be due to the overall smaller size of the Dayton region.

Table 52: Scenario 2 Forecast for Dayton

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	359375	364460	5084	1.42
Num_of_Jobs	536781	389587	-147194	-27.42
Office_Jobs	106070	125279	19209	18.11
Retail_Jobs	123112	67322	-55791	-45.32
Industrial_Jobs	105245	127807	22562	21.44
Other_Jobs	202354	69180	-133175	-65.81
Num_Of_Trips	2472116	2167127	-304988	-12.34
Avg_Trip_Dist	6.44	6.01	-0.43	-6.67
Total_VMT	15915697	13022052	-2893645	-18.18
VMT_CAR	8847138.50	7129743	-1717395.69	-19.41
VMT_TRUCK	7068558.71	5892309	-1176249.25	-16.64

The results for scenario 2 for Toledo are shown in Table 53. Again a small number of cells where changed producing a very small increase in VMT.

Table 53: Scenario 2 Forecast for Toledo

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE

Num_of_HH	282067	280790	-1277	-0.45
Num_of_Jobs	427340	313602	-113738	-26.62
Office_Jobs	72165	96699	24534	34.00
Retail_Jobs	106410	49948	-56462	-53.06
Industrial_Jobs	79912	105635	25723	32.19
Other_Jobs	168853	61320	-107533	-63.68
Num_Of_Trips	1999332	1675707	-323625	-16.19
Avg_Trip_Dist	6.19	6.02	-0.17	-2.80
Total_VMT	12383978	10088577	-2295401	-18.54
VMT_CAR	6891065.09	5627533	-1263531.60	-18.34
VMT_TRUCK	5492913.08	4461044	-1031869.36	-18.79

Figure 16 and Figure 17 show the maps of the VMT forecast for Akron and Columbus for Scenario 2.

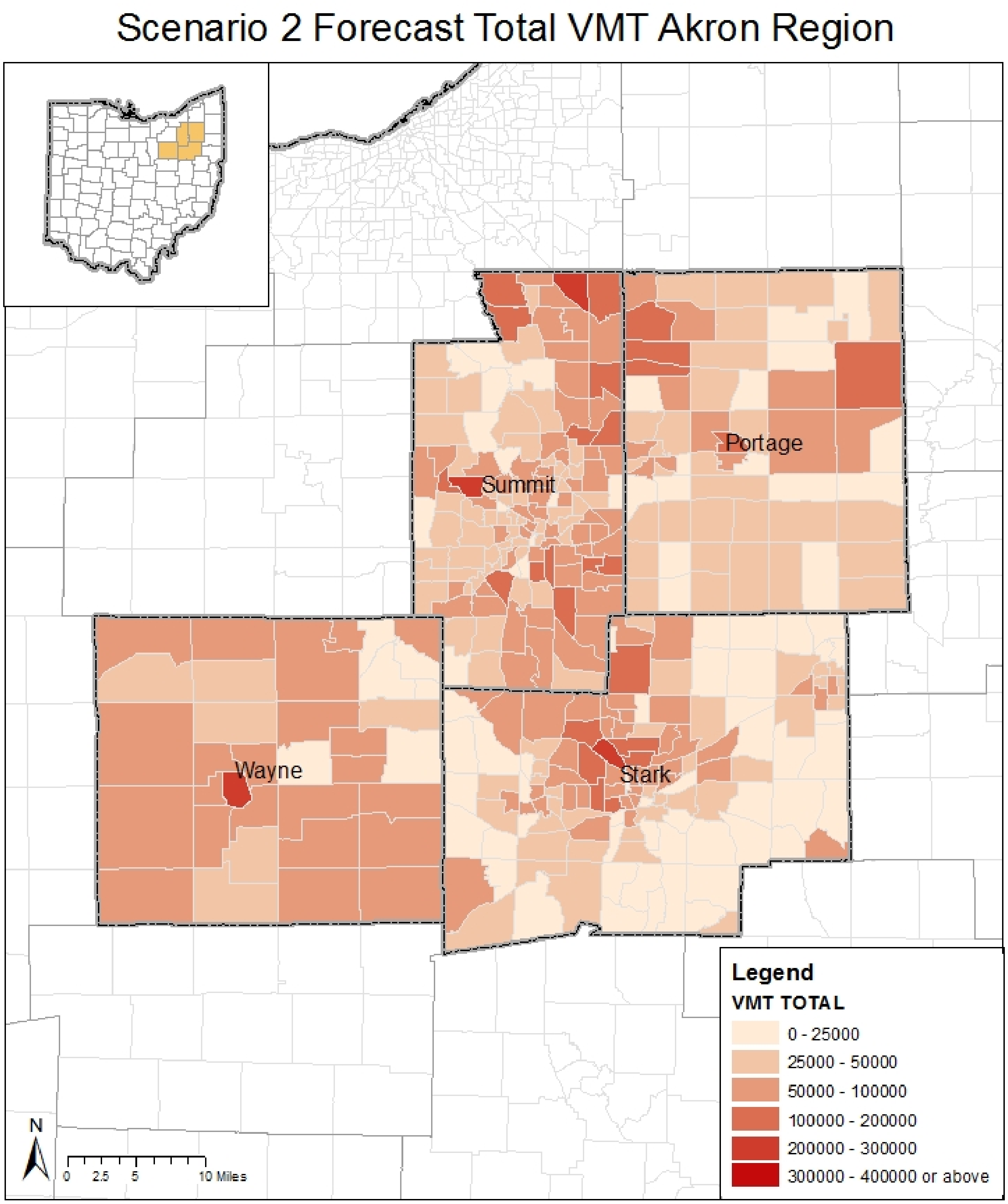

Figure 16: VMT Forecast Scenario 2 Akron

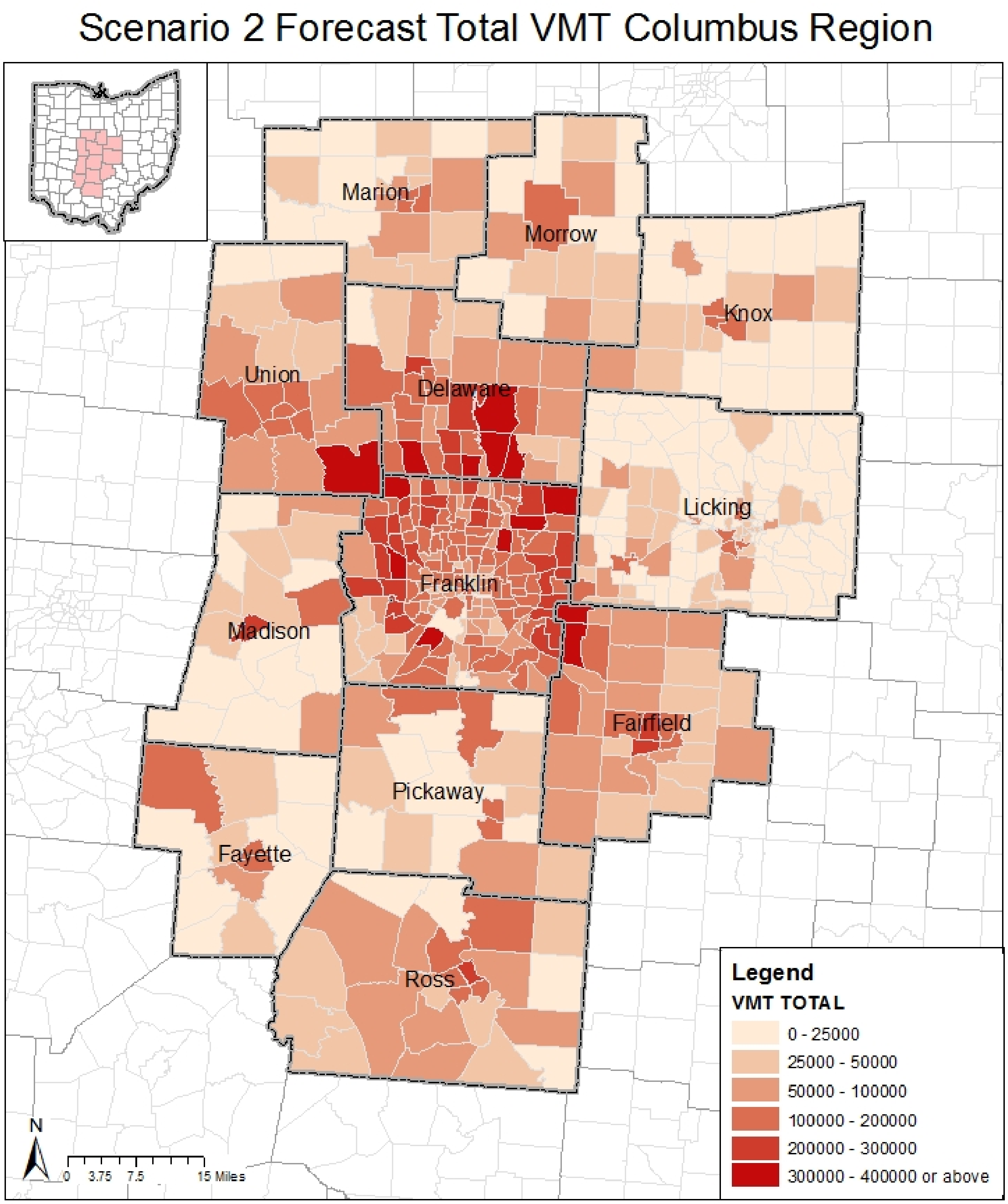

Figure 17: VMT Forecast Scenario 2 Columbus

5.3.3. Return to the Central County

Scenario 3 makes modest changes to the probability of development for cells in the central county of each region. It also reallocates 10% of the households back to the central county at the expense of the surrounding counties. In this scenario, no changes are made to the allocation of jobs. The results from this scenario are shown in Table 54 to Table 59.

The expectation from this scenario is that the total VMT should decline as people move back toward the central county with areas of higher population density and the availability of public transit. This indeed is the case for all of the regions except for Akron. For the Akron case, a forecast 1% increase in VMT is forecast. The underlying reason for this appears to be because of the removal of people from the Canton area in Stark County and placing them in lower density areas of Summit County. Because of the unusual dual central city nature of this region, the scenario does not play out as expected.

For all of the other regions, this scenario results in a reduction of VMT. For Cincinnati a small decrease of 0.3% occurs in VMT. In the Cleveland, Columbus, and Toledo regions, this scenario produces a reduction of almost 1% of the VMT. For Dayton, the reduction is closer to 0.5%. Overall, the scenario illustrates how shifts in household location decisions will impact travel demand.

Figure 18 and Figure 19 are maps illustrating the VMT forecasts for the Akron and Columbus regions.

Table 54: Scenario 3 Forecasts for Akron

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	462837	490014	27178	5.87
Num_of_Jobs	649671	683115	33444	5.15
Office_Jobs	102797	212871	110073	107.08
Retail_Jobs	157684	81396	-76288	-48.38
Industrial_Jobs	164825	243041	78217	47.45
Other_Jobs	224365	145808	-78558	-35.01
Num_Of_Trips	3223833	3033777	-190056	-5.90
Avg_Trip_Dist	6.34	6.30	-0.04	-0.71
Total_VMT	20440314	19099709	-1340606	-6.56
VMT_CAR	11028399.28	10141354	-887045.28	-8.04
VMT_TRUCK	9411915.12	8958355	-453560.33	-4.82

Table 55: Scenario 3 Forecasts for Cincinnati

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	591590	561574	-30016	-5.07
Num_of_Jobs	771145	783431	12286	1.59
Office_Jobs	305653	298744	-6909	-2.26
Retail_Jobs	180256	103831	-76425	-42.40
Industrial_Jobs	258395	283503	25108	9.72
Other_Jobs	26841	97353	70512	262.70
Num_Of_Trips	3895477	3491328	-404148	-10.38
Avg_Trip_Dist	6.17	6.28	0.11	1.78
Total_VMT	24044475	21933409	-2111065	-8.78
VMT_CAR	13463236.26	11780461	-1682774.79	-12.50
VMT_TRUCK	10581238.41	10152948	-428290.62	-4.05

Table 56: Scenario 3 Forecasts for Cleveland

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	851240	829967	-21273	-2.50
Num_of_Jobs	1348733	861739	-486994	-36.11
Office_Jobs	232429	281469	49040	21.10
Retail_Jobs	275967	127503	-148463	-53.80
Industrial_Jobs	294575	301546	6970	2.37
Other_Jobs	545762	151221	-394542	-72.29
Num_Of_Trips	5824259	4806797	-1017462	-17.47
Avg_Trip_Dist	6.26	5.62	-0.64	-10.19
Total_VMT	36431232	27003770	-9427463	-25.88
VMT_CAR	22173306.53	15458943	-6714363.95	-30.28
VMT_TRUCK	14257925.60	11544827	-2713098.59	-19.03

Table 57: Scenario 3 Forecasts for Columbus

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	815226	1067240	252014	30.91
Num_of_Jobs	976208	1241394	265186	27.17
Office_Jobs	402240	504755	102515	25.49
Retail_Jobs	224301	290315	66014	29.43
Industrial_Jobs	183773	238302	54529	29.67
Other_Jobs	165894	208022	42128	25.40
Num_Of_Trips	5250998	6862677	1611679	30.69
Avg_Trip_Dist	6.34	6.33	-0.01	-0.13
Total_VMT	33303838	43471317	10167479	30.53
VMT_CAR	17615912.92	22832103	5216190.26	29.61
VMT_TRUCK	15687925.32	20639214	4951288.31	31.56

Table 58: Scenario 3 Forecasts for Dayton

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	359375	364460	5084	1.42
Num_of_Jobs	536781	389587	-147194	-27.42
Office_Jobs	106070	125279	19209	18.11
Retail_Jobs	123112	67322	-55791	-45.32
Industrial_Jobs	105245	127807	22562	21.44
Other_Jobs	202354	69180	-133175	-65.81
Num_Of_Trips	2472116	2166942	-305173	-12.35
Avg_Trip_Dist	6.44	5.98	-0.46	-7.08
Total_VMT	15915697	12963267	-2952430	-18.55
VMT_CAR	8847138.50	7143802	-1703336.87	-19.25
VMT_TRUCK	7068558.71	5819466	-1249093.06	-17.67

Table 59: Scenario 3 Forecasts for Toledo

DESCRIPTION	YR2000	YR2035	CHANGE	PCT_CHANGE
Num_of_HH	282067	280790	-1277	-0.45
Num_of_Jobs	427340	313602	-113738	-26.62
Office_Jobs	72165	96699	24534	34.00
Retail_Jobs	106410	49948	-56462	-53.06
Industrial_Jobs	79912	105635	25723	32.19
Other_Jobs	168853	61320	-107533	-63.68
Num_Of_Trips	1999332	1675304	-324028	-16.21
Avg_Trip_Dist	6.19	5.97	-0.22	-3.58
Total_VMT	12383978	10005822	-2378157	-19.20
VMT_CAR	6891065.09	5610147	-1280918.25	-18.59
VMT_TRUCK	5492913.08	4395675	-1097238.36	-19.98

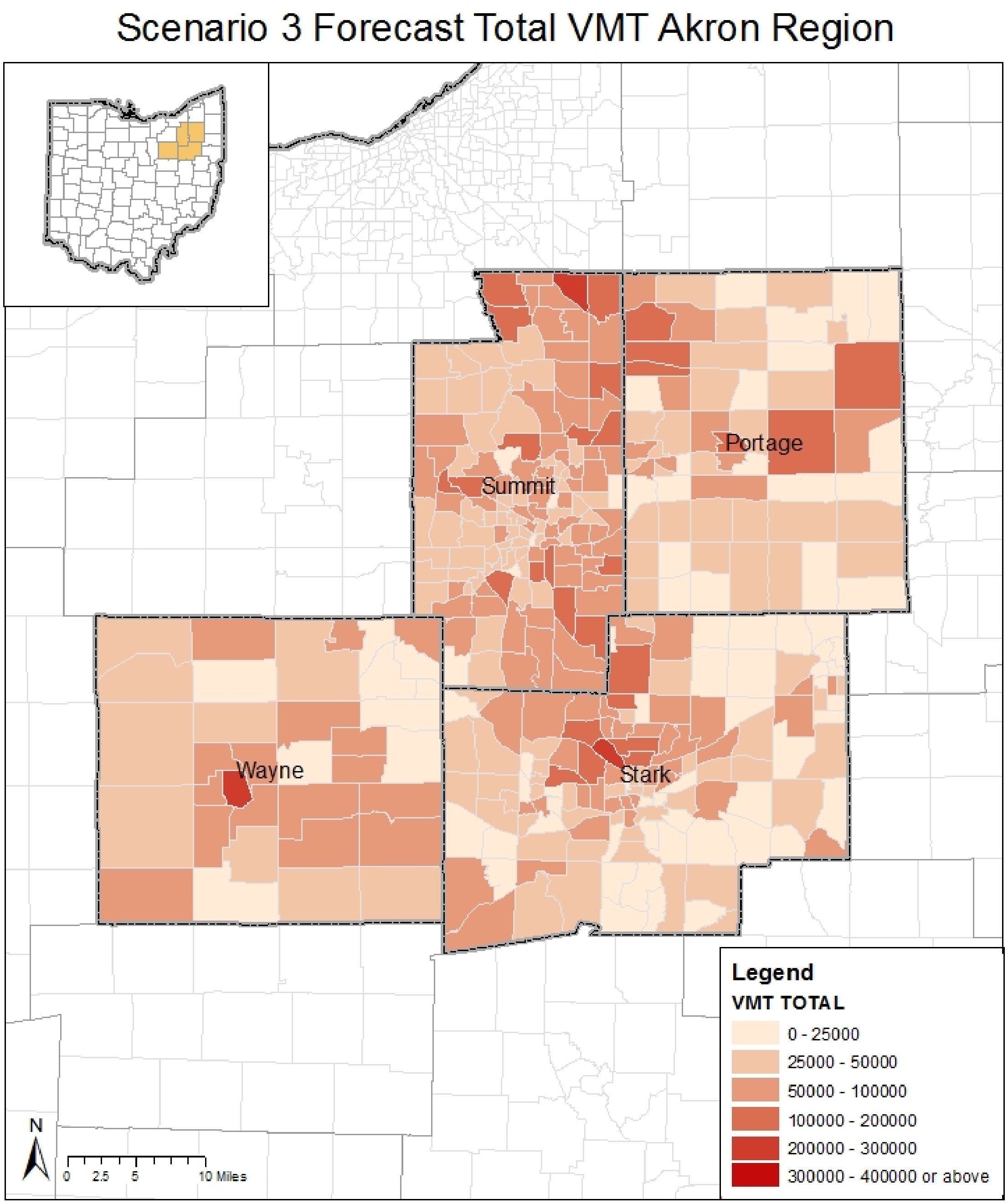

Figure 18: Scenario 3 VMT Forecast Akron

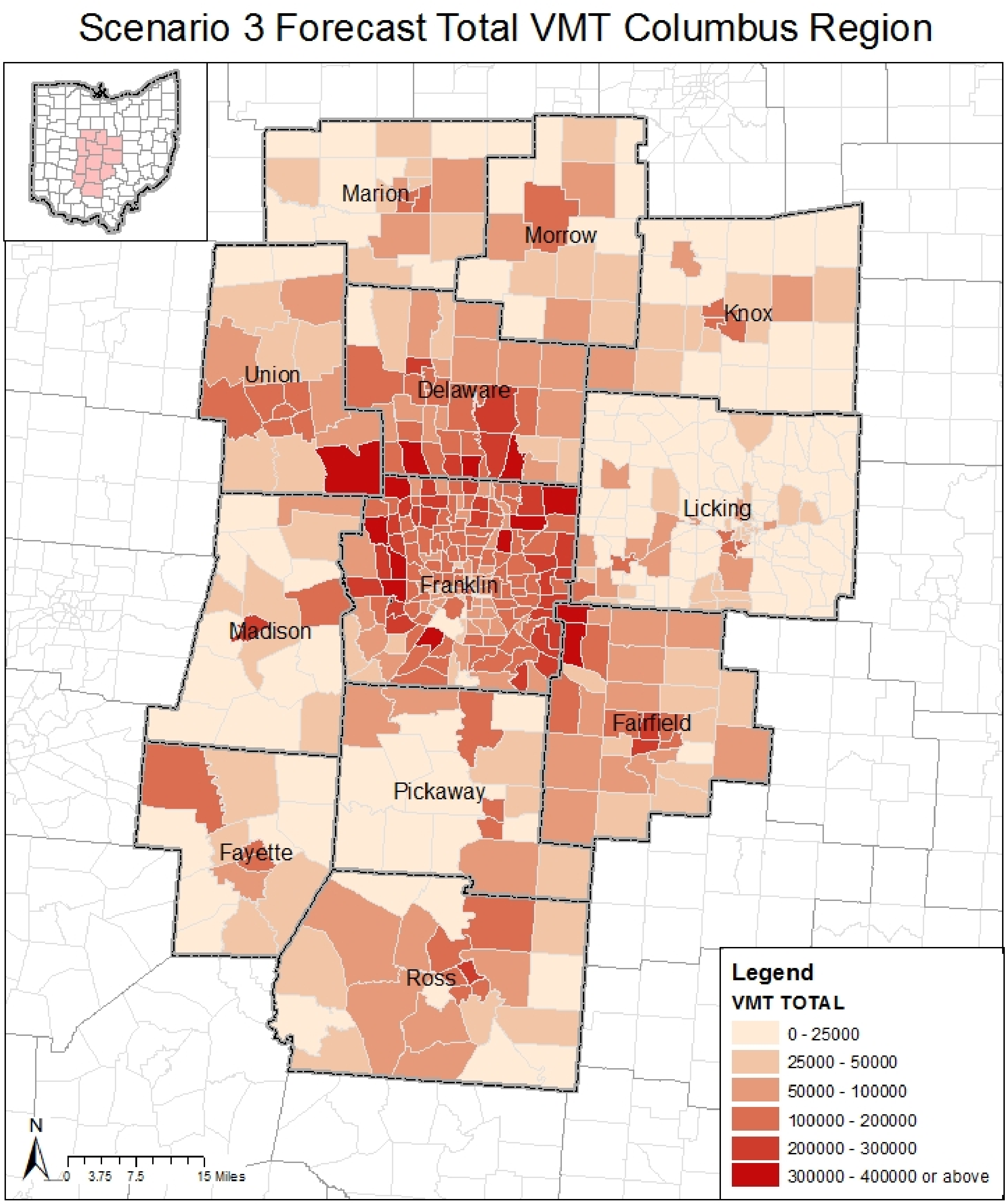

Figure 19: Scenario 3 VMT Forecast Columbus

6. CONCLUSIONS

In the previous project funded by ODOT, the PIs developed a *Regional Land-use Allocation Decision Analysis Tool,* which would enable decision makers quantify the impacts population and employment distribution and the resulting VMT. This tool includes two main components: Land Allocation Component and Transportation Component. The model uses information concerning infrastructure availability (accessibility, sewer, water services), current land-use policies where available, and environmental constraints to allocate regional and county forecasts of population and employment to 40 acre cells in each metropolitan region of Ohio. This study adds two critical components to this model*:* vehicle choice and a better understanding of the impacts of declines in population and employment. The model can forecast the changes in VMT by passenger cars and passenger trucks under changing land-use characteristics. The outputs of the revised land-allocation tool provide population and employment distribution to forecast auto trips, vehicle type distribution and trip distances at the TAZ level for each future scenario.

Three different land allocation scenarios and their impacts on the resulting VMT by two vehicle types are analyzed using this model. The scenarios are constructed to illustrate how differences in assumptions about land use intensity, the location of future land use and job growth, and the interactions with transit availability could impact auto trip rates, vehicle type distribution, trip distances and VMT.

The base case scenario assumes that the population growth and decline in Ohio's metropolitan areas will continue to follow historical trends. The results reveal that much larger decreases in the number of auto trips, VMT and VMT by vehicle type are forecasted for all regions where there is an overall decline in jobs and households. For Columbus, a large increase in the number of auto trips and VMT is projected reflecting both the increased growth in the region and the continuation of trends of low density urban sprawl.

The second scenario assumes that areas close to the centroids of all existing municipalities in the region are more likely to grow. This represents a possible return of population to urban centers and sub-centers but maintains a split between central city and suburban city development. We found that the changing trend of the number of auto trips and VMT across the metropolitan regions are similar to the base case. The total VMT only slightly increases under this scenario with respect to the base case.

The third scenario is based on the possibility that people will move back into the central counties of each region due to rising commuting costs and redeveloping central communities. In this scenario, changes are only made to the allocation of households. With the exception of the Akron region, the total VMT and VMT by passenger truck decline as there are more people in the central county with areas of higher population density and the availability of public transit.

These scenarios illustrate how different land-use development patterns and transportation facilities result in different travel trends within Ohio's metropolitan areas. The results are beneficial for understanding the relationships between land use and travel behavior. These results and outputs of other potential scenarios can provide insightful information for developing land-use and transportation policies.

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APPENDIX A: CONSIDERED MODELS FOR LAND ALLOCATION COMPONENT

This appendix provides a description of the considered models and the reasons why they were not selected. It includes two linear regression models, one multinomial logistic regression model, and one ordered logistic regression model.

There are two ways to classify the arbitrary nine groups of the four models according to different dependent variables. Table A- 1 is from the population percentage changes, and Table A- 2 is from the absolute population change. Both are classifying the number of census tracts for the 11 metropolitan areas, but exclude extreme cases as group -5 and 5. As shown in Figure A- 1, the variations are too broad to perform the analysis. From -6.9% to 247,000%, most data falls into the area near 0.

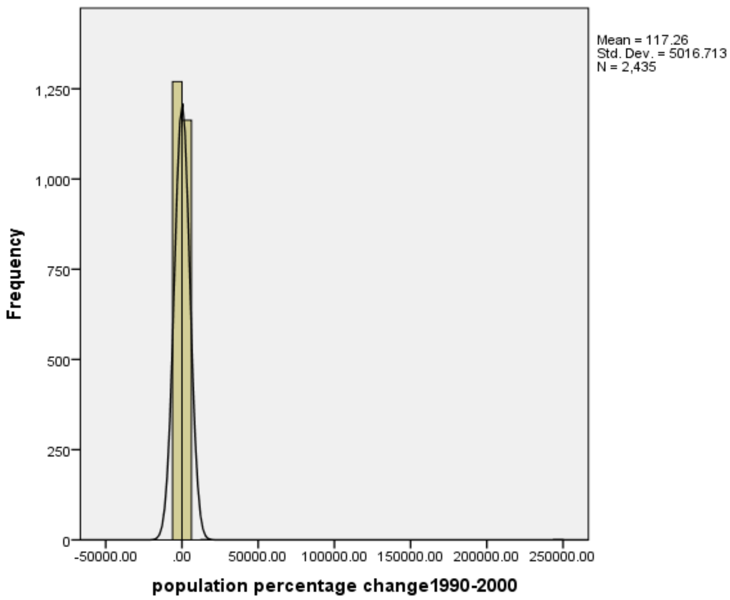

Figure A- 1: Distribution of Population Percentage Changes at the Census Tract level

Table A- 1: Distribution of the Population Percentage Change Groups

Groups	N	Mean	Minimum	Maximum	Std. Deviation
-5	3	-86.5802	-96.88	-78.55	9.37183
-4	87	-26.5475	-49.93	-20.05	6.31872
-3	289	-13.4843	-19.92	-10.02	2.63251
-2	716	-5.6609	-9.99	-2.00	2.17511
-1	175	-1.0123	-1.99	-.02	.55818
0	7	0.0000	0.00	0.00	0.00000
1	159	.9075	.02	2.00	.57988
2	375	5.5007	2.01	9.98	2.30484
3	485	22.7674	10.06	49.72	10.37370
4	72	67.0435	50.02	97.36	13.54035
5	67	4151.5132	100.25	247000.00	30185.13388
Total	2435	117.2612	-96.88	247000.00	5016.71331

Table A- 2: Distribution of the Absolute Population Change Groups

Groups	N	Mean	Minimum	Maximum	Std. Deviation
-4	8	-2271.7500	-3299.00	-1549.00	638.76147
-3	24	-1188.9167	-1452.00	-1011.00	147.02023
-2	150	-663.9267	-989.00	-500.00	134.81601
-1	1088	-207.1654	-499.00	-1.00	128.82114
0	7	.0000	.00	.00	.00000
1	680	203.7044	1.00	500.00	147.63182
2	240	723.1250	502.00	998.00	141.11161
3	98	1219.3673	1002.00	1500.00	149.04371
4	140	2458.3500	1506.00	6065.00	920.30771
Total	2435	165.9314	-3299.00	6065.00	766.50241

The analysis below shows the first model using population percentage changes and the rest use absolute population changes as dependent variable.

A1. Linear Regression Model with a Dependent Variable as Population Percentage Changes

This model has six independent variables that are significant. Above all, the R-squared value, as shown in Table A- 3, is 0.37. This shows that the model has a lower explanatory power as compared to the final model. New housing units are the most influential factor for population percentage changes. As shown in Table A- 4, 36.6% of 2345 units are correctly predicted, which is less than other models.

Table A- 3: The Result of OLS with a Dependent Variable as Population Percentage Changes

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	10.151	1.688		6.015	.000
% of total housing units built within 5 yrs	.825	.035	.428	23.561	.000
% of unemployed workers	-.341	.063	-.119	-5.392	.000
% of persons working within their county of residence	-13.015	1.657	-.143	-7.856	.000
The number of intersections	.012	.002	.103	5.831	.000
% of African American population	-.064	.015	-.094	-4.194	.000
% of persons who are 65+ years old	-9.426	5.177	-.031	-1.821	.069
No. of Obs	2365				
R^2	0.413				
SE of Estimate	13.8915				

Dependent Variable: population percentage changes 1990-2000

Table A- 4: Observed vs. Predicted Results from OLS with Population Percentage Changes

		Predicted Population Change from Regression								Total
		-4	-3	-2	-1	1	2	3	4	
Actual Change Groups	-4	4	43	25	4	1	5	5	0	87
	-3	4	72	157	18	9	16	13	0	289
	-2	0	46	319	115	71	125	40	0	716
	-1	1	3	67	22	18	42	22	0	175
	0	0	0	2	0	0	5	0	0	7
	1	1	4	50	13	13	59	19	0	159
	2	0	7	80	18	14	152	103	1	375
	3	1	2	32	14	17	133	284	2	485
	4	0	0	1	0	2	9	59	1	72
Total		11	177	733	204	145	546	545	4	2365

A2. Linear Regression Model with a Dependent Variable as Absolute Population Changes without Regional Dummies

This model shows the base case of the final model. It does not include regional dummies, but the model has nearly similar power of explanation. The coefficients and the comparison of observed and predicted values are comparable to the final model.

Table A- 5: The Result of Linear Regression without Regional Dummies

Model	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	t	Sig.
(Constant)	444.292	75.848		5.92	.000
1990 Total population	-.139	.009	-.251	-15.519	.000
the number of junctions	1.507	.089	.354	16.905	.000
1990 % new housing units built within 5yrs	28.13	1.458	.353	19.293	.000
1990 % old housing units built over 50 yrs	-1.029	.635	-.038	-1.621	0.105
1990 % African American population	-2.013	.623	-.086	-3.232	.001
1990 % vacant housing units	-8.47	2.672	-.057	-3.17	.002
1990 JOB-POP index 15 mins	3.045	0.599	.077	5.087	.000
1990 % unemployed workers	-10.256	2.914	-.063	-3.519	.009
1990 % workers within their county of residence	-3.021	.677	-.083	-4.464	.000
1990 % old population	-6.076	2.095	-.039	-2.9	.004
No. of Obs	2435				
R^2	0.462				
SE of Estimate	565.384				

Dependent Variable: population difference 2000-1990

Table A- 6: Observed vs. Predicted Results from OLS without Regional Dummies

		Predicted Population Change from Regression							Total
		-3	-2	-1	1	2	3	4	
Actual change group	-4	0	2	3	3	0	0	0	8
	-3	0	9	12	0	2	0	1	24
	-2	0	39	88	16	7	0	0	150
	-1	0	66	664	313	40	5	0	1088
	0	0	0	1	6	0	0	0	7
	1	1	8	179	346	115	23	8	680
	2	0	1	14	101	86	28	10	240
	3	0	0	4	31	36	18	9	98
	4	0	0	3	16	38	42	41	140
Total		1	125	968	832	324	116	69	2435

A3. Multinomial Logistic Regression Model (MLM)

We disregarded the below multinomial logistic model since many variables were not significant. The base outcome of the below model is the tracts with severe decline.

Table A- 7: The Result of MLM

Multinomial logistic regression					Number of obs =2435
					LR chi2(72) = 1834.29
					Prob > chi2 = 0
Log likelihood = -2713.1981					Pseudo R2 =0.2526
Groups	Variables	Coef.	Std.Err.	z	P>|z|
-4	(base outcome)				
-3	Pop9	-0.001	0.001	-1.31	0.192
	Intersections	0.004	0.006	0.72	0.474
	Bltyr9pro_5	0.136	0.104	1.3	0.193
	Bltyr9pro	-0.056	0.031	-1.8	0.071
	BLK1990	-0.025	0.020	-1.26	0.208
	Vac9pro	0.029	0.101	0.29	0.774
	UNEMPRT1990	-0.029	0.069	-0.42	0.673
	WRCNTY1990	0.102	0.035	2.97	0.003
	OLD1990	0.273	0.133	2.05	0.041
	_cons	-3.709	2.976	-1.25	0.213
-2	Pop9	-0.001	0.000	-2.15	0.031
	Intersections	0.003	0.005	0.61	0.539
	Bltyr9pro_5	0.039	0.102	0.38	0.704
	Bltyr9pro	-0.052	0.029	-1.77	0.076
	BLK1990	-0.034	0.018	-1.89	0.059
	Vac9pro	0.007	0.097	0.07	0.943
	UNEMPRT1990	-0.087	0.066	-1.32	0.187
	WRCNTY1990	0.116	0.032	3.61	0.000
	OLD1990	0.256	0.127	2.02	0.044
	_cons	0.823	2.495	0.33	0.741
-1	Pop9	-0.002	0.000	-3.76	0.000
	Intersections	0.004	0.005	0.7	0.487
	Bltyr9pro_5	-0.002	0.101	-0.02	0.984
	Bltyr9pro	-0.063	0.029	-2.14	0.032
	BLK1990	-0.054	0.018	-2.97	0.003
	Vac9pro	-0.068	0.097	-0.7	0.482
	UNEMPRT1990	-0.096	0.066	-1.46	0.143
	WRCNTY1990	0.120	0.032	3.81	0.000
	OLD1990	0.337	0.127	2.66	0.008
	_cons	6.183	2.404	2.57	0.010
0	Pop9	-0.002	0.001	-3.82	0.000
	Intersections	0.008	0.006	1.43	0.153

	Bltyr9pro_5	-0.025	0.146	-0.17	0.863
	Bltyr9pro	-0.046	0.035	-1.28	0.199
	BLK1990	-0.084	0.041	-2.03	0.042
	Vac9pro	-0.127	0.171	-0.74	0.460
	UNEMPRT1990	-0.117	0.134	-0.88	0.380
	WRCNTY1990	0.112	0.038	2.95	0.003
	OLD1990	0.139	0.160	0.87	0.386
	_cons	4.959	3.292	1.51	0.132
1	Pop9	-0.002	0.000	-4.32	0.000
	Intersections	0.007	0.005	1.37	0.171
	Bltyr9pro_5	0.098	0.101	0.97	0.331
	Bltyr9pro	-0.064	0.030	-2.16	0.031
	BLK1990	-0.063	0.018	-3.4	0.001
	Vac9pro	-0.056	0.098	-0.57	0.569
	UNEMPRT1990	-0.131	0.067	-1.94	0.052
	WRCNTY1990	0.110	0.032	3.48	0.001
	OLD1990	0.316	0.127	2.49	0.013
	_cons	6.953	2.406	2.89	0.004
2	Pop9	-0.002	0.000	-4.33	0.000
	Intersections	0.009	0.005	1.78	0.074
	Bltyr9pro_5	0.142	0.101	1.4	0.161
	Bltyr9pro	-0.081	0.030	-2.69	0.007
	BLK1990	-0.060	0.020	-3.06	0.002
	Vac9pro	-0.074	0.099	-0.75	0.455
	UNEMPRT1990	-0.212	0.076	-2.8	0.005
	WRCNTY1990	0.107	0.032	3.38	0.001
	OLD1990	0.270	0.128	2.11	0.035
	_cons	6.438	2.424	2.66	0.008
3	Pop9	-0.002	0.000	-4.27	0.000
	Intersections	0.010	0.005	1.82	0.069
	Bltyr9pro_5	0.160	0.101	1.58	0.114
	Bltyr9pro	-0.118	0.033	-3.59	0.000
	BLK1990	-0.108	0.035	-3.07	0.002
	Vac9pro	-0.083	0.102	-0.82	0.413
	UNEMPRT1990	-0.170	0.096	-1.78	0.075
	WRCNTY1990	0.100	0.032	3.16	0.002
	OLD1990	0.278	0.129	2.15	0.032
	_cons	5.827	2.472	2.36	0.018
4	Pop9	-0.003	0.000	-5.11	0.000
	Intersections	0.014	0.005	2.59	0.010
	Bltyr9pro_5	0.170	0.101	1.68	0.092
	Bltyr9pro	-0.128	0.033	-3.92	0.000
	BLK1990	-0.043	0.021	-2.07	0.039
	Vac9pro	-0.116	0.101	-1.14	0.253
	UNEMPRT1990	-0.193	0.090	-2.14	0.033
	WRCNTY1990	0.098	0.032	3.08	0.002

OLD1990	0.244	0.130	1.88	0.060
_cons	6.584	2.447	2.69	0.007

A4. Ordered Logistic Regression Model (OLM)

The ordered logistic regression model is significant with 9 independent variables.

Table A- 8: The Result of OLM

Ordered logistic regression			Number of obs =	2435
			LR chi2(9) =	1470.85
			Prob > chi2 =	0.0000
Log likelihood = -2894.9214			Pseudo R2 =	0.2026
Variables	Coef.	Std. Err	z	P>|z|
Pop9	-0.00044	3.29E-05	-13.48	0.000
Intersections	0.004153	0.000319	13.02	0.000
Bltyr9pro_5	0.089374	0.005767	15.5	0.000
Bltyr9pro	-0.00836	0.002302	-3.63	0.000
BLK1990	-0.01126	0.0023	-4.9	0.000
Vac9pro	-0.0297	0.009108	-3.26	0.001
UNEMPRT1990	-0.04412	0.010813	-4.08	0.000
WRCNTY1990	-0.00958	0.002376	-4.03	0.000
OLD1990	-0.02005	0.007432	-2.7	0.007
/cut1	-8.83403	0.458936	-9.73353	-7.93453
/cut2	-7.39789	0.339728	-8.06375	-6.73204
/cut3	-5.42288	0.293523	-5.99818	-4.84759
/cut4	-1.95423	0.266391	-2.47635	-1.43211
/cut5	-1.93668	0.266333	-2.45869	-1.41468
/cut6	0.121915	0.264694	-0.39688	0.640705
/cut7	1.374572	0.273185	0.839139	1.910006
/cut8	2.216858	0.283214	1.661768	2.771947

Positive coefficients indicate that higher values on the explanatory variables make it more likely that the census tracts will be in a higher (growth) category, while negative coefficients indicate otherwise.

Unemployment, old housing, African American population and aging population in 1990 have negative effects on population change. Housing units built within 5 years and intersections are positively supportive of population changes.

Ordered logistic regression assumes that the relationship between each pair of outcome groups is the same. This is called the proportional odds assumption, and can be tested by the Brant test. In our case, the Brant test indicated that the parallel assumptions were violated. The test indicates that the influence of aging population, new or old housing units are not proportional across each population change category.

Table A- 9: The Result of Brant Test

Variable	chi2	p>chi2
All	-1142.92	1.000
Pop9	76.36	0.000
Intersections	21.02	0.004
Bltyr9pro_5	63.35	0.000
Bltyr9pro	25.24	0.001
BLK1990	25.24	0.001
Vac9pro	16.14	0.024
UNEMPRT1990	4.66	0.702
WRCNTY1990	18.25	0.011
OLD1990	45.74	0.000

The table below shows the prediction results of the OLM. This model predicted 55% of the tracts correctly. The majority of errors appear in the growth areas and this model is hardly predicted the severe population decline areas.

Table A- 10: Observed vs. Predicted Results from OLM

		Predicted change groups from OLM					Total
		-2	-1	1	2	4	
Actual Change Groups	-4	2	3	3	0	0	8
	-3	2	19	2	0	1	24
	-2	1	132	17	0	0	150
	-1	4	933	147	2	2	1,088
	0	0	3	4	0	0	7
	1	1	305	335	20	19	680
	2	0	35	161	17	27	240
	3	0	9	59	9	21	98
	4	0	7	48	16	69	140
	Total	10	1,446	776	64	139	2,435

APPENDIX B: VEHICLE CHOICE COMPONENT

B1. Experimental Outputs of 2010 Motor Vehicle Emission Simulator (MOVES)

This section includes tables for the test outputs based on the 2010 Motor Vehicle Emission Simulator (MOVES) from Environmental Protection Agency (EPA). These test results are the basis for using 8 years as the cut-point for vehicle vintage in this study.

Table B- 1: Years 0 to 5

test_0yearold		*test_5yearold*	
Mean	0.0938	Mean	0.0990
Standard Error	0.0010	Standard Error	0.0010
Median	0.0031	Median	0.0032
Mode	0.0000	Mode	0.0000
Standard Deviation	0.4551	Standard Deviation	0.4574
Sample Variance	0.2072	Sample Variance	0.2093
Kurtosis	157.1052	Kurtosis	153.4417
Skewness	11.3677	Skewness	11.1860
Range	7.9164	Range	7.9164
Minimum	0.0000	Minimum	0.0000
Maximum	7.9164	Maximum	7.9164
Sum	20172.3105	Sum	21288.1770
Count	215040.0000	Count	215040.0000
Confidence Level (95.0%)	0.0019	Confidence Level (95.0%)	0.0019

Table B- 2: Years 7 to 8

Test_7yearold		*Test_8Yearold*	
Mean	0.1197	Mean	0.1459
Standard Error	0.0010	Standard Error	0.0013
Median	0.0033	Median	0.0057
Mode	0.0000	Mode	0.0000
Standard Deviation	0.4723	Standard Deviation	0.6034
Sample Variance	0.2231	Sample Variance	0.3641
Kurtosis	133.5078	Kurtosis	117.2169
Skewness	10.2282	Skewness	9.8028
Range	7.9164	Range	8.9358
Minimum	0.0000	Minimum	0.0000
Maximum	7.9164	Maximum	8.9358
Sum	25750.7222	Sum	31383.7645
Count	215040.0000	Count	215040.0000
Confidence Level (95.0%)	0.0020	Confidence Level (95.0%)	0.0026

Table B- 3: Years 9 to 10

Test_9Yearold		*Test_10yearold*	
Mean	0.5547	Mean	0.5635
Standard Error	0.0031	Standard Error	0.0031
Median	0.0216	Median	0.0257
Mode	0.0000	Mode	0.0000
Standard Deviation	1.4338	Standard Deviation	1.4501
Sample Variance	2.0557	Sample Variance	2.1029
Kurtosis	23.6673	Kurtosis	23.7114
Skewness	4.6167	Skewness	4.6183
Range	10.5083	Range	11.4969
Minimum	0.0000	Minimum	0.0000
Maximum	10.5083	Maximum	11.4969
Sum	119291.4933	Sum	121170.0649
Count	215040.0000	Count	215040.0000
Confidence Level (95.0%)	0.0061	Confidence Level (95.0%)	0.0061

B2. Vehicle Choice Models – Discrete Choice

Tables in this section present the variables, descriptive statistics and model results for three types of discrete choice models on vehicle types. The explanatory power of these models is very low.

Table B- 4: Variable definitions for Discrete Vehicle Choice Models

Variable name	Explanation	Source
Age	Age of primary driver (age groups)	Household Travel Surveys
Female	Dummy variable. (1, if the primary driver is female)	Household Travel Surveys
Employee	Dummy variable. (1, if primary driver is employed)	Household Travel Surveys
Household with children	Dummy variable. (1 if HH of primary driver has children)	Household Travel Surveys
Household with retiree	Dummy variable. (1 if HH of primary driver has retiree)	Household Travel Surveys
Household size	Household size of the primary driver	Household Travel Surveys
Vehicles per drive	Number of vehicles per driver at the household level	Household Travel Surveys
HH Income	Household income (in 10k)	Household Travel Surveys
HH Income^2	Household income squared (in 10k)	Household Travel Surveys
Transit availability	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Household density	Number of households divided by the TAZ area	2010 Census/ divide by area
All non-retail employment density	Number of all non-retail jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained above.	needs to be calculated
% bachelor	% of population (over 25) with at least bachelor degree at TAZ	2006-2010 ACS 5-year estimate
Cincinnati	1 if the residential TAZ locates in Cincinnati	Metropolitan boundary

Table B- 5: Descriptive Statistics of the Estimation Sample - Discrete Vehicle Choice Models

	Mean	Std. Dev.
Age	52.64	15.91
Female	0.51	0.50
Employee	0.64	0.48
Household with children	0.29	0.45
Household with retiree	0.13	0.33
Household size	2.61	1.31
Vehicles per drive	1.16	0.48
HH Income (10k)	5.72	1.91
HH Income^2 (10k)	36.31	19.97
Transit availability (binary variable)	0.58	0.49
Household density	1387.46	1291.72
All non-retail employment density	1020.01	3749.25
JOB_HH	0.84	0.13
% bachelor	31.06	17.313
Cincinnati	0.28	0.45
Sample size	9149	

Table B- 6: Binary Logit Vehicle Choice Model (Car VS Truck)

Dependent variable= Dummy-1 if vehicle is car		
	Coefficient	z stat.
Constant	1.037895	3.23
Socio-Demographics		
Age (36 to 50 years is the base case)		
17 to 22 years	1.210637	10.22
23 to 35 years	0.5900291	7.04
51 to 65 years	0.0599324	0.96
Over 65 years	0.2528572	2.88
Female	0.210002	4.75
Employee	0.2129812	3.78
Household with children	-0.2090276	-2.83
Household with retiree	0.1894775	2.18
Household size	-0.1540033	-5.86
Vehicles per drive	-0.20084	-4.29
HH Income	-0.3567224	-3.33
HH Income^2	0.028986	2.85
Transit Accessibility		
Transit availability (binary variable)	0.2342018	4.35
Residential Location Characteristics		
Household density	0.0000567	2.53
All non-retail employment density	0.0000121	1.33
JOB_HH	0.3237994	1.66
% bachelor	0.0031149	2.19
Cincinnati	-0.0277263	-0.50
Number of observations	9149	
Log Likelihood	-5926.4549	
Pseudo R^2	0.0402	

Table B- 7: Multinomial Logit Model (Base case: Old Car)

Variable	New car		New truck		Old truck	
	Coefficient.	z stat.	Coefficient	z stat.	Coefficient	z stat.
Constant	-1.202229	-2.96	-2.748591	-5.62	-.8414312	-2.02
Socio-Demographics						
Age (36 to 50 years is the base case)						
17 to 22 years	-0.7016369	-5.16	-2.29483	-10.74	-1.00212	-7.07
23 to 35 years	0.0199287	0.19	-0.4828727	-4.08	-0.6564967	-5.66
51 to 65 years	0.0903752	1.07	-0.0842889	-0.93	0.0630813	0.73
Over 65 years	0.2944638	2.62	-0.0592902	-0.47	-0.1389819	-1.14
Female	0.24094	4.25	0.2509262	3.92	-0.413252	-6.74
Employee	0.2937217	3.98	-0.0614143	-0.75	-0.0863083	-1.14
HH with Children	0.0148108	0.15	0.2752279	2.58	0.1770514	1.76
HH with retiree	0.0105364	0.10	-0.1596556	-1.26	-0.2070376	-1.75
HH size	-0.1204208	-3.44	0.0234762	0.62	0.1614247	4.63
Vehicles per driver	-0.4683707	-6.94	-0.313906	-4.31	0.2145665	3.68
HH income	0.3433629	2.56	0.7320436	4.48	0.4149549	2.97
HH income2	-0.0126143	-0.99	-0.0391499	-2.56	-0.0388046	-2.89
Transit Accessibility						
Transit availability (binary variable)	-0.1896725	-2.79	-0.386049	-4.98	-0.2837555	-3.82
Residential Location Characteristics						
Household density	-0.000053	-2.06	-0.000114	-3.52	-0.000051	-1.69
All non-retail employment density	2.37e-06	0.35	-4.30e-06	-0.39	-0.000018	-1.33
JOB_HH	0.2524818	0.99	0.2107961	0.74	-0.5625628	-2.17
% bachelor	0.007672	4.31	0.0066023	3.25	-0.0054525	-2.74
Cincinnati	-0.7621319	-10.28	-0.7668065	-9.27	0.0683558	0.92
No. of Obs.	9149					
Log likelihood:	-11734.493					
Pseudo R^2:	0.0616					

Table B- 8: Multinomial Logit Model (Base case: Passenger Car)

Variable	SUV		Pickup Truck		Van	
	Coefficient.	z stat.	Coefficient	z stat.	Coefficient	z stat.
Constant	-1.745023	-4.26	-2.265558	-4.02	-2.886106	-5.56
Socio-Demographics						
Age (36 to 50 years is the base case)						
17 to 22 years	-1.096856	-7.25	-0.9192356	-4.34	-1.647039	-7.42
23 to 35 years	-0.559553	-5.35	-0.496413	-3.22	-0.7385133	-5.22
51 to 65 years	-0.1403043	-1.83	-0.0350694	-0.32	0.1374948	1.36
Over 65 years	-0.4545528	-4.11	-0.1374587	-0.90	0.0926027	0.64
Female	0.165356	3.00	-1.920644	-18.44	0.2227505	3.04
Employee	-0.1209584	-1.71	-0.0290039	-0.28	-0.4990203	-5.69
HH with Children	0.181939	1.98	-0.0585313	-0.44	0.527794	4.55
HH with retiree	-0.1180968	-1.05	-0.211145	-1.38	-0.2469663	-1.70
HH size	0.0009824	0.03	0.1656846	3.50	0.3827964	9.95
Vehicles per driver	-0.0890067	-1.38	0.4995395	7.51	0.3143504	4.09
HH income	0.335218	2.44	0.8014354	4.21	0.0766379	0.44
HH income2	-0.0193812	-1.50	-0.0841832	-4.67	-0.0081691	-0.49
Transit Accessibility						
Transit availability (binary variable)	-0.1199706	-1.86	-0.7502729	-7.79	-0.1410797	-1.62
Residential Location Characteristics						
Household density	-0.0000768	-2.79	8.78e-06	0.21	-0.0000271	-0.72
All non-retail employment density	-3.34e-06	-0.39	-0.0000607	-1.89	-0.0000245	-1.11
JOB_HH	-0.038179	-0.16	-1.202052	-3.73	-0.2542859	-0.81
Cincinnati	-0.1288649	-1.87	0.1838399	1.96	0.1233553	1.39
No. of Obs.	9149					
Log likelihood:	9267.4673					
Pseudo R^2:	0.0734					

B3. Vehicle Distribution Model – OLS Regression (Two Vehicle Types) (Cincinnati & Cleveland)

This section presents the variables, descriptive statistics and estimated results of vehicle distribution model (two vehicle types: passenger car and passenger car) for the samples of **Cincinnati and Cleveland** together. The dependent variable is the percentage of passenger cars.

Table B- 9: Variable definitions for Vehicle Distribution Model at the TAZ level

Variable name	Explanation	Source
Household density	Number of households divided by the TAZ area	2010 Census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained above.	needs to be calculated
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Housing Median Age	Median age of housing unit at TAZ	2006-2010 ACS 5-year estimate
% white	Median household income at TAZ	2006-2010 ACS 5-year estimate

Table B- 10: Descriptive Statistics of the Estimation Sample - Vehicle Distribution Model

	Mean	Std. Dev.
Household density	1271.47	1272.87
Employment density	2128.01	9494.75
JOB_HH	0.81	0.14
Transit availability (binary variable)	0.56	0.50
Housing Median Age	44.87	16.75
% white	75.44	28.27
Sample size	760	

Table B- 11: Vehicle Distribution Model (Cincinnati & Cleveland)

Dependent variable= % of Passenger Car		
	Coefficient	t stat.
Household density	.0021911	2.34
Employment density	.0001232	1.28
JOB_HH	10.05377	1.56
Transit availability (binary variable)	6.209325	2.80
Housing Median Age	-.1008649	-1.41
% white	-.1200263	-3.19
Constant	58.43832	8.34
Number of observations	760	
R^2	0.0758	
Adjusted R^2	0.0685	

B4. Vehicle Distribution Models – OLS Regression (Four Vehicle Types) (Cincinnati & Cleveland)

This section presents the variables, descriptive statistics and estimated results of four vehicle distribution models (new car, old car, new truck and old truck) for the samples of **Cincinnati and Cleveland** together. The dependent variable is the percentage of each vehicle type.

Table B- 12: Variable definitions for Vehicle Distribution Models at the TAZ level

Variable name	Explanation	Source
Model 1: Percentage of new car		
Household density	Number of households divided by the TAZ area	2010 Census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained above.	needs to be calculated
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Housing Median Age	Median age of housing unit at TAZ	2006-2010 ACS 5-year estimate
Household income	Median household income at TAZ	2006-2010 ACS 5-year estimate
Cincinnati	1 if the TAZ locates in Cincinnati	Metropolitan boundary
Model 2: Percentage of old car		
Household density	Number of households divided by the TAZ area	2010 Census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Median age of POP	Median population age at TAZ	2010 Census
% workers by private vehicle	% of workers using private vehicle for commuting at TAZ	2006-2010 ACS 5-year estimate
Cincinnati	1 if the TAZ locates in Cincinnati	Metropolitan boundary
Model 3: Percentage of new truck		
Household density	Number of households divided by the TAZ area	2010 Census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area

Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Median age of POP	Median population age at TAZ	2010 Census
Cincinnati	1 if the TAZ locates in Cincinnati	Metropolitan boundary
<u>Model 4: Percentage of old truck</u>		
Household density	Number of households divided by the TAZ area	2010 Census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained above.	needs to be calculated
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Housing Median Age	Median age of housing unit at TAZ	2006-2010 ACS 5-year estimate
Housing median value	Median housing value at TAZ	2006-2010 ACS 5-year estimate
Cincinnati	1 if the TAZ locates in Cincinnati	Metropolitan boundary

Table B- 13: Descriptive Statistics of the Estimation Sample - Vehicle Distribution Models

	Mean	Std. Dev.
Household density	1271.47	1272.87
Employment density	2128.01	9494.75
JOB_HH	0.81	0.14
Transit availability (binary variable)	0.56	0.50
Housing Median Age	44.87	16.75
Household income	58247.38	26545.00
Household income^2	4.10E+09	4.26E+09
Median age of POP	37.80	8.54
% workers by private vehicle	88.64	10.18
Housing Median Age	44.87	16.75
Housing median value	170751.6	87491.28
Cincinnati	0.45	0.50
Sample size	760	

Table B- 14: Vehicle Distribution Model 1 (Cincinnati & Cleveland)

Dependent variable= % of New Car		
	Coefficient	t stat.
Household density	0.002326	2.74
Employment density	0.000148	1.72
JOB_HH	10.03964	1.65
Transit availability (binary variable)	6.265661	3.23
Housing Median Age	-0.34725	-4.92
Household income	0.0002	1.94
Household income^2	-8.61E-10	-1.47
Cincinnati	-8.33363	-4.96
Constant	22.33082	2.87
Number of observations	760	
R^2	0.1000	
Adjusted R^2	0.0904	

Table B- 15: Vehicle Distribution Model 2 (Cincinnati & Cleveland)

Dependent variable= % of Old Car		
	Coefficient	t stat.
Household density	0.001777	2.04
Employment density	-0.00027	-2.53
Transit availability (binary variable)	3.134913	1.47
Median age of POP	-0.28977	-2.42
% workers by private vehicle	-0.40495	-3.53
Cincinnati	6.865507	3.8
Constant	73.76634	7.21
Number of observations	760	
R^2	0.0876	
Adjusted R^2	0.0804	

Table B- 16: Vehicle Distribution Model 3 (Cincinnati & Cleveland)

Dependent variable= % of New Truck		
	Coefficient	t stat.
Household density	-0.00131	-2.1
Employment density	0.000126	1.69
Transit availability (binary variable)	-4.35237	-2.82
Median age of POP	0.340908	4.16
Cincinnati	-6.36722	-4.82
Constant	11.58394	3.22
Number of observations	760	
R^2	0.0851	
Adjusted R^2	0.0791	

Table B- 17: Vehicle Distribution Model 4 (Cincinnati & Cleveland)

Dependent variable= % of Old Truck		
	Coefficient	t stat.
Household density	-0.00183	-2.15
Employment density	-0.00013	-1.53
JOB_HH	-7.79555	-1.28
Transit availability (binary variable)	-3.21041	-1.65
Housing Median Age	0.093254	1.42
Housing median value	-2.1E-05	-2.18
Cincinnati	7.310603	4.35
Constant	29.56584	4.39
Number of observations	760	
R^2	0.0588	
Adjusted R^2	0.0501	

B5. Vehicle Distribution Models – OLS Regression (Four Vehicle Types) (Cleveland)

This section presents the variables, descriptive statistics and estimated results of four vehicle distribution models (new car, old car, new truck and old truck) for the sample of **Cleveland**. The dependent variable is the percentage of each vehicle type. As compared to the models using both the samples of Cincinnati and Cleveland together, the results using only Cleveland sample are better in terms of explanatory power and the significance of variables.

Table B- 18: Variable definitions for Vehicle Distribution Models at the TAZ level

Variable name	Explanation	Source
Model 1: Percentage of new car		
Household density	Number of households divided by the TAZ area	2010 census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained below.	needs to be calculated
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Housing Median Age	Median age of housing unit at TAZ	2006-2010 ACS 5-year estimate
% white	% of white population at TAZ	2010 Census
Household income	Median household income at TAZ	2006-2010 ACS 5-year estimate
% family w/children	% of family with children at TAZ	2010 Census
% female	% of female population at TAZ	2010 Census
Model 2: Percentage of old car		
Household density	Number of households divided by the TAZ area	2010 census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained below.	needs to be calculated
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Housing Median Age	Median age of housing unit at TAZ	2006-2010 ACS 5-year

		estimate
Household income	Median household income at TAZ	2006-2010 ACS 5-year estimate
<u>Model 3: Percentage of new truck</u>		
Household density	Number of households divided by the TAZ area	2010 census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Household size	Average household size at TAZ	2010 Census
% white	% of white population at TAZ	2010 Census
% bachelor	% of population (over 25) with at least bachelor degree at TAZ	2006-2010 ACS 5-year estimate
% single-parent	% of single-parent households at TAZ	2010 Census
% female	% of female population at TAZ	2010 Census
<u>Model 4: Percentage of old truck</u>		
Household density	Number of households divided by the TAZ area	2010 census/ divide by area
Employment density	Number of all jobs divided by the TAZ area	2006-2010 CTPP ACS 5-year estimate/ divide by area
JOB_HH	Index. Calculation equation is explained below.	needs to be calculated
Transit availability (binary variable)	1 if there is at least one transit stop within 0.5 miles of TAZ centroid or if at least one transit stop within TAZ when not in the 0.5-mile buffer; 0 otherwise	Transit authorities
Housing median value	Median housing value at TAZ	2006-2010 ACS 5-year estimate
% household w/60+	% of households with one or more people 60 years and over	2010 Census

Table B- 19: Descriptive Statistics of the Estimation Sample - Vehicle Distribution Models

	Mean	Std. Dev.
Household density	1416.57	1367.56
Employment density	2022.65	7149.42
JOB_HH	0.85	0.12
Transit availability (binary variable)	0.63	0.48
Housing Median Age	48.22	15.83
% white	72.28	31.09
Household income	55,082.45	25706.40
% family w/children	42.23	8.11
% female	51.72	2.81
Household size	2.18	0.52
% bachelor	15.83	9.14
% single-parent	10.23	7.30
Housing median value	163,638.40	80930.07
% household w/60+	36.41	8.86
Sample size	421	

Table B- 20: Vehicle Distribution Model 1 (Cleveland)

Dependent variable= % of New Car		
	Coefficient	t stat.
Household density	0.0028547	3.46
Employment density	0.0006964	5.00
JOB_HH	12.28511	1.61
Transit availability (binary variable)	3.317345	1.51
Housing Median Age	-0.1675402	-2.06
% white	0.1011808	2.36
Household income	0.0003106	2.34
Household income^2	-1.36e-09	-1.85
% family w/children	-0.3362029	-3.01
% female	1.127837	2.87
Constant	-43.90859	-1.89
Number of observations	421	
R^2	0.2093	
Adjusted R^2	0.1900	

Table B- 21: Vehicle Distribution Model 2 (Cleveland)

Dependent variable= % of Old Car		
	Coefficient	t stat.
Household density	-0.0014702	-1.49
Employment density	-0.000182	-1.28
JOB_HH	-11.62644	-1.34
Transit availability (binary variable)	5.055951	2.04
Housing Median Age	0.2930174	3.25
Household income	-0.0001751	-3.83
Constant	35.8515	3.71
Number of observations	421	
R^2	0.1498	
Adjusted R^2	0.1375	

Table B- 22: Vehicle Distribution Model 3 (Cleveland)

Dependent variable= % of New Truck		
	Coefficient	t stat.
Household density	-0.0011217	-1.57
Employment density	-0.000319	-2.25
Transit availability (binary variable)	-3.469845	-1.60
Household size	2.74865	1.49
% white	-0.0532725	-1.23
% bachelor	0.3337692	2.91
% single-parent	-0.3073801	-1.67
% female	-0.7281319	-2.00
Constant	58.00634	2.91
Number of observations	421	
R^2	0.1490	
Adjusted R^2	0.1325	

Table B- 23: Vehicle Distribution Model 4 (Cleveland)

Dependent variable= % of Old Truck		
	Coefficient	t stat.
Household density	-0.0014662	-1.87
Employment density	-0.0002551	-2.08
JOB_HH	-9.068908	-1.27
Transit availability (binary variable)	-3.052212	-1.51
Housing median value	-0.0000404	-3.50
% household w/60+	-0.1896335	-1.77
Constant	44.82802	6.22
Number of observations	421	
R^2	0.0657	
Adjusted R^2	0.0522	

APPENDIX C: CRETERIA AND WEIGHT OF GROWTH SCORES

Table C- 1: Criteria and Weights for Employment Growth Scores

Category	Feature		Long description	Jobs
Econ Dev	TIF	TIF	Majority of grid in Tax Increment Financing (TIF) district	8
Econ Dev	CRA	CRA	Majority of grid in Community Reinvestment Area (CRA)	5
Econ Dev	Innovation Hubs	INNOHUB	Majority of grid in ODOD Innovation Hub zone	5
Econ Dev	CEDA	CEDA	Majority of grid in Cooperative Economic Development Agreement (CEDA) area	2
Econ Dev	JEDZ	JEDZ	Majority of grid in Joint Economic Development District/Zone (JEDD/JEDZ)	2
Econ Dev	EZ	EZ	Majority of grid in Enterprise Zone (EZ)	2
Environ	Forests	FOREST	More than 25% of grid with land cover of forest	-4
Environ	Streams (1/4 mile)	STREAM	Majority of grid within 1/4 mile of rivers and streams	-4
Environ	Wellhead Zone 5-year	WELL5	Majority of grid in Ohio EPA modeled 5-Year Wellhead Zone related to ground water wells	-4
Environ	High Slope (>24 %)	SLOPE	Majority of grid has slope greater than 24% in soil survey data	-4
Environ	Upstream from water in-take	CMZ	Majority of grid in Ohio EPA defined Corridor Management Zone (CMZ) related to surface water intakes	-6
Environ	Upground Reservoirs	UPRES	Majority of grid within 1/4 mile of upground reservoirs	-2
Environ	Wellhead Zone 1-year	WELL1	Majority of grid in Ohio EPA modeled 1-Year Wellhead Zone related to ground water wells	-6
Environ	Agricultural Easements	EASEMENT	More than 25% of grid in agricultural easement	-9
Infra	Adjacent to Developed	DEVELOPEDI	Considered together neighboring grids are at least 40% developed	9
Infra	Currently Served by Sanitary Sewer	SEWER	Majority of grid within a sanitary sewer service area	9
Infra	Major Intersections (1/2	INTSEC_H	Majority of grid within 1/2 mile of major intersections and	8

	mi)		interchanges	
Infra	High Frequency of Transit Service	TRAN_H	Majority of grid within 1/4 mile of bus stop that has 336 buses/7-day week (avg. 2/hr.)	7
Infra	Major Intersection (1 mi)	INTSEC_1	Majority of grid within 1 mile of major intersections and interchanges	6
Infra	1/2 mi. of Currently Served by Sanitary Sewer	SEWER_H	Majority of grid within 1/2 mile of a sanitary sewer service area	6
Infra	Mixed Land Use Grid Types	MIXEDUSE	Future land use of grid has mixed use classification	6
Infra	Intermodal Yards (1/2 mi)	YARD_H	Majority of grid within 1/2 mile of intermodal yard	5
Infra	Medium Frequency of Transit Service	TRAN_M	Majority of grid within 1/4 mile of bus stop that has 168-335 buses/7-day week (avg. 1-2/hr.)	4
Infra	Airport (within 1 mile)	AIRPORT1M	Majority of grid within 1 mile of airport terminal	4
Infra	Future Sanitary Service Area	SEWER_F	Majority of grid within future sanitary service area according to 208 plans and local facility plans	3
Infra	Bike Facilities (Existing)	EX_BIKE	Majority of grid within 1/2 mile of bike lanes and paths	1
Infra	Small Average Census Block Size (density)	PED	Majority of grid has small average census block size (# of blocks per block group/block group area)	2
Infra	Intermodal Yards (1 mi)	YARD_1	Majority of grid within 1 mile of intermodal yard	2
Infra	Low Frequency of Transit Service	TRAN_L	Majority of grid within 1/4 mile of bus stop that has 1-167 buses/7-day week (avg. less than 1/hr.)	2
Infra	Bike Facilities (Future)	PR_BIKE	Majority of grid within 1/2 mile of future bike lanes and paths in Regional Bikeway Plan	1
Infra	Parks	PARKS	Majority of grid within 1/2 mile of parks	1
Infra	Congestion	CONGST	Majority of grid within 1/4 mile of roadway where volume exceeds capacity all four modeled time periods of a day	-1
Nuisance	Airport Noise (65 db)	AIRPORT	Majority of grid within modeled noise ring around runways where airport noise > 65 db	0

Nuisance	Airport Noise (60 db or parcel boundary)	AIRPORT_O	Majority of grid within modeled noise ring around runways where airport noise > 60 db -OR- majority of grid within parcel boundaries of airport	0
Nuisance	Quarries	QUARRY	Majority of grid within 1/4 mile of quarry	-1
Nuisance	Substations & High Tension Lines	ELECTR	Majority of grid within 1/4 mile of substations & high tension power lines	-3
Nuisance	Landfills	LANDFILL	Majority of grid within 1/2 mile of landfills	-9
Nuisance	Wastewater Treatment Plant	WWTP	Majority of grid within 1/2 mile of wastewater treatment plant	-4

Table C- 2: Criteria and Weights for Household Growth Scores

Category	Feature		Long description	People
Econ Dev	TIF	TIF	Majority of grid in Tax Increment Financing (TIF) district	3
Econ Dev	CRA	CRA	Majority of grid in Community Reinvestment Area (CRA)	2
Econ Dev	Innovation Hubs	INNOHUB	Majority of grid in ODOD Innovation Hub zone	2
Econ Dev	CEDA	CEDA	Majority of grid in Cooperative Economic Development Agreement (CEDA) area	1
Econ Dev	JEDZ	JEDZ	Majority of grid in Joint Economic Development District/Zone (JEDD/JEDZ)	1
Econ Dev	EZ	EZ	Majority of grid in Enterprise Zone (EZ)	1
Environ	Forests	FOREST	More than 25% of grid with land cover of forest	-2
Environ	Wellhead Zone 5-year	STREAM	Majority of grid in Ohio EPA modeled 5-Year Wellhead Zone related to ground water wells	-2
Environ	High Slope (>24 %)	WELL5	Majority of grid has slope greater than 24% in soil survey data	-2
Environ	Streams (1/4 mi)	SLOPE	Majority of grid within 1/4 mile of rivers and streams	-4
Environ	Upstream from water in-take	CMZ	Majority of grid in Ohio EPA defined Corridor Management Zone (CMZ) related to surface water intakes	-6
Environ	Upground Reservoirs	UPRES	Majority of grid within 1/4 mile of upground reservoirs	-2
Environ	Wellhead Zone 1-year	WELL1	Majority of grid in Ohio EPA modeled 1-Year Wellhead Zone related to ground water wells	-6
Environ	Conservation and Ag Easements	EASEMENT	More than 25% of grid in conservation or agricultural easement	-9
Infra	Adjacent to Developed	DEVELOPEDI	Considered together neighboring grids are at least 40% developed	9
Infra	Currently Served by Sanitary Sewer	SEWER	Majority of grid within a sanitary sewer service area	8
Infra	Mixed Land Use Grid Types	MIXEDUSE	Future land use of grid has mixed use classification	7
Infra	Small Average Census Block Size	PED	Majority of grid has small average census block size (# of blocks per	7

	(density)		block group/block group area)	
Infra	High Frequency Transit Service	TRAN_H	Majority of grid within 1/4 mile of bus stop that has 336 buses/7-day week (avg. 2/hr.)	6
Infra	1/2 mi. of Currently Served by Sanitary Sewer	SEWER_H	Majority of grid within 1/2 mile of a sanitary sewer service area	5
Infra	Parks	PARKS	Majority of grid within 1/2 mile of parks	5
Infra	Major Intersection (1 mi)	INTSEC_1	Majority of grid within 1 mile of major intersections and interchanges	4
Infra	Medium Frequency Transit Service	TRAN_M	Majority of grid within 1/4 mile of bus stop that has 168-335 buses/7-day week (avg. 1-2/hr.)	4
Infra	Major Intersection (1/2 mi)	INTSEC_H	Majority of grid within 1/2 mile of major intersections and interchanges	4
Infra	Future Sanitary Service Area	SEWER_F	Majority of grid within future sanitary service area according to 208 plans and local facility plans	3
Infra	Bike Facilities (Existing)	EX_BIKE	Majority of grid within 1/2 mile of bike lanes and paths	1
Infra	Low Frequency Transit Service	TRAN_L	Majority of grid within 1/4 mile of bus stop that has 1-167 buses/7-day week (avg. less than 1/hr.)	2
Infra	Bike Facilities (Future)	PR_BIKE	Majority of grid within 1/2 mile of future bike lanes and paths in Regional Bikeway Plan	1
Infra	Airport	AIRPORT1M	Majority of grid within 1 mile of airport terminal	0
Infra	Intermodal Yards (1 mi)	YARD_1	Majority of grid within 1 mile of intermodal yard	-2
Infra	Congestion	CONGST	Majority of grid within 1/4 mile of roadway where volume exceeds capacity all four modeled time periods of a day	-2
Infra	Intermodal Yards (1/2 mi)	YARD_H	Majority of grid within 1/2 mile of intermodal yard	-3
Nuisance	Quarries	QUARRY	Majority of grid within 1/4 mile of quarry	-3
Nuisance	Airport Noise (60 db or parcel boundary)	AIRPORT	Majority of grid within modeled noise ring around runways where airport noise > 60 db -OR- majority of grid within parcel	-6

			boundaries of airport	
Nuisance	Substations & High Tension Lines	ELECTR	Majority of grid within 1/4 mile of substations & high tension power lines	-9
Nuisance	Landfills	LANDFILL	Majority of grid within 1/2 mile of landfills	-9
Nuisance	Wastewater Treatment Plant	WWTP	Majority of grid within 1/2 mile of wastewater treatment plant	-9
Nuisance	Airport Noise (65 db)	AIRPORT_O	Majority of grid within modeled noise ring around runways where airport noise > 65 db	-9

Table C- 3: Density Constraints by Land Use Type

Grid type	Land Use Name	HH per acre	Jobs per acre	HH per 40 acre grid	Job per 40 acre grid	Notes
Ag	Agriculture	0.01	0.02	0.40	0.60	99.9 % agricultural
Off	Office	0.80	0.00	32.00		10% residential, 90% office. 20% of land taken out for roads and streets. Residential assumed at 10 units per acre. Office assumed at 10000 square feet per acre with 350 square feet per employee
OffU	Office (URBAN)	1.20	77.71	48.00	3108.57	15% residential, 85% office. 20% of land taken out for roads and streets. Residential assumed at 10 units per acre. Office assumed at 40000 square feet per acre with 350 square feet per employee
Rcom m	Regional Commercial	0.00	34.00	0.00	1360.00	100% commercial. 15% of land taken out for roads and streets. Commercial assumed at 10000 square feet per acre with 250 square feet per employee
Ccom	Community Commercial	0.80	20.57	32.00	822.86	10% residential, 90% commercial. 20% of land taken out for roads and streets. Residential assumed at 10 units per acre. Commercial assumed at 10000 square feet per acre with 350 square feet per employee
Ncom	Neighborho od Commercial	0.64	28.80	25.60	1152.00	10% residential, 90% commercial. 20% of land taken out for roads and streets. Residential assumed at 8 units per acre. Commercial assumed at 10000 square feet per acre with 250 square feet per employee
Nmix U	Neighborho od Mix (Urban- as in county seats, towns	2.24	14.40	89.60	576.00	40% residential, 60% commercial. 20% of land taken out for roads and streets. Residential assumed at 7 units per acre. Commercial assumed

	and villages)					at 10000 square feet per acre with 250 square feet per employee
Nmix	Neighborhood Mix (as in suburban areas)	2.40	12.00	96.00	480.00	60% residential, 40% commercial. 20% of land taken out for roads and streets. Residential assumed at 5 units per acre. Commercial assumed at 10000 square feet per acre with 250 square feet per employee
Ind	Industry	0.12	10.39	4.80	415.63	5% residential, 95% industry. 20% of land taken out for roads and streets. Residential assumed at 3 units per acre. industry assumed at 12500 square feet per acre with 800 square feet per employee, and an additional 10% land reduction
Lind	Light Industry	0.40	7.62	16.00	304.69	25% residential, 75% industry. 20% of land taken out for roads and streets. Residential assumed at 2 units per acre. industry assumed at 12500 square feet per acre with 800 square feet per employee, and an additional 10% land reduction
Ware	Warehouse/ Distribution	0.00	5.83	0.00	233.33	0% residential, 100% industry. 20% of land taken out for roads and streets. Residential assumed at 8 units per acre. industry assumed at 12500 square feet per acre with1500 square feet per employee, and an additional 10% land reduction
Quar	Quarry	0.00	4.50	0.00	180.00	100% quarry. 10% of land taken out for roads and streets. 12500 square feet per acre, 2500 square feet per employee.
Os	Open Space	0.00	0.00	0.00	0.00	no residential, no employment
pro	Protected	0.00	0.00	0.00	0.00	no residential, no employment
Park	Park	0.00	0.03	0.00	1.00	no residential, no employment,

						.03 employees per acre
Hurb	Residential High Urban	6.40	45.71	256.00	1828.57	50% residential, 50% commercial. 20% of land taken out for roads and streets. Residential at 16 units per acre. Commercial at 40000 square feet per acre, and 350 square feet per employee
Lurb	Residential Low Urban	5.40	12.00	216.00	480.00	60% residential, 40% commercial. 10% of land taken out for roads and streets. Residential at 10 units per acre. Commercial at 10000 square feet per acre, and 300 square feet per employee
Hsub	Residential High Suburban	6.75	7.50	270.00	300.00	75% residential, 25% commercial. 10% of land taken out for roads and streets. Residential at 10 units per acre. Commercial at 10000 square feet per acre, and 300 square feet per employee
Msub	Residential Mod Suburban	3.04	1.33	121.60	53.33	95% residential, 5% commercial. 20% of land taken out for roads and streets. Residential at 4 units per acre. Commercial at 10000 square feet per acre, and 300 square feet per employee
Sub	Residential Suburban	1.52	1.33	60.80	53.33	95% residential, 5% commercial. 20% of land taken out for roads and streets. Residential at 2 units per acre. Commercial at 10000 square feet per acre, and 300 square feet per employee
Lsub	Residential Low	1.14	1.13	45.60	45.33	95% residential, 5% commercial. 20% of land taken out for roads and streets. Residential at 1.5 units per acre. Commercial at 8500 square feet per acre, and 300 square feet per employee
Rrur	Residential Rural	0.40	0.00	16.00	0.00	100% residential, 0% commercial. 20% of land taken out for roads and streets.

						Residential at 0.5 units per acre.
Rest	Residential Rural Estate	0.16	0.00	6.40	0.00	100% residential, 0% commercial. 20% of land taken out for roads and streets. Residential at 0.2 units per acre.
Wat	Water	0.00		0.00	0.00	no residential or commercial
Row	Right of Way	0.00	0.00	0.00	0.00	no residential or commercial
Hed	Higher Education	0.38	71.72	15.00	2868.75	10% residential, 90% university. 25% of land taken out for roads and streets. Residential at 5 units per acre. University at 8500 square feet per acre, and 80 square feet per employee
Ed	Education	0.50	9.84	20.00	393.75	20% residential, 80% school. 20% of land taken out for roads and streets. Residential at 2.5 units per acre. School at 8500 square feet per acre, and 200 square feet per employee
Corf	Correctional Facility	0.00	32.40	0.00	1296.00	No residential, 100% correctional facility. 10% of land taken out for roads and streets. Correctional facility at 9000 square feet per acre, and 250 square feet per employee
Govt	Government	0.28	16.39	11.20	655.71	10% residential, 90% university. 20% of land taken out for roads and streets. Residential at 3.5 units per acre. Govt bldgs at 8500 square feet per acre, and 350 square feet per employee
Utl	Utility	0.00	0.80	0.00	32.00	No residential, 100% utility. 20% of land taken out for roads and streets. Utility at 5000 square feet per acre, and 10000 square feet per employee
REL	Religious Facility	0.28	1.75	11.20	69.94	10% residential, 90% religious. 20% of land taken out for roads and streets. Residential

						at 3.5 units per acre. Religious at 8500 square feet per acre, and 1000 square feet per employee
HOS	Hospital	0.28	61.20	11.20	2448.00	10% residential, 90% university. 20% of land taken out for roads and streets. Residential at 3.5 units per acre. University at 8500 square feet per acre, and 100 square feet per employee
AIR	Airport	0.00	1.08	0.00	43.20	No residential, 100% utility. 10% of land taken out for roads and streets. Utility at 3000 square feet per acre, and 2500 square feet per employee
RRYD	Rail Yard	0.00	1.50	0.00	60.00	No residential, 100% utility. 25% of land taken out for roads and streets. Utility at 5000 square feet per acre, and 2500 square feet per employee

APPENDIX D: MOVES FOR COLUMBUS SCENARIOS

D1. Input Data Description

The update version of Motor Vehicle Emission Simulator (MOVES2010a) from the U.S. Environmental Protection Agency (EPA) is a state-of-the-art tool for estimating emissions from highway vehicles under a wide range of user-defined conditions. The MOVES User Guide states that the modeling process requires the user specifies vehicle types, time periods, geographical areas, pollutants, vehicle operating characteristics, and road types. For our study, we use specified inputs provided by the Ohio Department of Transportation, except VMT and vehicle distribution. These two items are changed based on the three scenarios for mid-Ohio region.

Each scenario provides a total daily VMT which needs to be converted to annual VMT using the conversion tool ("aadvmtcalculator_hpms.xls") from EPA. We first calculate daily VMT for each vehicle type group (HPMSVtype: 10, 20, 30, 40, 50, 60, explained in Table D- 1) based on the distribution provided by ODOT WIM (weigh in motion) stations. The calculated daily VMT for each HPMSVtype is inserted into the conversion tool to get the annual VMT for each HPMSVtype and corresponding fractions (month, day and hour).

Table D- 1 explains the 13 vehicle types in MOVES. Each scenario estimates percentages of passenger cars and passenger trucks (the sum of these two percentages is 100). Using the original vehicle distribution (13 types) from ODOT, the numbers of passenger cars and passenger trucks are updated using the estimated percentages of these two vehicle types from the scenario. For example, there are 1,330,479 passenger cars and 588,067 passenger trucks in the original data input from ODOT. Thus the total number of these vehicle types is 1,918,564. The estimated percentage of passenger cars in base scenario is 49.09%. Therefore, the adjusted number of passenger cars becomes 941,813. The numbers for the other vehicle types are kept the same.

Table D- 2 summarizes the estimated VMT and percentages of passenger cars and trucks from three scenarios for Columbus region. The updated numbers of vehicles based on these three scenarios are reported in Table D- 3.

Table D- 1: Vehicle Types in MOVES

Vehicle Type ID	Description
11	Motorcycle
21	Passenger Car
31	Passenger Truck
32	Light Commercial Truck
41	Intercity Bus
42	Transit Bus
43	School Bus
51	Refuse Truck
52	Single Unit Short-haul Truck
53	Single Unit Long-haul Truck
54	Motor Home
61	Combination Short-haul Truck
62	Combination Long-haul Truck

Table D- 2: Outputs of Scenarios

	Base Scenario	Scenario 2	Scenario 3
Total VMT	43876444.54	43853820.99	43471316.81
% of Passenger Cars	49.09	49.28	49.44
% of Passenger Trucks	50.91	50.72	50.56

Table D- 3: Vehicle Type Distribution for MOVES

Vehicle Type ID	Base Scenario	Scenario 2	Scenario 3
11	85801	85801	85801
21	941813	945493	948519
31	976751	973071	970045
32	17698	17698	17698
41	545	545	545
42	146	146	146
43	2928	2928	2928
51	384	384	384
52	345	345	345
53	444	444	444
54	1849	1849	1849
61	5666	5666	5666
62	6516	6516	6516

D2. MOVES Summary Report

Using the input data described in previous section, we run MOVES for three scenarios and get summary reports with five items as explained in Table D- 4. The summary reports for three scenarios are in Table D- 5, Table D- 6 and Table D- 7.

Table D- 4: Description of MOVES Summary Report

Output	Description
NMHC	Non-Methane Hydrocarbons
NMOG	Non-Methane Organic Gases
TotalHC	Total Gaseous Hydrocarbons
VOC	Volatile Organic Compounds
Distance	Annual distance in mile

Table D- 5: Summary Report for Columbus Base Scenario

Vehicle Type	NMHC	NMOG	TotalHC	VOC	Distance
11	139783776	150517344	143045328	149749984	106326040
21	442824320	481478240	525469344	480526272	18889521152
31	208118992	223305264	226736720	222280192	5626010624
32	235188	242826	443516	240103	9012753
41	2441167	2487141	3695048	2470748	28565364
42	424004	432335	651201	429364	5762236
43	1484713	1520494	2460610	1507735	24417228
51	15786119	16097183	24269948	15986261	193107040
52	3422707	3527077	6269262	3489860	63506236
53	3587590	3694875	6513656	3656619	65123336
54	1862848	1909774	3142676	1893041	28594224
61	47441472	48294672	70711224	47990428	517829280
62	51807472	52702724	76224264	52383488	531792928

Table D- 6: Summary Report for Columbus Scenario 2

Vehicle Type	NMHC	NMOG	TotalHC	VOC	Distance
11	139712336	150440416	142972192	149673456	106271216
21	442606240	481240832	525209920	480289280	18879782912
31	207991680	223168768	226596368	222144320	5622731776
32	235933	243596	444918	240864	9041562
41	2439909	2485859	3693143	2469474	28550632
42	423786	432112	650865	429143	5759265
43	1483949	1519712	2459344	1506959	24404640
51	15777976	16088880	24257430	15978015	193007440
52	3420941	3525258	6266027	3488060	63473492
53	3585741	3692971	6510299	3654734	65089764
54	1861888	1908789	3141055	1892064	28579478
61	47417032	48269788	70674800	47965704	517562240
62	51780772	52675564	76184984	52356492	531518752

Table D- 7: Summary Report for Columbus Scenario 3

Vehicle Type	NMHC	NMOG	TotalHC	VOC	Distance
11	138505008	149140736	141736480	148380464	105344296
21	438773824	477072864	520660576	476129376	18715107328
31	206176960	221221440	224622240	220205888	5573378560
32	234603	242223	442416	239506	8990160
41	2418630	2464180	3660937	2447937	28301608
42	420090	428344	645191	425401	5709031
43	1471029	1506482	2437950	1493840	24191774
51	15640361	15948552	24045858	15838655	191324016
52	3391105	3494511	6211378	3457638	62919860
53	3554467	3660762	6453519	3622859	64522044
54	1845650	1892142	3113661	1875563	28330200
61	47003452	47848772	70058400	47547340	513047936
62	51329200	52216192	75520624	51899900	526882656