THE EFFECT OF COMPACT DEVELOPMENT ON TRAVEL BEHAVIOR, ENERGY CONSUMPTION AND GHG EMISSIONS IN PHOENIX METROPOLITAN AREA

A Thesis
Presented to
The Academic Faculty

by
Wenwen Zhang

In Partial Fulfillment
of the Requirements for the Degree
Master in the
School of City and Regional Planning
and School of Civil and Environmental Engineering

Georgia Institute of Technology
May 2013

THE EFFECT OF COMPACT DEVELOPMENT ON TRAVEL BEHAVIOR, ENERGY CONSUMPTION AND GHG EMISSIONS IN PHOENIX METROPOLITAN AREA

Approved by:

Dr. Subhrajit Guhathakurta, Advisor
School of City and Regional Planning
Georgia Institute of Technology

Dr. Steven P. French
School of City and Regional Planning
Georgia Institute of Technology

Dr. Yanzhi Xu
School of Civil and Environmental Engineering
Georgia Institute of Technology

Date Approved: April 3, 2013

ACKNOWLEDGEMENTS

First I would like to offer my sincere gratitude to my parents, Anming Zhang and Ping Li. Without their guidance and support I would not be able to continue my graduate education in the United States.

I would also like to show my gratefulness to my thesis advisor and committee chair, Dr. Subrhajit Guhathakurta, who has provided many intuitive advices through my thesis. I would also like to thank my thesis committee members, Dr. Steven P. French and Dr. Yanzhi Xu, for their precious knowledge and assistance. Additionally, special thanks to Dr. Steven P. Steven who support me financially and mentally for my graduate study during the past two years, as my advisor in Master of City and Regional Planning program.

Lastly, and also importantly, I wish to thank all my friends from the City and Regional Planning Program, especially, Amy Moore, Kathrynne Colberg, Landon Reed and Susannah Lee. I came to the United States without any acquaintance. It was your caring heart and inspiring spirit that helped me adjust to the new environment.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF SYMBOLS AND ABBREVIATIONS

ACS	American Community Survey
EPA	US Environmental Protection Agency
FFS	Free Flow Speed
FTP	Federal Test Procedure
FHWA	Federal Highway Association
GHG	Greenhouse Gas
GIS	Geographic Information System
HBO	Home-based other trips
HBSH	Home-based shopping trips
HBW	Home-based work trips
MAG	Maricopa Association of Governments
MIC	Duluth-Superior Metropolitan Institute of Council
MPG	Miles per Gallon
MPO	Metropolitan Planning Organization
NAICS	North American Industry Classification System Code
NCHRP	National Cooperative Highway Research Program

NHB	Non-Home-based trips
NHTS	National Household Travel Survey
NPTS	National Personal Travel Survey
OD	Origin-Destination
OLS	Ordinary Least Square
SCAG	Southern California Association Government
SEM	Structural Equation Model
SIC	Standard Industrial Classification Code
TAZ	Transportation Analysis Zone
US DOT	US Department of Transportation
VMT	Vehicle Mile Travel

SUMMARY

Suburban growth in the U.S. urban regions has been defined by large subdivisions of single-family detached units. This growth is made possible by the mobility supported by automobiles and an extensive highway network. These dispersed and highly automobile-dependent developments have generated a large body of work examining the socioeconomic and environmental impacts of suburban growth on cities. The particular debate that this study addresses is whether suburban residents are more energy intensive in their travel behavior than central city residents. If indeed suburban residents have needs that are not satisfied by the amenities around them, they may be traveling farther to access such services. However, if suburbs are becoming like cities with a wide range of services and amenities, travel might be contained and no different from the travel behavior of residents in central areas.

This paper will compare the effects of long term suburban growth on travel behavior, energy consumption, and GHG emissions through a case study of neighborhoods in central Phoenix and the city of Gilbert, both in the Phoenix metropolitan region. Motorized travel patterns in these study areas will be generated using 2001 and 2009 National Household Travel Survey (NHTS) data by building a four-step transportation demand model in *TransCAD*. Energy consumption and GHG emissions, including both Carbon Dioxide (CO_2) and Nitrous Oxide (N_2O) for each study area will be estimated based on the corresponding trip distribution results. The final normalized outcomes will not only be compared spatially between Phoenix and Gilbert within the same year, but also temporally between years 2001 and 2009 to determine how the different land use changes in those places influenced travel.

The results from this study reveal that suburban growth does have an impact on people's travel behaviors. As suburbs grew and diversified, the difference in travel behavior between people living in suburban and urban areas became smaller. In the case

of shopping trips the average length of trips for suburban residents in 2009 was slightly shorter than that for central city residents. This convergence was substantially due to the faster growth in trip lengths for central city compared to suburban residents in the 8-year period. However, suburban residents continue to be more energy intensive in their travel behavior, as the effect of reduction in trip length is likely to be offset by the more intensive growth in trip frequency. Additionally, overall energy consumption has grown significantly in both study areas over the period of study.

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Introduction

Suburban growth in the U.S. urban regions has been defined by large subdivisions of single-family detached units. This growth was made possible by the mobility supported by automobiles and an extensive highway network. The suburbanization process was not free at all, as it comes with expensive economic, social, and environmental costs.

In the past decade, vehicle miles of traveled (VMT) in the U.S., grew from 2.6 trillion in 2000 to close to 3.4 trillion in 2011 (US Department of Transportation, 2011). Such rapid growth made transportation the largest gasoline consumer among all groups, occupying 71% of the total Petroleum use in United States, as shown in Figure 1.1. The large consumption of energy made the United Sates more dependent on petroleum import, which has raised concerns regarding national security issues for a long time.

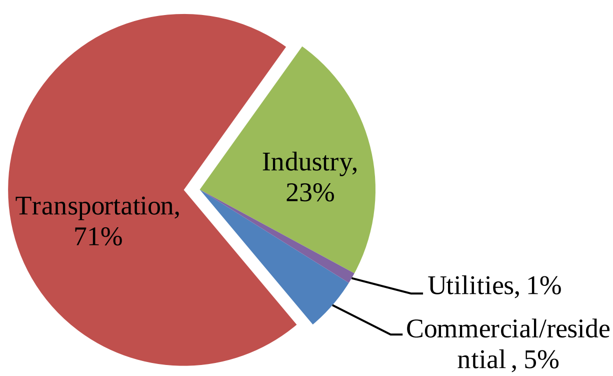


Figure 1.1: Percentage of Total U.S. Petroleum Use by Sector in 2009

Source: U.S. Department of Transportation Statistics Annual Report 2010

Additionally, there were also irreversible damages to the environment. According to the annual report from US Department of Transportation (US DOT), transportation sector was the second largest of source of greenhouse gas (GHG), mainly carbon dioxide, emissions in the United States, just after electric power generation. Global warming, caused by the gigantic amount of GHG emissions has also been a concern worldwide in the recent decade. Health risk associated with harmful transportation gas emission has also threatened the welfare of urban residents, which occupied up to around 80% of the entire United Sates population. Many metropolitan regions have experienced difficulty in meeting the federal clean air standards.

To reduce the negative effects, in September 2008, California State Legislature passed the first state law (Senate Bill 375) to curb the suburbanization process using land use policies, in the hope that the VMT and GHG could be maintained under control. Incentives for compact development was offered to local government and developers to achieve the ambitious goal, as the State Government realized that improvement in vehicle technology alone could not help the state to achieve their GHG emissions reduction goal by the year of 2020. However, the latest feedback of the policy revealed that the effect of compact development on VMT was rather limited (TRB, 2009). Such estimate reflects the limited information regarding the impact of compact development on motorized travel pattern from the perspective the temporal evolution. In other words, although the contemporary literature indicates the positive effect of compact development on VMT reduction, no intuitive result exist regarding how the effect is likely to evolve over time and how long it takes the new development to cast effect on the VMT reduction.

1.2 Research Questions

Based on the urgent needs for a deeper understanding of interactive relationship between land use and travel behavior, the particular debate that this study addresses is whether suburban residents are more energy intensive in their travel behavior than central city residents. If indeed suburban residents have needs that are not satisfied by the amenities around them, they may be travelling farther to access such services. However, if suburbs are becoming like cities with a wide range of services and amenities, travel might be contained and no different from the travel behavior of residents in central areas.

This paper will compare the effects of long term suburban growth on travel behavior, energy consumption, and GHG emissions through a case study of neighborhoods in central Phoenix and the city of Gilbert, both in the Phoenix metropolitan region. Motorized travel patterns in these study areas will be generated, using 2001 and 2009 National Household Travel Survey (NHTS) data, to calibrate and build a four-step transportation demand model in *TransCAD*. Energy consumption and GHG emissions, including both Carbon dioxide (CO_2) and Nitrous Oxide (N_2O) for each study area will be estimated based on the corresponding trip distribution results. The final normalized outcomes will not only be compared spatially between Phoenix and Gilbert within the same year, but also temporally between years 2001 and 2009, to determine how the differential land use changes in those places influenced regional and local travel behavior in both study areas.

CHAPTER 2

LITERATURE REVIEW

2.1 Compact development and motorized travel behavior

Before 1990s most of the research work has focused on travel demand modeling using land use characteristics, as the highway construction was considered of the most urgency during that period of time. Motivated by the mobility improvement accompanied by the highway development, more development occurred dispersedly in the remote suburban areas, which led to costly impacts on environment, economy as well as the health and welfare of the residents.

To combat the side effects generated by suburban sprawl, in early 1990s, there was an upsurge of new urbanism movement, leaded by community planners, in suburban areas all over the country. This urban design movement intended to promote walkable neighborhoods with a mixed land use development. The movement was characterized by urban design standards such as mixed land use, especially for retail and residential land, grid road network system, traffic calming, etc. Those design standards were developed based on the rationale that they could to some extent reduce vehicle usage while encouraging walk trips. Thus during this period of time most of the literature focused on the debate whether these design standards could actually help achieve their original goal. Some early 1990s studies posited the positive relationship between new urbanism or neotraditional planning and the reduction of Vehicle Miles Traveled (VMT). Peter Calthrope (1993) noted that VMT can be expected to be reduced by 57%, if the grid network, instead of the conventional suburban network, could be implemented in residential development. McNally and Ryan (1993) also proposed a similar report regarding how driving behavior could be discouraged in a grid road network system. However, it has to be pointed out that those conclusions were drawn based on the critical assumption that the trip generation rate would not be changed after the implementation of new grid road network, which was rather suspicious in the real world. Therefore, Randall Crane (1996) reviewed the problem based on economic theory and claimed that the ultimate impact of new urbanism design can be ambiguous. In his paper, he argued that although the travel distance could be reduced after the implementation of the neotraditional design methods, there was a possibility that people would generate more trips due to the decline of associated travel cost. Therefore, there was a possibility that the effect of travel length reduction would be offset by a higher motor trip generation frequency. However, Crane's work focused primarily on the debate of whether the grid network could be expected to reduce VMT. The paper didn't establish a comprehensive framework to understand in which way the compact development, promoted in new urbanism, was likely to influence the travel behavior.

In the mid and late 1990s, triggered by the suspicious attitude towards new urbanism, many studies were conducted to reveal the quantitative relationship between compact development and travel behavior based on case studies across the country. These earlier attempts mainly used Ordinary Least Square (OLS) multiple regression models to determine the elasticities between travel behavior and explanatory variables. The dependent travel behavior variable was a measure of individual household travel. Individual VMT or household level VMT were the most commonly employed measure of travel behavior (Ewing and Cervero, 2010). The explanatory variables could be further classified into two major categories: 1) land sue variables and 2) socioeconomic variables. Those variables were later summarized by Cervero and Kockelman (1997) as the "D" variables: Density, Design and Diversity.

Density was most commonly defined as the household unit density, population density and sometimes employment. Design variable was commonly defined as the street pattern, which was generally quantified by measures such as block size, road or intersection density, fraction of four-way intersections, etc. (Cervero and Kockelman, 1997; Frank et al., 2007; Bhat et al., 2009) Diversity was defined as the diversification of land use type within a particular study unit. There were two widely accepted indexes to measure the diversity: 1) Entropy Index (Frank and Pivo, 1995) and 2) Dissimilarity Index (Kockelman 1996; Cervero and Kockelman, 1997). Compared with dissimilarity index, entropy index was more frequently utilized in the researches. The formula for both land use mix index are shown as below:

$$Entropy = \sum_{j=1}^{J} \frac{P_j \ln{(P_j)}}{\ln(J)}$$

Where, P_j is defined as the proportion of land in the j^{th} land use type, and J is the number of land use type within the study unit.

$$Dissimilarity = \sum_{j}^{k} \sum_{i=1}^{8} [\frac{X_i/8}{K}]$$

Where, *K* is the number of developed grid cells in the larger geographic area, *j* indexes grid cells, and *i* indexes the eight grid cells that abut a grid cell when units are divided into a rectangular grid, with X_i=1 if adjacent grid cells have differing land uses.

In addition to the above three-D variables, Destination Accessibility and Distance to Transit were also frequently included into the regression model as the fourth and fifth D variable. In a large number of motorized travel studies, destination accessibility was commonly interpreted as the accessibility of employment across a larger regional area (Boarnet, 2011). In most research, the variables were calculated as the total number of employment within a certain distance to the study unit. The threshold for distance varied among studies, as stated by Handy and Niemeier (1997) “no one best approach to measure accessibility exists”. Cervero and Duncan (1996) included accessibility variables with different distance threshold into their models to determine the best approach for their study cases.

The study results from these OLS regression studies from 1990s revealed that more compact development could help reduce the individual or household level VMT and in most studies and the results were statistically significant. The most common problems encountered by the researchers, developing multiple regression models, were the underestimation of standard errors of estimated coefficients, leading to inflated significance level (Boarnet, 2011). Such problem could be corrected using multilevel linear modeling method (Ewing et al., 2003).

Although, the multiple regressions could indicate the relationship between travel behaviors and land use variables, the underlying rationale associated with the relationship was somehow neglected. Therefore, the OLS models were only sufficient for hypothesis testing, i.e. whether the correlation between travel behavior and land use development patterns exists. Whereas, those models cannot answer the questions such as how compact development and travel behavior could interactive with each other and why the elasticities vary among cases. Therefore, in the most recent decade, the research attention has shifted from OLS regression model to structural models, which can potentially unveil land use and travel behavior interaction.

The structural model based studies attempted to connect land use pattern with travel cost, which would eventually alter travel behavior. These studies were commonly structured based on the micro-economic theories. Boarnet and Crane's study in 2001 attempted to connect land use and travel behavior together using travel cost variables. This research noted that the land use pattern change could cast influence on travel time cost by changing travel distance or travel speed. The most recent approaches proposed by Crane (2011) were models based on the microeconomics of travelers' demand, which was controlled by three factors: tastes, resources and prices. The results from many structural model studies indicated that the compact development could indeed reduce travel speed or travel distance, which would possibly lead to reduced individual VMT (Boarnet and Crane, 2001; Chatman 2008 and Zegras 2010).

To solve “self-selection” occurred in some early researches, the structural models, which connected land use type and travel behavior using household vehicle ownership variables, were developed. In early 1990s, Cervero (1994) suggested that individuals may choose residential location based on their travel habit. For example, residents living in Transit Oriented Development (TOD) zones may be preferred to travel via transit mode. Thus, based on this theory, some structural models associated residential location with vehicle ownerships. Join models of vehicle ownership and travel behaviors were established in this kind of studies (Bhat and Guo, 2007; Brownstone and Golob 2009; Bento and et al., 2003). The results from these studies revealed that by controlling the self-selection effect, higher residential density could still reduce household VMT generation. However, simultaneous estimation in this type of structural model turned out to be rather complicated as the relationship between residential density and vehicle ownership was commonly nonlinear. While on the other hand, some recent research has posited that a large set of socioeconomic variables could help reduce the self-selection problem in the conventional OLS regression model (Hand et al., 2006; Cao et al., 2009).

In reality, the dependent variable and explanatory variables will intertwine with each other. However, the above mentioned models cannot handle such complex relationship quite well. Therefore, with a better power to explore this kind of multiple relationship among variables, the Structural Equation Models (SEM) have become a more prevailing tool in most recent studies (Liu & Shen, 2011; Ewing et al., 2013). The study results from this type of research indicated a negative relationship between development density and VMT (Liu & Shen, 2011). The national level study from Ewing’s team also revealed that the density could have a positive effect on VMT reduction (Ewing et al., 2013).

2.2 Current research limitations

First of all, results from most current studies could not be directly applied to regional policy decision making process. The example of California Senate Bill 375 could be served as an evidence for such limitation. To make the research more intuitive to policy decision makers, more studies may focus on a larger spatial area, instead of the current prevailing community neighborhoods or single household units. The relationship between regional level land use patterns may be further studied to support land use policy decision making.

Additionally, the effect of temporal land use change, especially the dominant suburbanization process, on individual travel behavior may also be further analyzed to determine whether the relationship between development pattern and travel behavior will change over time. Therefore, the temporal comparison will be conducted in this thesis to check the potential variation of the relationship between the suburbanization and travel behavior and to determine, if indeed there is positive variation in travel pattern, will the energy consumption and GHG emissions be reduced based on such change.

Furthermore, in most of the current meta-analysis the elasticities between VMT and land use variables were estimated at metropolitan level or community level. Not many studies have focused on the difference between urban and sub-urban households. However, there is a possibility that the elasticities may vary in those areas. Moreover, little spatial models were established to eliminate the spatial autocorrelation problem associated with variables and residuals. Therefore, this thesis will include appropriate spatial models based on Robust LM tests results for conventional OLS regression models.

CHAPTER 3

ANALYSIS FRAMEWORK DEVELOPMENT

3.1. Regional Motorized Travel Pattern Analysis

To analyze motorized travel patterns, two specific trip purposes: home-based work (HBW) and home-based shopping (HBSH) trips, were studied. These two kinds of trips could contribute to up to around 35% of the daily motorized trips in Phoenix Metropolitan Region. Other types of trips will be further studied in the future, due to the current data and time limitation. The specific trip definitions employed in this research are as follows: the HBW trips are defined as trips between households and employment places and HBSH trips are those between households and retail associated places. Figure 3.1 illustrates the definition of different trip purposes for readers' reference.

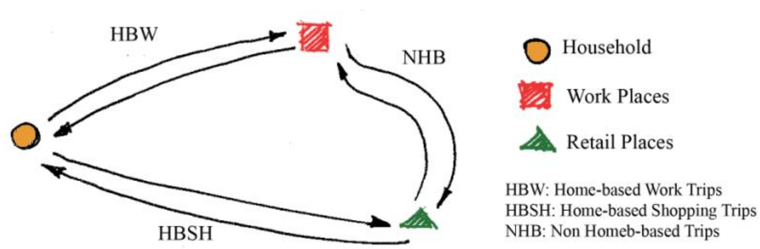


Figure 3.1: Trip Purpose Classification

Source: Adapted by Author

The traditional four-step transportation model was built in this study to estimate the regional travel patterns for HBW and HBSH trips. The choice was made based on the following reasons:

First, the purpose of this research is not to forecast travel demand in the future but to analyze the trip distribution between TAZs, based on the travel impedance costs among them. Therefore, the gravity model inherited in four-step model is sufficient to perform analysis. Secondly, compared with other types of models, such as tour based models and activity based models, four-step model (trip based model) is less data consuming and easier to perform in software such as *TransCAD*. Other models require tour origin and destination TAZs as inputs, which are not accessible in this research. Additionally, there is no sufficient information to develop the accessibility utility function for each TAZ, which is another required input in activity based models.

Based on the trip generation definition from the four-step model, the production of home-based trip is always defined as the trip end that occurs at home and attraction is always the end that occurs at the non-home location. Therefore, for trips that start at work places and end at home the production is still the TAZ where the household locates and attraction is the TAZ where the work place is situated. Based on these definitions, the number of trips in the OD matrix cells can be interpreted as the trips between origin and destination TAZs. For example, if 5 trips are estimated between Origin TAZ 1 and Destination TAZ 4, it indicates that 5 trips are generated between home in TAZ 1 and employment in TAZ 4. While there is no further information regarding whether the trips actually start within origin or destination TAZs based on the OD matrix. The trip production and attraction definitions are illustrated in Figure 3.2 for reference.

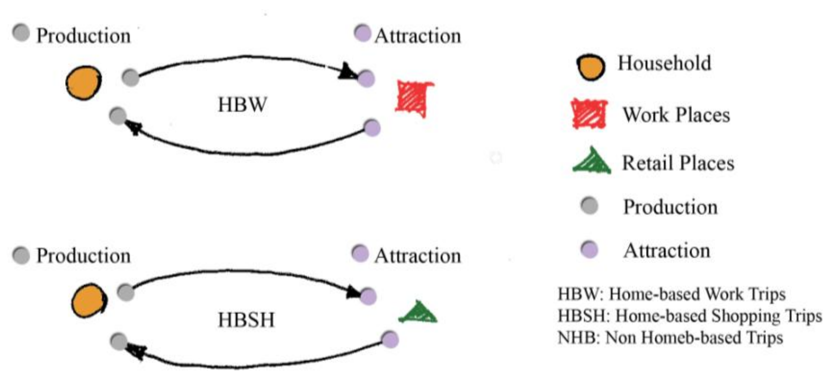


Figure 3.2: Trip Production and Attraction Definition

Source: Adapted by Author

3.2. Local Travel Pattern Analysis for Study Areas

Two study areas with different development patterns were selected within Phoenix Metropolitan area. The first, with more intensive development, located within the Central Phoenix area, while the other with comparatively less development, situated at the suburban area in City of Gilbert. The two selected areas have comparatively similar size while dramatically different development patterns. The land use pattern variables employed in this study were: 1) population density, 2) employment accessibility, 3) road density, and 4) land use type diversity (entropy index).

To compare the travel patterns in the two study areas, HBW and HBSH trips were further classified into three types based on the location of origin and destination TAZs. Intra zonal trips were those with both origin and destination located within the study area, illustrated as the red arrows in Figure 3.3. The Inter-in trips were those produced by households outside of the study area, while attracted by facilities within the study area shown as the green arrows. The Inter-out trips were those produced by households within the study area, while attracted by facilities located outside of the study area, displayed as the purple arrows.

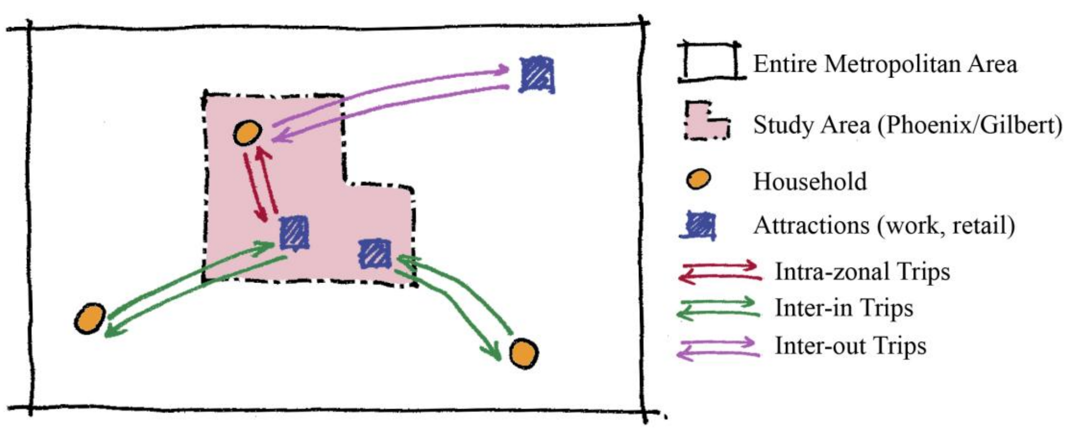


Figure 3.3: Trip Type Classification

Source: Adapted by Author

Based on the definitions of different type of trips, the intra-zonal trips number was achieved from the Four Step Model output OD matrix with both origin and destination TAZs within the study area. The inter-out trips number will be the sum of those with origin TAZs within the study area and destination TAZs outside the study area. The total number of trips produced by households within the study area was obtained by adding the intra-zonal and inter-out trips together.

The trip attributes such as frequencies, average trip lengths, as well as the total VMT for the above mentioned three types of trips were estimated to analyze the travel patterns for both study areas. Those attributes were then compared between local and non-local residents for Phoenix and Gilbert study areas. The purpose of such comparison was to determine whether the suburbanization process in Phoenix Metropolitan area actually encouraged more trips regional wide to the suburban area, or regional residents still preferred to travel to the central urban area to work and shop. Comparison was also made between local residents from Central Phoenix and Gilbert to determine whether the different spatial distribution of employment and retail service will affect these inhabitants in different manners.

3.3. Study Area Energy Consumption and GHG Emissions

The energy (gasoline) consumption was estimated based on the VMT distribution results. The energy consumption was calculated by multiplying the VMT results with average Miles per Gallon (MPG) for different vehicle types obtained from 2001 and 2009 NHTS data. Although this method was rather simple, it still to some extent considered the traffic condition and travel speed in energy estimation process. The road network developed for VMT calculation was established based on inter TAZ travel time and travel speed. For road segments located within different areas, such as urban, suburban, and rural, different travel time and travel speed were assigned.

The Greenhouse Gas (GHG) is the type of gas that traps heat in the earth atmosphere. Environmental Protection Agency (EPA) defined four major types of GHG as Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O) and air conditioning refrigerant (HFC-134a). In 2010, a total of 6882 million metric tons of CO_2 equivalent were emitted into atmosphere, 27% of which came from transportation sector (EPA, 2013). According to EPA data, CO_2 occupies up to 95% of the GHG emissions within transportation fields, while the other three types only account for 1-5% of GHG emissions. Global Warming Potentials (GWPs) were applied in this study to convert the emissions of three minor GHG gases into equivalent CO_2 emissions. The higher the number of GWP, the more heat the gas is likely to capture compared with CO_2. The GHG emissions composition and CO_2 equivalent calculation standards are listed in Table 3.1.

Table 3.1: GHG emissions composition and Global Warming Potential (GWP) standards

GHG Emissions Type	**GWP[1]**	**Percentage**	**Emission Calculation Standard[2]**
Carbon Dioxide (CO_2)	1	95-99%	8.8Kg CO_2/gallon
Methane (CH_4)	25	1-5%	Associated the travel mile and age of the vehicle.
Nitrous Oxide (N_2O)	298		
Air Conditioning Refrigerant (HFC-134a)	1430		Don't have clear standard, depends largely on the condition of the car service.

1. GWP: global warming potential, used to convert the emission into CO_2 equivalents.
2. Data Source: EPA 2012

Compared with Methane, N_2O is commonly considered as more harmful, as its global warming potential (GWP) is much higher. Additionally, there was no sufficient information to estimate Methane emission. Therefore, Methane emission was not studied in this paper. Although the Air Conditioning Refrigerant (HFC-134a) has the highest GWP among the three minor GHG gases, it was not included in GHG calculation, as the latest vehicle technology was able to eliminate this type of gas emission.

3.4. Regression Models Development

OLS regression models were first established on different spatial scales: regional, urban area and non-urban area for both study years 2001 and 2009. The "D" variables included in this research were: employment accessibility, retail service accessibility, road density, and Diversity (Entropy Index). The objectives of model development were 1) to explore whether the elasticitites between travel behavior and built environment remained the same over study period, 2) to determine how they were likely to change with the variation of D-variables over time and 3) to check whether spatial factors should be taken into considerations. Market incremental tests were conducted to find out if separate models should be accepted for urban and non-urban areas. If indeed the travel patterns were spatially auto-correlated, spatial models, such as spatial-lag and spatial-error models, would be developed to explain the travel behaviors for the entire region. This kind of comparison could provide more information for metropolitan level of policy decision making process.

3.5.Analysis Framework Summary

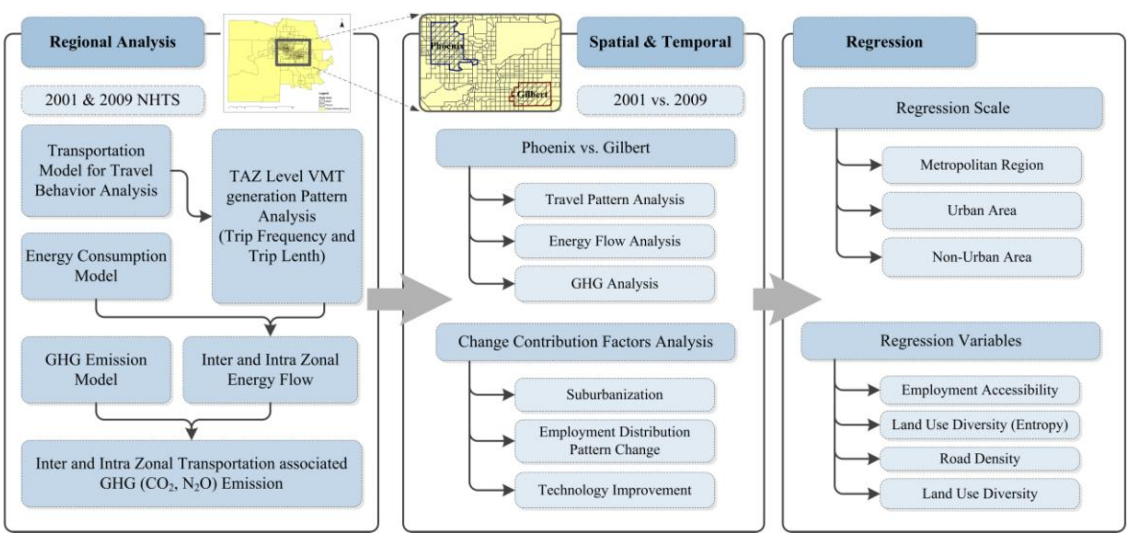


Figure 3.4: Research Flowchart

To summarize, a top-down analysis method was employed in this research. First the regional travel pattern was analyzed for the entire metropolitan region based on the trip generation and distribution methods in four-step model. Then the trip distribution results associated with the two specific study areas were extracted and energy consumption and GHG emissions were estimated for those areas. The results from the above research steps were compared not only spatially between central Phoenix and Gilbert, but also longitudinally between years 2001 and 2009. In addition to the descriptive comparison analysis, Ordinary Least Square (OLS) models as well as spatial regression models were developed to quantify the elasticities between built environment associated variables and motorized travel behavior patterns. The underlying reasons to longitudinal changes were also discussed, in the hope that it could provide new perspectives for decision makers to support their land use policy making process. The detailed research flowchart is illustrated in Figure 3.4.

CHAPTER 4

CASE STUDY FOR PHOENIX METROPOLITAN AREA

4.1.Data Source and Study Area

4.1.1. Data Source

2001 and 2009 National Household Travel Survey (NHTS) data were the major data source used in this study to produce Origin-Destination (OD) matrix for HBW and HBSH trips. NHTS is a periodic national household level travel survey aiming at facilitating transportation planners and policy makers. Up to now, there are two sets of NHTS data including 2001 and 2009. Previous to NHTS, Federal Highway Administration (FHWA) conducted National Personal Transportation Survey (NPTS), which could be dated back to 1969. Sates and Metropolitan Planning Organization (MPO) have the right to purchase more household samples in the area that they are particularly interested in. The 2009 NHTS for Phoenix Metropolitan area has 4707 households, including not only the public accessible data, but also the add-on data purchased by the MPO, Maricopa Association of Governments (MAG). The spatial distributions of the 2009 NHTS sampled households and the ACS census tract level households were compared in Figure 4.1. The color of each census tract was assigned based on quantile classification method, i.e. each color represents 10% of the entire dataset. According to the result, the sampled households were proportionate to the total spatial distribution of entire households. The suburban area was slightly oversampled, while in urban area, especially in the center of Phoenix County, comparatively fewer households were sampled. The 2001 NHTS data only had 498 households for Arizona State and the sampled number of different household was not proportionate to the entire household population. Additionally, there was missing information regarding the location of those households, rendering it unfeasible to conduct trip production based on this dataset. Fortunately, the FHWA also published 2001 NHTS transferability National files, including adjusted census tract level vehicle trip generation rates for HBW and HBSH, on their official website. Therefore, the transferability data was used in this research for 2001 trip production. This dataset may not be accurate to estimate local travel behaviors, as it was adapted for each census tract based on 2001 NHTS data, 2000 Transportation Planning Package data and American Community Survey (ACS) data. However, to make it feasible to perform temporal comparison, this dataset was employed, as it was more comparable with 2009 NHTS data in the aspects of the survey and data processing methods. The trip travel time distribution from 2001 Arizona NHTS data was used to validate the trip distribution output.

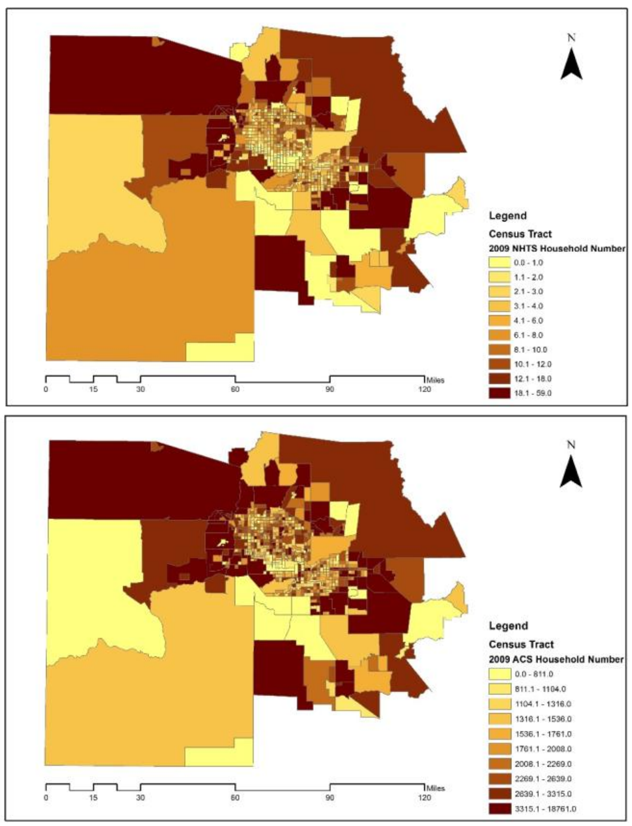


Figure 4.1: Comparison of Sampled household number (top) and actual household number (bottom) in 2009

Source: Adapted by Author based on 2009 NHTS data and 2009 ACS data

The census tract level demographic and socio-economic information, such as household number, household size, average household vehicle ownership, and median household income, was obtained to estimate trip production using cross classification method. For year 2001, the 2002 census tract level summary file data from American Community Survey (ACS) was employed and the 2009 ACS data (5-year estimates) was used for 2009 trip production.

The trip attraction process mainly relied on the 2000 and 2010 Phoenix Metropolitan area disaggregated employment data from MAG. The employment from 2000 was reclassified with 2-digit Standard Industrial Classification (SIC) code, while the 2009 data was marked with 6-digit North American Industry Classification System (NAICS) code.

2000 and 2010 Phoenix Metropolitan area road network data was applied to implement trip distribution process. It has to be pointed out the road network data was quite crude, without advanced information such as average travel speed, number of lanes for each road segments, etc.

4.1.2. Study Area

Phoenix Metropolitan area was selected as the macro-area to analyze the regional travel pattern, as it would be unfeasible to estimate inter and intra zonal travel behavior without larger study context. The Phoenix Metropolitan area has a total of 2001 TAZs and an area of 11193.7 square miles. The total population increased rapidly during the study period from 3233820 to 4130721. Specific Transportation Analysis Zones (TAZs) within the Phoenix and Gilbert were selected to determine the impact of compact development on motorized travel behavior, energy consumption and GHG emissions. The selection process was based on the area attributes such as development density and total area, so that the two smaller study areas would have different development pattern but similar size. The study areas are illustrated in Figure 4.2.

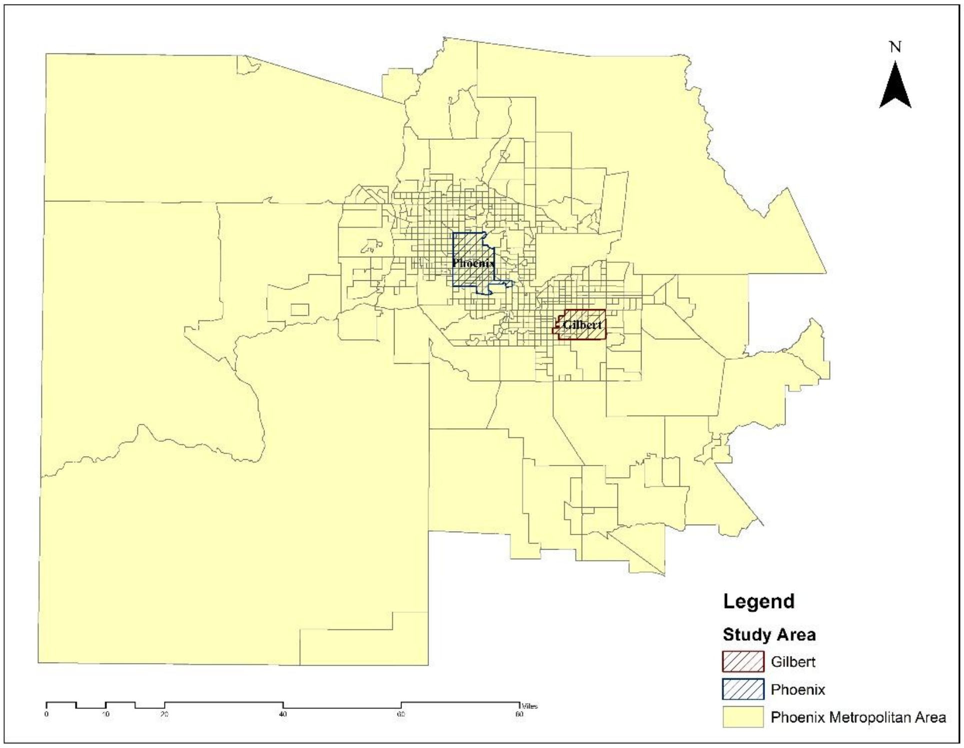


Figure 4.2: Phoenix and Gilbert Study Areas

Source: Adapted by Author

The two study areas, Phoenix and Gilbert, had substantially different development patterns throughout the study period. The 2001 and 2009 average development density indexes for both of the areas were tabulated in Table 4.1. Gilbert has witnessed more intensive development in the past decade compared with Phoenix area. However, the overall development density in Phoenix area was still substantially higher in Phoenix, especially in the aspect of various kind of employment, where Phoenix was still six times more condensed than Gilbert study area in 2009.

Table 4.1: Average density information for Phoenix and Gilbert in 2001 and 2009

Study Area	Area (Acres)	Population Density			Employment Density			Road Density (Mile/acre)		
		2000	2009	Change	2000	2009	Change	2000	2009	Change
Phoenix	39934.4	8.54	8.68	2%	6.48	6.71	4%	0.0288	0.0291	1%
Gilbert	24684.3	4.81	6.52	36%	0.94	1.35	43%	0.0133	0.0242	82%

Data source: adapted by author using ACS population data, employment and road data from MAG.

In addition to the average densities change, the spatial distributions of condensed development within the two study areas have also changed slightly, as shown in Figure 4.3. In phoenix study area, compared with the distribution in 2001, the residential density and employment density in 2009 were more evenly distributed, as the range (difference between the highest and lowest) of residential density declined slightly from 24.9 people per acre to 23.8 people per acres and the range of employment density decreased from 88.5 employments per acre to 74.8 employments per acre. Such change indicated the decentralization of central urban area. On the other hand, the southeastern part of Gilbert study area has become more condensed in the past decade, due to the regional suburbanization process.

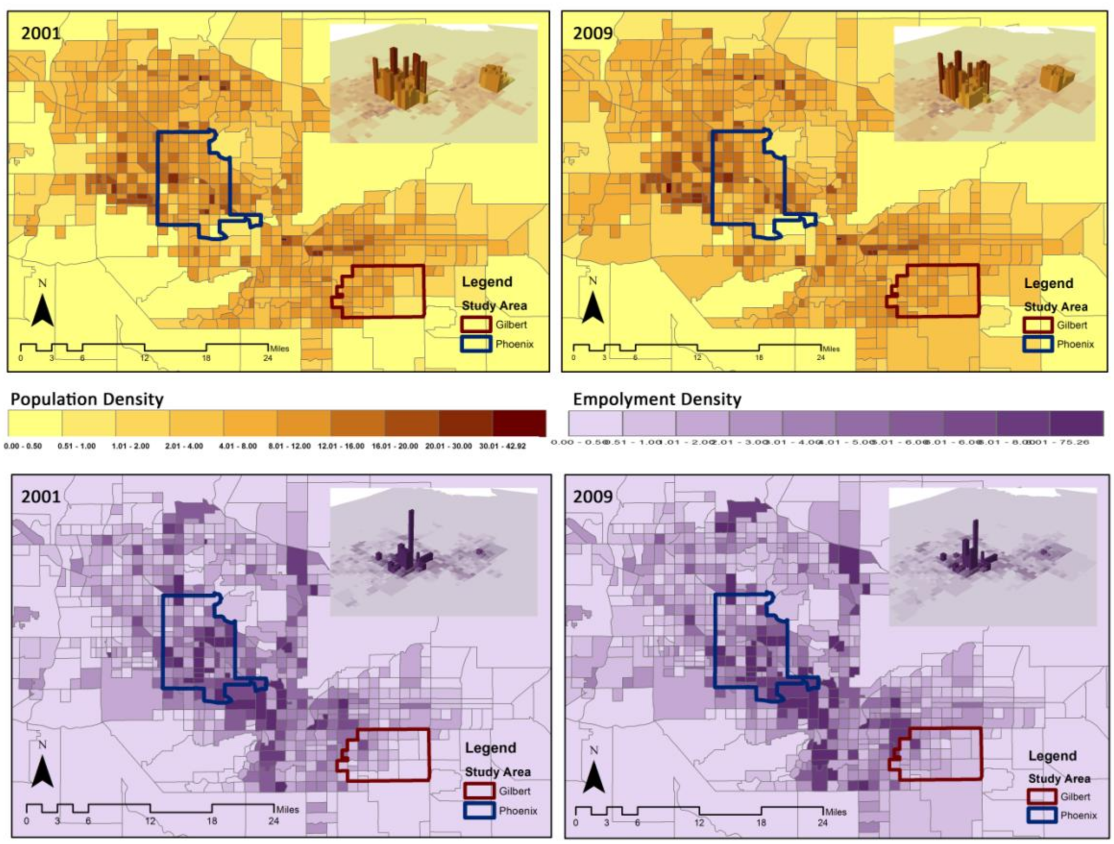


Figure 4.3: Residential and employment density change for Phoenix and Gilbert

Source: Adapted by Author based on ACS population data and Employment data from MAG

To convert the above mentioned census tract level data into TAZ level data, the census tracts were divided into smaller pieces, as the boundary of census tract and TAZ did not coincide with each other (i.e. some census tracts fall into two TAZs). The census tract level data was then reallocated to each smaller polygons based on area information. The TAZ-level data was then developed by aggregating all spatially intersected census tract data together. Eventually, the TAZ level demographic and socio-economic data was applied to implement the trip generation process for Phoenix Metropolitan area. The spatial distributions of these data are attached in Appendix A.

4.2.Phoenix Metropolitan Area Regional Travel Pattern

4.2.1. Trip Production

4.2.1.1. Trip production with Cross Classification Method

Although the cross classification method was used as the major trip production estimation method, different detailed processes were implemented for years 2001 and 2009, due to data quality limitation. The specific procedures are discussed in the following paragraphs.

Instead of using the 2001 NHTS survey data to generate the cross classification table, the NHTS transferability table was used to estimate generation rates for Phoenix Metropolitan area, as there was no sufficient sample number and trip attributes in 2001 NHTS data. In the transferability table, households within each census tract were stratified into 25 categories by household size and vehicle number. Number of households, vehicle trip generation rate as well as HBW and HBSH adjustment index for each household category were provided in the table. The HBW and HBSH productions were estimated using the following formula for year 2001:

$$Trip_i\ production\ for\ Census\ Tract_k = \sum_{j=1}^{n} number\ of\ household_{kj} * vehicle\ trip\ generation\ rate_{jk} * trip_i\ \ adjustment\ index_{jk}$$

Where,

i, is the type of trip, such as HBW and HBSH;

j, is the type of household, classified by household size and vehicle ownership;

k, is the k^{th} census tract.

The trip production cross classification table for 2009 was generated using 2009 NHTS data. The sampled households were classified into 48 categories by household size, household vehicle ownership, and household income. The numbers of HBW and HBSH trips were aggregated by household types. The trip generation rates for each kind of household category were then calculated using the following formula. The cross classification table for households within only one people is tabulated in Table 4.2 and the entire table can be achieved from Appendix B.

$$Trip\ production\ rate_{ij} = \frac{Total\ number\ of\ trips(type_{ij})}{Total\ number\ of\ households_j}$$

Where,

i, is the type of trips, such as HBW or HBSH;

j, is the category of household.

Table 4.2: 2009 HBW and HBSH trip generation rate

Household size	Household vehicle	Household income	HBW generation rate	HBSH generation rate
1	<=1	1=<$10,000	0.167	1.542
		2=$10,000-$19,999	0.140	1.364
		3= $20,000 to $34,999	0.288	1.268
		4= $35,000 to $49,999	0.580	1.232
		5= $50,000 to $69,999	0.577	1.282
		6> =$70,000	0.545	0.955

>1	1=<$10,000	0.200	1.000
	2=$10,000-$19,999	0.182	1.000
	3= $20,000 to $34,999	0.091	2.364
	4= $35,000 to $49,999	0.304	1.174
	5= $50,000 to $69,999	0.647	1.118
	6>=$70,000	0.548	1.290

Source: Adapted by Author

The calculated trip generation rates were assigned to TAZs based on their average household size, household vehicle ownership, and household income, estimated using 2009 ACS data. The TAZ level trip productions were then calculated by multiplying the number of households within a specific TAZ with the corresponding generation rate. The TAZ level HBW and HBSH production results for 2001 and 2009 are shown in Figure 4.4 and Figure 4.5 separately. The detailed formula for production calculation is shown as below:

$$Trip\ production_{ik} = Trip\ production\ rate_{ik} * number\ of\ household_k$$

Where,

i, is the type of trips, such as HBW or HBSH;

k, is the k[th] TAZ.

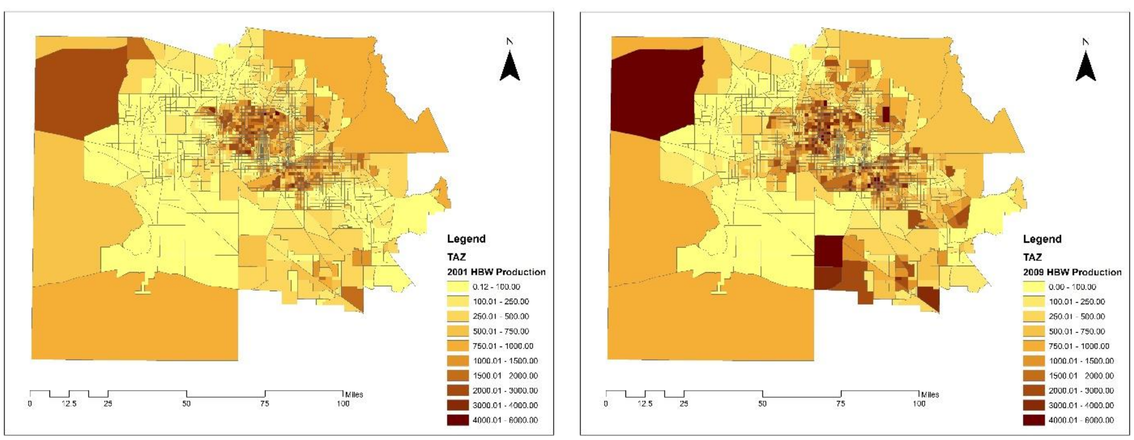


Figure 4.4: 2001 (left) and 2009 (right) HBW Trip Production Result

Source: Adapted by Author

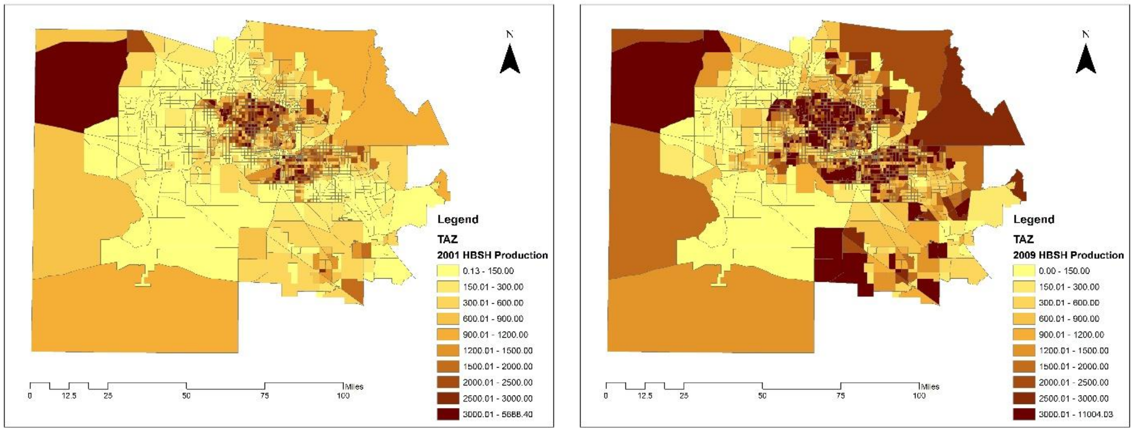


Figure 4.5: 2001 (left) and 2009 (right) HBSH Trip Production Result

Source: Adapted by Author

The final trip production results by trip purpose for both study years are displayed in Figure 4.6. Although this study focused primarily on HBW and HBSH trips, three other kinds of trips such as Home-based Social and Recreational (HBSO), Home-based Other (HBO) and Non Home-based Trips (NHB) were also estimated here, so that the final results could be compared with the original NTHS data to validate the trip production outputs. The major trip purposes distributions remained stable in the past decade, as HBSH and NHB trips were still the most dominant (>50%) trip purpose. According to the trip production results, the total trip number within Phoenix Metropolitan area increased by 57% from 8.0 million to 12.6 million. The number of HBW trips increased by 40%, from 1 million to 1.4 million. Meanwhile the population number within the region increased by approximately 35%.

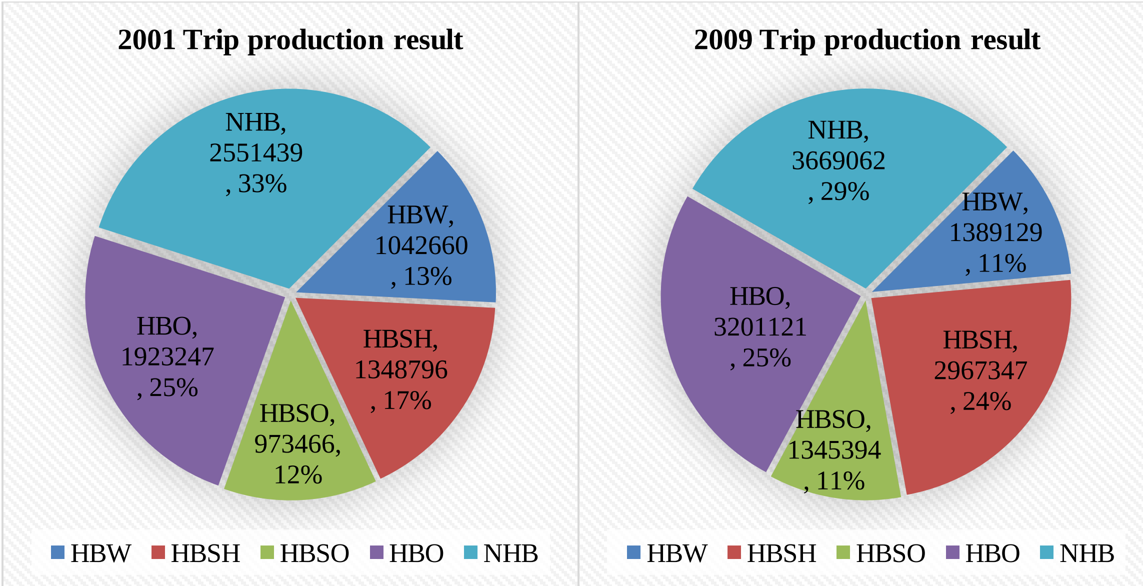


Figure 4.6: 2001 and 2009 Trip Production Result

Source: Adapted by Author

4.2.1.2. <u>Trip Production Result Validation</u>

To validate the trip production results, the trip composition was compared with that from NHTS data. The 2001 trip productions and NHTS survey results are illustrated in Figure 4.7. Compared with the survey data, the 2001 trip production result had a higher portion of HBO trip and a lower portion of HBSH trips. The other trip type percentages were similar with the survey data. There were three possible reasons to such difference: 1) The 2001 NHTS Data summary was for the entire Arizona State; 2) the 2001 NTHS sample size was rather limited, as it was obtained from FHWA website without add-on data; 3) The trip generation rate was not directly generated from the survey data but provided by transferability table, which was adjusted by FHWA based on national data. The difference indicated that in 2001 compared with national average, residents in Phoenix Metropolitan area tended to shop more frequently.

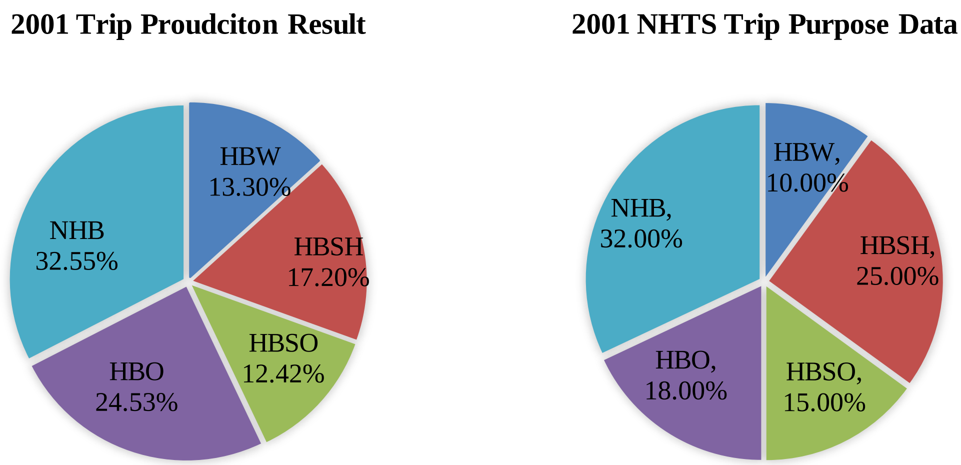


Figure 4.7: Comparison between trip production result and NHTS data for 2001

Source: Adapted by Author based on 2001 NHTS data

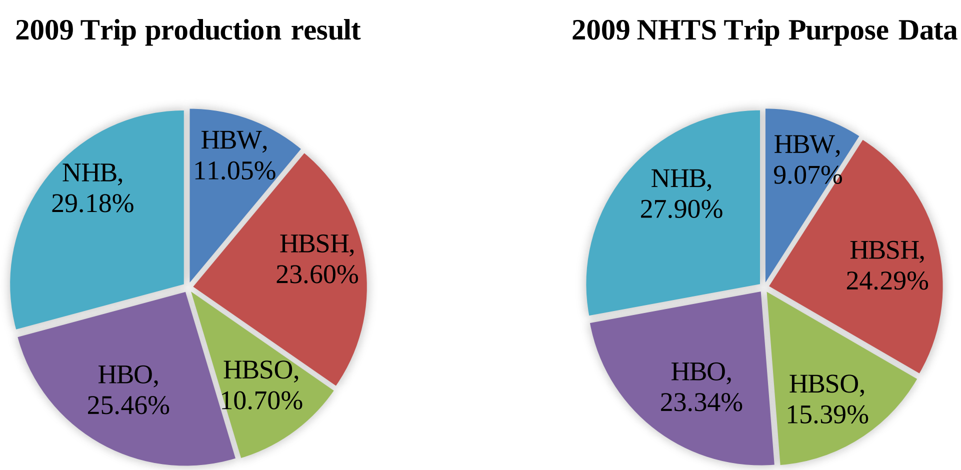


Figure 4.8: Comparison between trip production result and NHTS data for 2009

Source: Adapted by Author based on 2009 NHTS data

The trip production result for 2009, as displayed in Figure 4.8, was more comparable with the distribution from 2009 NHTS. The major differences were the inflation of HBW and NHB trips while HBSO and HBO were underestimated. However, all the differences were controlled within 5%.

4.2.2. Trip Attraction

The regression method was commonly employed to implement trip attraction process (NCHRP, 365). Information such as trip destination and employment data was required to build such models. Due to confidentiality issues, however, the detail trip destination data was not achievable in this study. The linear regression method recommended by NCHRP and implemented by some MPOs indicated that the number of trip attraction was proportionate with the number of disaggregated employment. Therefore, the attractions were estimated by allocating total production based on the corresponding employment type. The final trip attraction rate per employment was calculated and compared with the national average data from NCHRP 716 and other MPO trip attraction results to validate this method.

4.2.2.1. Home-based Work Trips Attraction

HBW trip attractions were estimated by reallocating HBW production to TAZs based on their total employment number, including basic, retail, and service employments. The results for years 2001 and 2009, as illustrated in Figure 4.9, suggested that the commuting trip attractions were more sprawled in 2009 and large amount of trips were attracted to the urban fringe TAZs, where used to be rural areas in 2001.

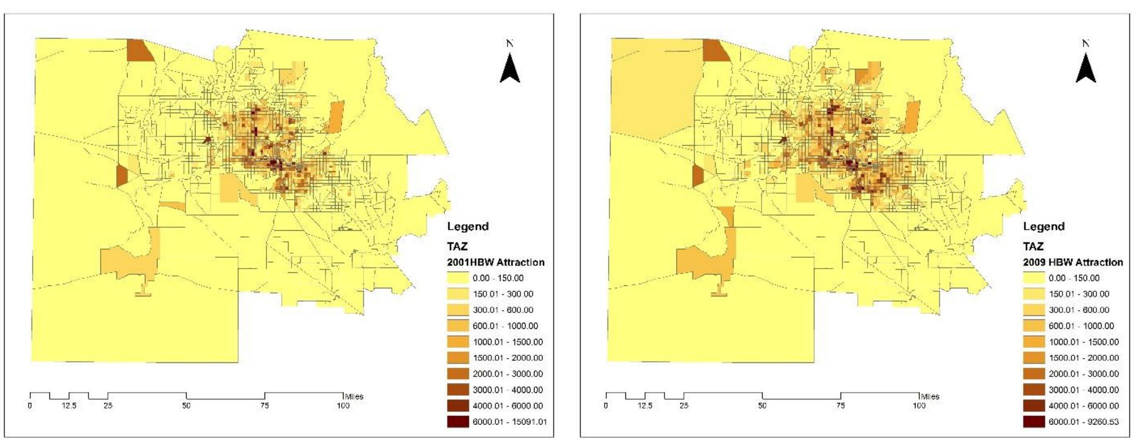


Figure 4.9: 2001 (left) and 2009 (right) HBW Trip Attraction Result

Source: Adapted by Author

HBW trip attraction per total employment within the Metropolitan area was calculated for year 2001 and 2009, as tabulated in Table 4.3. The calculation results were compared against national ratio from NCHRP 716 report and data from two MPOs, who estimated attractions with total employment data. The results suggested that the method introduced in this thesis was quite solid, as the trip attraction ratios for both study years were quite reasonable compared with data from other sources.

Table 4.3: HBW Trip Attraction per Total Employment for 2001 and 2009

Year	HBW Production	Total Employment	Trip Attraction /Employment	Results from other sources		
				NCHRP 716	SCAG[1]	MIC[2]
2001	1042660	866444	1.203	1.200	1.075	1.18
2009	1389128	1364347	1.018			

1. Data Source: Southern California Association Government (SCAG).
2. Data Source: Duluth-Superior Metropolitan Institute of Council (MIC).

4.2.2.2. Home-based Shopping Trips Attraction

Most MPOs used retail employment data to estimate HBSH attractions. The retail employments were defined as employments with two-digit NAICS codes 44-45 or SIC codes 52-59. However, based on the NHTS data, some shopping trips were described as trips to financial institutions such as banks. Thus, part of the finance employments with two-digit NAICS codes 52-53 or SIC codes 62-65 were also included in the retail employments to estimate HBSH attractions. The HBSH attraction estimation results are displayed in Figure 4.10.

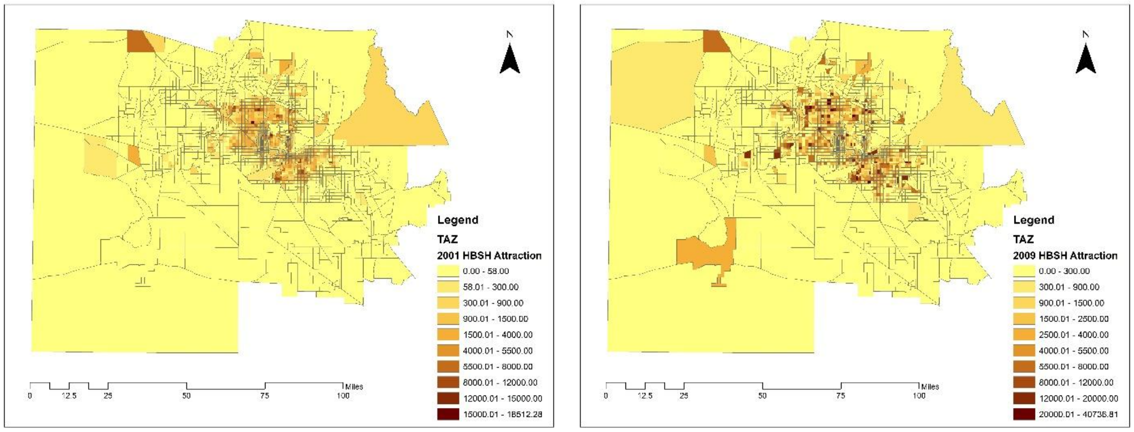


Figure 4.10: 2001 (left) and 2009 (right) HBSH Trip Attraction Result

Source: Adapted by Author

The HBSH trip attractions per retail employment calculation results for Phoenix Metropolitan area are tabulated in Table 4.4. As national reports doesn't analyze HBSH as a separate trip purpose (usually included in the HBO trips), the calculation results were only compared with data from two MPOs. It seems that the results from this study were slightly higher compared with two other regions. However, considering the fact that Phoenix Metropolitan area had a higher portion of HBSH trips compared with national average data, as analyzed in trip production section, this result was quite reasonable.

Table 4.4: HBSH Trip Attraction per Retail Employment for 2001 and 2009

Year	HBSH Production	Total Employment	Trip Attraction /Employment	Results from other sources	
				SCAG[1]	MIC[2]
2001	1348796	125537	10.744	9.260	8.420
2009	2967347	304658	9.740		

1. Data Source: Southern California Association Government (SCAG).
2. Data Source: Duluth-Superior Metropolitan Institute of Council (MIC).

4.2.3. Trip Distribution

4.2.3.1. Regional Network Development

The road network hierarchy was identified based on the road types and road length and the classification standards are tabulated in Table 4.5.

Table 4.5: Road Hierarch Identification Standards

	>100000 Km	>50000 and <= 100000 Km	>5000 and <= 50000 Km	<=5000 Km
The US-highway and interstate highway	Freeway	Freeway	Freeway	Freeway
State Route	Expressway	Expressway	Expressway	Expressway
Avenue	Principal	Major Road	Minor Road	Collector
Street	Principal	Major Road	Minor Road	Collector
Boulevard	Major Road	Minor Road	Minor Road	Collector
Drive, road, pl, ln, circle	Major Road	Minor Road	Collector	Collector

Data source: NCHRP 365 Report

Road hierarchy alone was not sufficient to define the average travel speed for each segment of road network, as the speed also relied heavily on the location of segments. For example, the average travel speed in urban area tends to be smaller than that in the rural area. Thus, the location of road segments was classified into four categories: rural, suburban, urban and Central Business District (CBD) in this study. The classification of TAZ location was based on the spatial corresponding TAZ level socio-economic employment and residential density (Plessis, 2001; Albrecht, 2006). The criteria are listed in Table 4.6. If a road segment was located within a suburban TAZ, then it would be considered as a suburban road. The classification results, as displayed in Figure 4.11, indicated that Phoenix Metropolitan area has experienced dramatic suburban growth in the past decade, as there were substantially more suburban TAZs within the area.

Table 4.6: TAZ location Identification Method

Household Density	Employment Density ≤0.2	Employment Density >0.2 and ≤4	Employment Density >4 and ≤40	Employment Density >40
≤0.15	Rural	Rural	Suburban	Urban
> 0.15 and ≤2	Rural	Suburban	Urban	CBD
>2	Suburban	Urban	Urban	CBD

Data source: Adapted by author based on Plessis (2001) and Albrecht (2006)

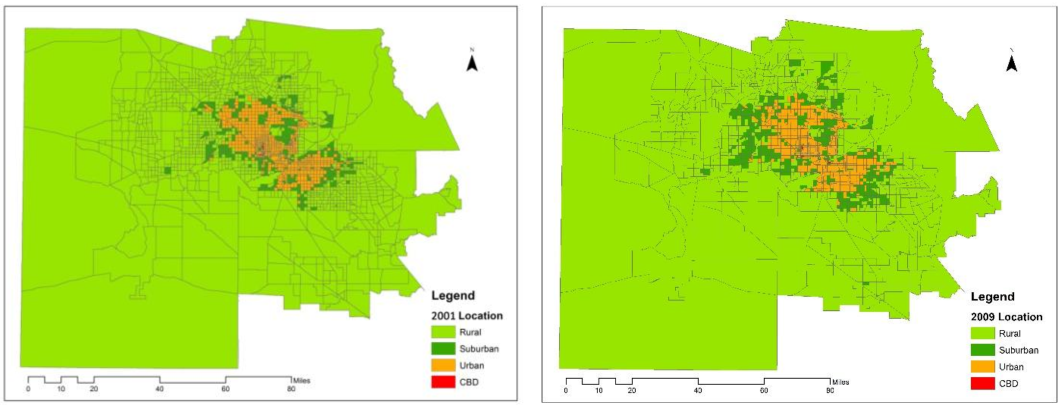


Figure 4.11: 2001 (left) and 2009 (right) TAZ Location Identification Results

Source: Adapted by Author

The Free Flow Speed (FFS) was assigned to each road segment based on the road hierarchy and the location of the segment (NCHRP 365) and the standards are listed in Table 4.7. The average urban and rural speed was assigned to road segments within suburban area. As the road network utilized in this study didn't have median information, the average speed for divided and undivided principal arterial and major arterial was assigned to these types of road facilities.

Table 4.7: Free Flow Speed (FFS) Assignment Standard

Road Hierarchy	Median	Area Type		
		CBD FFS (MPH)	Urban FFS (MPH)	Rural FFS (MPH)
Freeway		60	60	60
Expressway		45	45	55

Principal Arterial	divided	35	45	50
	undivided	35	35	45
Major Arterial	divided	35	45	40
	undivided	35	35	35
Minor Arterial		30	35	35
Collector		15	30	30

Data Source: NCHRP 365.

4.2.3.2. Regional Travel Time Cost Matrix Development

The travel time cost between each pair of Origin-Destination (OD) matrix was developed using the OD cost tool in ArcGIS 10.0. TAZs were first converted into centroid points as inputs for origins. This conversion was based on the assumption that the households were evenly distributed within the TAZ area. The HBW TAZ destination points were generated using the total employment point data. The geometric center of employment points (weighted by employment number) within a TAZ was set as the destination points for the TAZ. Similarly TAZ destination points for HBSH were generated using the retail employment data. The shortest time path was selected as the travel time cost between each pair of TAZs. A GIS model was built to facilitate the calculation process, as it was rather time consuming to calculate the OD cost matrix. The model is illustrated in Figure 4.12.

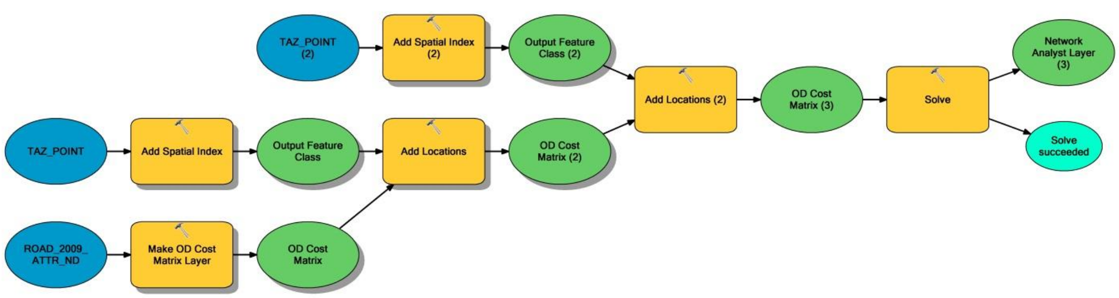


Figure 4.12: GIS Model for Travel Time Cost Generation

Source: Adapted by Author

The OD cost matrix obtained from the previous steps could only show travel time for inter-zonal trips. The intra-zonal travel time was calculated as zero or really small number, which was obviously incorrect. The intra-zonal travel time was calculated using the following formula obtained from NCHRP report 365:

$$Intrazonal\ Time = 0.5 * \sqrt{Zonal\ Area} * 60/Intrazonal\ Speed\ (by\ Area\ Type)$$

Where:

Intrazonal Time, is expressed in minutes;

Zonal Area, is the TAZ area is expressed in square miles;

Intrazonal Speed, is expressed in Miles per Hour (MPH), which can be achieved in the Table 4.8.

Table 4.8: Intra-zonal Free Flow Speed Look up Table

TAZ Location Type	Intra-zonal Free Flow Speed (MPH)
CBD	15
Urban	20
Suburban	25
Rural	30

Data source: NCHRP 365 Report

In addition to the travel time cost on the road, the terminal time costs were also taken into consideration. The terminal times represent time costs at both ends of a trip such as the amount of time and time value of money required to walk to and from a transit mode, to park or access a parked car, to pay parking cost, etc. The terminal time was also estimated and assigned to TAZs based on the location of TAZs, as shown in the following table (NCHRP 365).

Table 4.9: Terminal Time Look up Table

TAZ Type	Terminal Time (Minutes)
CBD	5
Urban	3
Suburban	2
Rural	1

Data source: NCHRP 165 Report

The final travel time between each pair of OD TAZs was generated using the following formula, according to NCHRP 365:

$$Final\ Travel\ Time\ between\ TAZ\ i\ and\ j (i \neq j)$$
$$= Interzoanl\ travel\ time_{ij} + Terminal\ Time_i + Terminal\ Time_j$$

4.2.3.3. Regional Friction Factor Matrix Development

Gamma functions were applied in this study to calculate frication factor matrix from OD travel time cost matrix. The choice was made based on two major reasons: 1) Gamma function is so far the most prevailing method used by MPO and 2) the national average function is available in NCHRP 365 report to validate the local gamma function calibration results.

The basic form of gamma function is shown as below:

$$f(d_{ij}) = a * d_{ij}^{-b} * e^{-c * d_{ij}}$$

Where,

a, *b*, and *c* are the parameters of the function, which should be calibrated by local data;

d_{ij}, is the travel time cost (or travel impedance) between TAZ i and j.

The calibrated local gamma function for 2001 and 2009 HBW and HBSH trips are tabulated in Table 4.10.

Table 4.10: Calibrated Gamma Functions

Trip Type	Source	a	b	c
HBW	2001	3792.726	1.2201	0.0541
	2009	3264.5	0.9313	0.0327
	NCHRP	28507	0.02	0.123
HBSH	2001	166811.6	3.8302	0.000001
	2009	166811.6	3.8302	0.000001
	NCHRP[1]	139173	1.285	0.094

1. a, b, and c for HBO trips in NCHRP 365 report

Data source: National data from NCHRP 365 report, local data calibrated by author

For HBW, the gamma function changed a lot from 2001 to 2009. The value of parameter b declined from 1.22 to 0.93, indicating that the commuting trip length increased within the region. While the HBSH trip length seemed to be quite stable without much variation. Additionally, compared with HBW trips, the trip length distributions of the shopping trips were more similar with exponential distribution, as the values of parameter c were rather small.

4.2.3.4. Gravity Model Application and Validation

The gravity model was implemented with gamma functions obtained from the previous section to generate the trip distribution result. To validate the trip distribution process, the model output travel time distributions were compared with that from the original NHTS data. The HBW and HBSH comparison results are illustrated in Figure 4.13 and 4.14 separately. For HBW trips in 2009, although the most dominant travel time was still approximately 20 minutes for the entire region, more 10-minute trips shifted to 20-minute trips. This reflected the fact that the employments were more widely spread over the region. While in the case of HBSH, there was a significant increase in the number of trips which were less than 20 minutes during the study period, indicating a potential reduction in shopping trip travel time. Additionally, the model output results for shopping trips were more comparable to that from NHTS data, compared with commuting trips. To further validate the similarities in distribution, Chi-square Goodness of Fit tests were performed to determine whether the differences were statistically significant. The test results for four scenarios were all above 0.99, suggesting that the null hypothesis (the distribution of *TransCAD* output and NHTS data arethe same) cannot be rejected. In conclusion, the trip distribution results were quite valid.

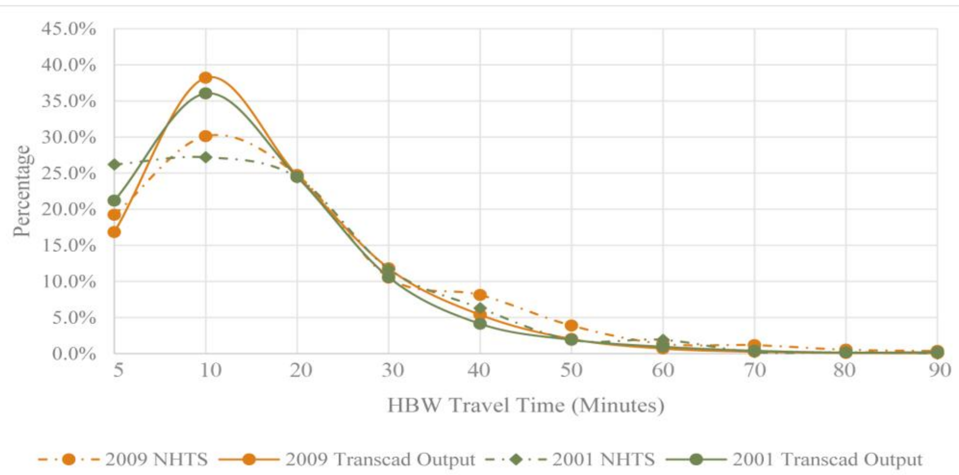


Figure 4.13: HBW Travel Time Comparison

Source: Adapted by Author

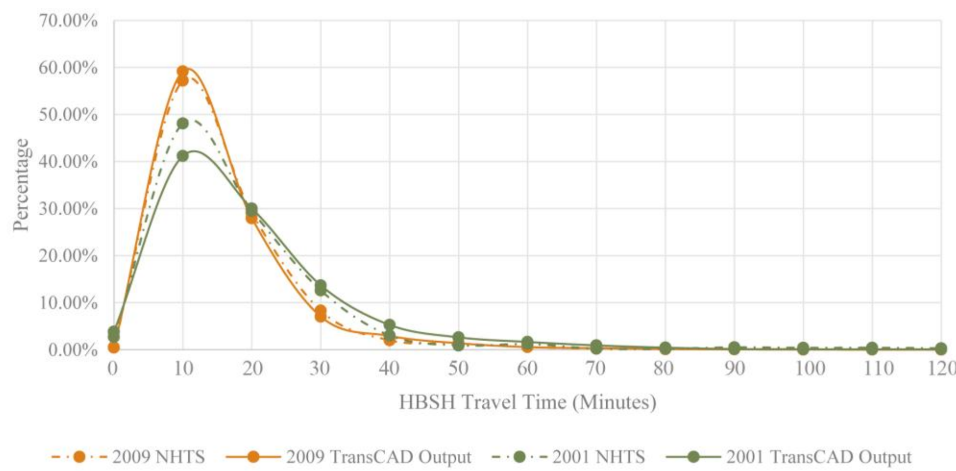


Figure 4.14: HBSH Travel Time Comparison

Source: Adapted by Author

4.3.Travel Pattern Analysis for Phoenix and Gilbert

4.3.1. Local vs. Non-local Residents

Trips associated with Phoenix and Gilbert study areas were further classified into two categories: 1) trips generated by local residents and 2) trips generated by non-local residents but were attracted by facilities within Phoenix or Gilbert. The first type was calculated as the sum of intra and inter-out trips, while the non-local ones were the inter-in trips. The results were further analyzed to determine how suburbanization during the study period changed the attractiveness utilities for both urban and suburban areas.

4.3.2. Phoenix Residents vs. Gilbert Residents

Travel behaviors for local residents from both study areas were analyzed to see whether suburban residents were more energy intensive and whether the difference between them were reduced due to the more condensed development within suburban areas. First of all, the variations for trip frequency and average length for intra and inter-out HBW and HBSH trips were studied over time. The overall VMT variations for both local inhabitants were then estimated and results revealed whether the change in frequency and trip length would reduce the energy consumption for suburban residents. In addition to the quantity change analysis, the spatial distribution variations of those local trips were also visualized using *TransCAD* to explore the potential rationale behind the variations over time.

4.4.Transportation Energy Consumption for Phoenix and Gilbert

4.4.1. Regional Vehicle Composition and MPG

Regional vehicle composition and the average Miler per Gallon (MPG) information were obtained from NHTS vehicle tables. In 2001 NHTS, the 933 surveyed vehicles were classified into 8 categories such as: auto vehicles, van, sport utility vehicles, pickup truck, other truck, recreational vehicles, motorcycles and other specified vehicles. While in 2009, a total of 9191 vehicles were surveyed and one more vehicle category "golf cart" was added into the inventory. However, this type only represents 0.96% of the entire vehicle inventory. The 2001 and 2009 regional vehicle compositions are illustrated in Figure 4.15 and 4.16.

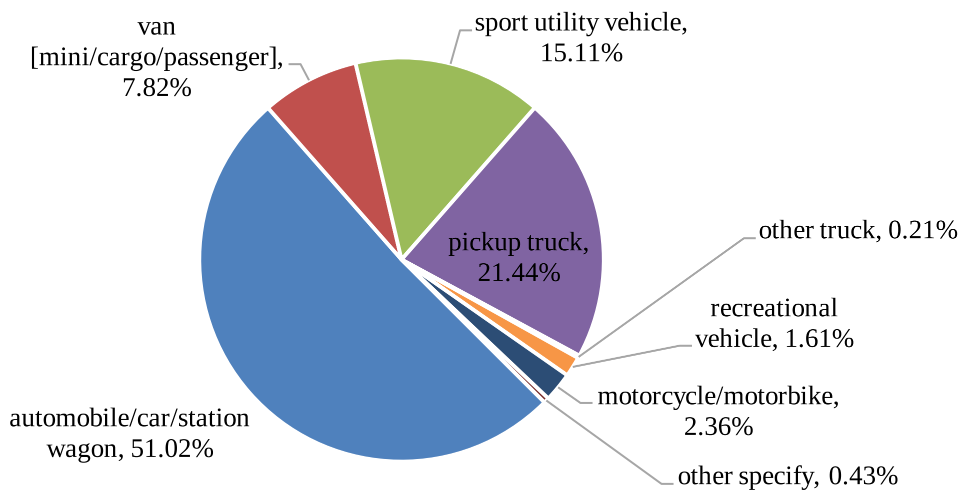


Figure 4.15: 2001 Regional Vehicle Composition

Source: Adapted by Author, based on 2001 NHTS data

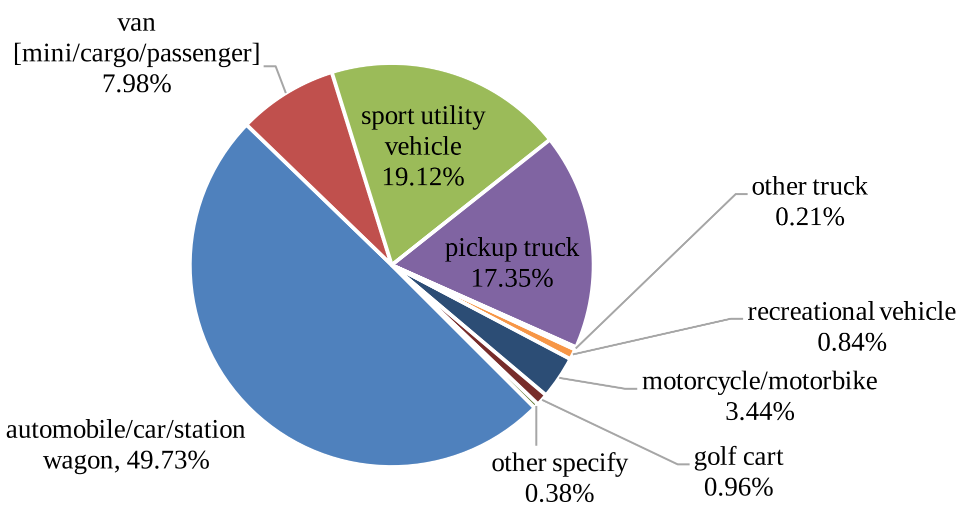


Figure 4.16: 2009 Regional Vehicle Composition

Source: Adapted by Author, based on 2009 NHTS data

Figure 4.15 and 4.16 illustrated the similar regional vehicle composition patterns from 2001 to 2009. The most dominant vehicle type was auto vehicles in both study years, occupying approximately 50% of the entire vehicle inventory. The portion of pickup truck decreased from 21.44% to 17.35%, while the percentage of sport utility vehicle and motorcycles increased slightly by around 5%.

The MPG information for each sampled household vehicle was also provided in NHTS data. According to FHWA, This attribute was originally adapted using Environmental Protection Agency (EPA) method based on the vehicle model and year of manufacture. Average MPG was calculated for each type of vehicle to estimate the gasoline consumption. Some 2001 MPG data, such as that for other trucks, recreational vehicles and other specified vehicles, was actually borrowed from 2009 data, as there was no relevant information in 2001 survey. However, these vehicle types only occupied 2.25% of the entire vehicle inventory. Therefore, the error was expected to be limited. The calculated average MPGs for each type of vehicles are tabulated in Table 4.11. Based on the calculation results, almost all MPGs increased from 2001 to 2009, especially for sport utility vehicles, pickup truck and motorcycles.

Table 4.11: 2001 and 2009 Vehicle MPGs

Vehicle Type	Percentage	2001 MPG	2009 MPG	Change
automobile/car/station wagon	49.73%	20.43	22.34	9.35%
van [mini/cargo/passenger]	7.98%	16.96	18.50	9.04%
sport utility vehicle	19.12%	14.03	16.94	20.76%
pickup truck	17.35%	13.44	15.74	17.08%
other truck	0.21%	7.58	7.58	N/A
recreational vehicle	0.84%	3.60	3.60	N/A
motorcycle/motorbike	3.44%	41.95	48.21	14.91%
golf cart	0.96%	N/A	13.80	N/A
other specify	0.38%	11.37	11.37	N/A

Data source: 2001 and 2009 NHTS data, adapted by author

4.4.2. Energy Consumption Estimation

To estimate the study area energy consumption, Vehicle Miles Traveled (VMT) was calculated by multiplying the number of trips between two TAZs with the corresponding average trip length. The average trip length was the shortest route length between the two TAZs. The origin and destination points were the same as the ones used in travel time cost estimation process.

The energy consumption was estimated using VMT data from trip distribution and the MPG data from NHTS. Based on the assumption that the percentage of VMT accomplished by certain vehicle type was proportionate to the fraction of that type of vehicles within the entire vehicle inventory, the following formula was employed to estimate energy consumption:

$$Energy\ Consumption = \sum_{i=1}^{n} VMT * Vehicle_i\ Percentage * Vehicle_i\ MPG$$

Where,

VMT, vehicle mile travel;

i, is the type of vehicle;

n, is the number of vehicle categories.

4.5.GHG Emissions for Phoenix and Gilbert

4.5.1. Carbon Dioxide Emission Estimation

The CO_2 emission was further assessed based on the energy consumption results. According to EPA, an average of 8.8 Kg of CO_2 will be generated after consuming one gallon of gasoline by automobiles. Based on this standard, the CO_2 emissions were calculated using the following equation:

$$CO_2\ Emission = Energy\ Consumption\ (Gallong/day) * 8.8\ (Kg/Gallon)$$

4.5.2. Nitrous Oxide Emission Estimation

To estimate Nitrous Oxide emissions, vehicles were reclassified by fuel type and emission technology which was directly associated with the manufacture year of the vehicle. The classification results for both study years are tabulated in Table 4.12. The detailed calculation formula is shown as follow:

$$N_2O\ Emission = VMT(mile) * FTP_i(g/mile) * Percent_i/1000$$

Where,

FTP_i is the N_2Oemission standard for vehicle type i.

$Percent_i$ is the regional portion of vehicle type i.

Table 4.12: Vehicle Nitrous Oxide emission classification result for 2001 and 2009

Vehicle Type	Fuel	Emission Control Technology	Year of Manufacture	2001Inventory		2009 Inventory		FTP[1] (g/mi)
				Num	Percent	Num	Percent	
Passenger Cars	Gas	Oxidation Catalyst	after 1975	437	50.93%	4261	47.83%	0.042
		Non-Catalyst	1973-1974	3	0.35%	175	1.96%	0.017
		Uncontrolled	before 1973	12	1.40%	0	0.00%	0.017
	Diesel	Advanced	after 1996	1	0.12%	17	0.19%	0.001
		Moderate	1983-1995	0	0.00%	1	0.01%	0.001
		Uncontrolled	before 1983	3	0.35%	3	0.03%	0.001
Light Truck	Gas	Tier 0	after 1980	365	42.54%	3860	43.33%	0.090
		Oxidation Catalyst	1975 - 1979	7	0.52%	0	0.00%	0.054
		Non-Catalyst	1973 - 1974	0	0.00%	112	1.26%	0.019
		Uncontrolled	before 1973	2	0.23%	0	0.00%	0.019
	Diesel	Advanced	after 1996	1	0.12%	54	0.61%	0.002
		Moderate	1983-1995	2	0.23%	7	0.08%	0.002
		Uncontrolled	before 1983	0	0.00%	4	0.04%	0.002
Motorcycle	N/A	Non-Catalyst	after 1996	14	1.63%	327	3.67%	0.007
		Uncontrolled	before 1996	11	1.28%	88	0.99%	0.009

1. FTP: The emission standard is determined using U.S. Federal Test Procedure.

Data source: 2001 and 2009 NHTS data and EPA, adapted by author

It is an international standard to express GHG emissions in the unit of Carbon Dioxide equivalent, commonly written as CO_2e (EPA, 2013). A given quantity of GHG was converted into the amount of CO2e by multiplying the amount of gas emission with its global warming potential (GWP). In this study, the total CO_2e was estimated by aggregating the amount of CO_2 and CO_2e of Nitrous Oxide together. The formula for total CO_2e is shown as below. The GWP for different type of GHG can be retrieved from table 3.1.

$$Total\ CO_2e\ Emission = GWP_{CO_2} * CO_2\ Emission + GWP_{N_2O} * N_2O\ Emission$$

4.6. Regression Model Development and Testing

OLS regression models were developed for individual HBW and HBSH VMT generation for years 2001 and 2009 on three different study scales: entire region, urban, and non-urban areas. The incremental segment tests were used in this study to determine two separate models should be used for different area in Phoenix Metropolitan Area. The test process is shown as follow:

H_0: the VMT generation patterns from urban and non-urban TAZs are similar;

H_1: the VMT generation patterns from urban and non-urban TAZs are different.

$$F_0 = \frac{\left[SSE_p - (SSE_1 + SSE_2)\right]/(J+1)}{(SSE_1 + SSE_2)/[(N_1 - J - 1) + (N_2 - J - 1)]} =< F_{\alpha,J,n}$$

Where,

SSE_p, is the sum of square error for the regional model;

SSE_1, SSE_2 : are the sum of square error for urban and non-urban models;

J is the number of variable used in the model;

N_1, is the sample number in urban models;

N_2, is the sample number in non-urban models.

F_0 was compared with F statistic to determine whether the null hypothesis should be rejected or not. In other words, if the result is statistically significant, then two separate models should be used to estimate the VMT generation pattern, otherwise the patterns seem to be similar in both areas. Some hypotheses (but not all) of the OLS regression model were tested to validate the models. The tests included in this research were normality test, heteroskadasticity test, and multi-collinearity test.

Additionally, the spatial models were developed in *Goeda*, an open source program, developed by Arizona State University specialized in spatial regression model development. Robust Lagrange Multiplier (LM) lag and error tests were conducted based on the OLS regression results to determine which specific type of spatial model was more appropriate for Phoenix Metropolitan Region. Spatial-Lag Model indicates that the variable value from defined neighborhood units can cast influence on the dependent variables in the unit *i*. With spatial-lag in traditional OLS models, the assumption of uncorrelated error terms and independent observations are violated, rendering the estimate results biased and inefficient. Whereas the Spatial-Error Model suggests that error terms in different units are auto-correlated, violating the assumption that the errors are randomly distributed. With the spatial errors in OLS, although the estimates will remain unbiased, the results will be inefficient. The detailed model selection process is displayed in Figure 4.17.

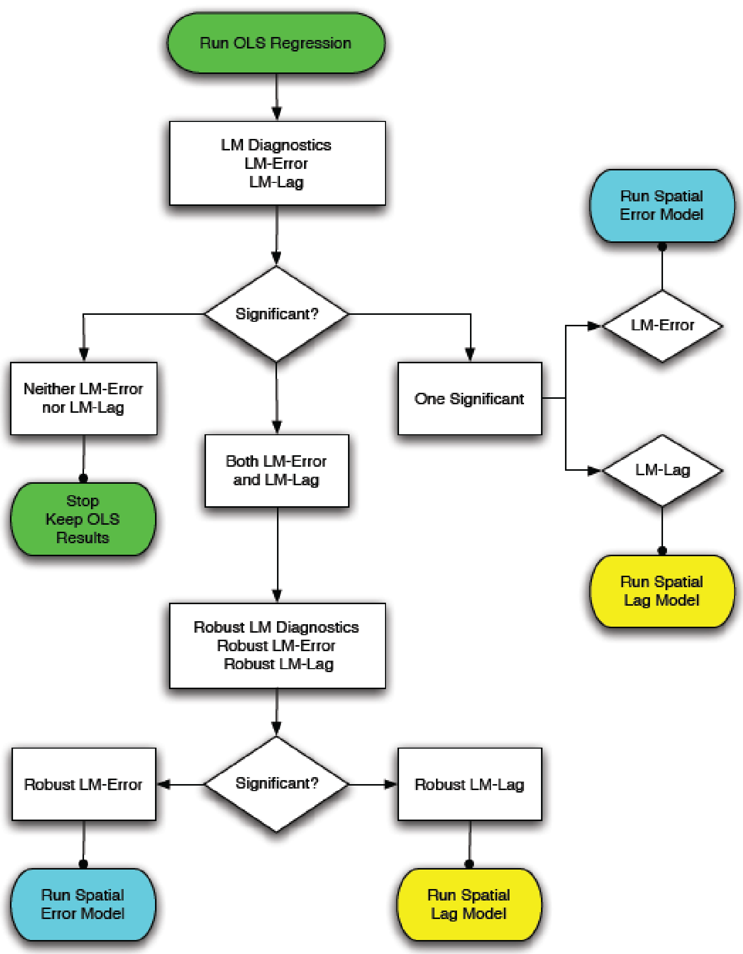


Figure 4.17: Spatial Regression Model Decision Process

Source: Geoda Workbook Pp.199

CHAPTER 5

STUDY RESULT COMPARISON FOR PHOENIX AND GILBERT

5.1.Suburban Growth in Phoenix Metropolitan Area

5.1.1. Total Employment Spatial Distribution Change

From 2001 to 2009, a significant amount of development took place in the suburban area of Phoenix Metropolitan region. Employment number within the region has increased by 56.3% from 0.87 million to 1.36 million. As shown in Figure 5.1, the most dramatic increase did not concentrated within the central urban area but dispersed widely along the urban boundary, especially in the northern suburban areas and areas adjacent to Gilbert study area. The spatial distributions of TAZ level total employment for 2001 and 2009 are attached in Appendix C.

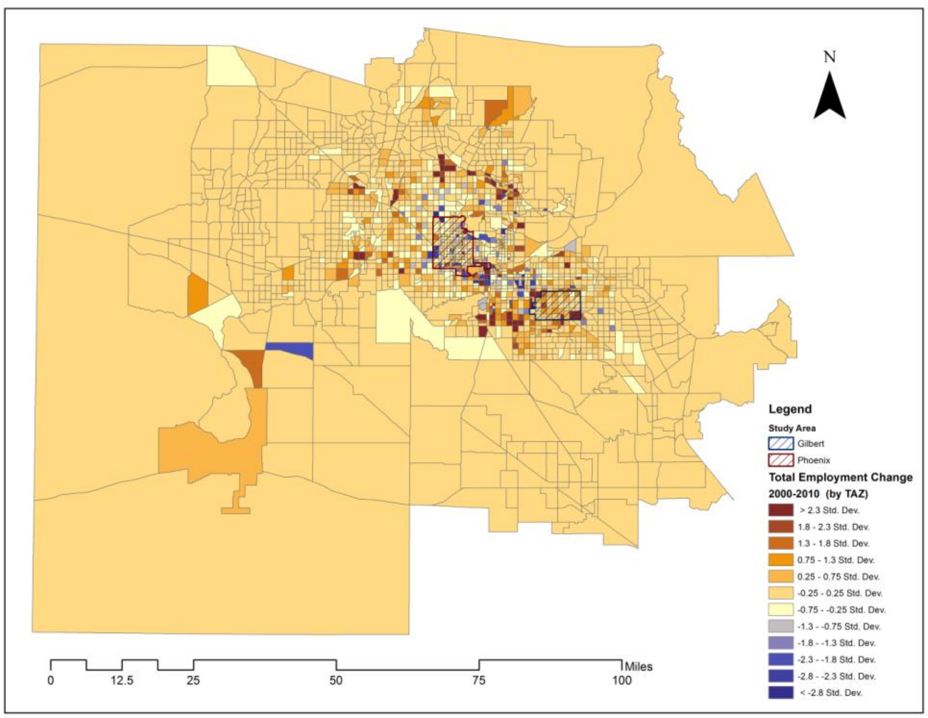


Figure 5.1: Total Employment Change from 2001 to 2009

Source: Adapted by Author, based on 2001 and 2009 employment data from MAG

For Phoenix Study area, the number of total employment declined by 4.5%, from 0.27 million to 0.26 million. While in Gilbert the corresponding number amplified by 125.6%, from 16 thousands to 36 thousands. The growth was particularly intensive in the southeastern part of Gilbert. Additionally, the growth rate in Gilbert surpassed the regional average by 69.3%. Furthermore, as shown in Figure 5.2, compared with inhabitants in Gilbert area, central Phoenix residents had less accessibility to those southern suburban employments in 2009.

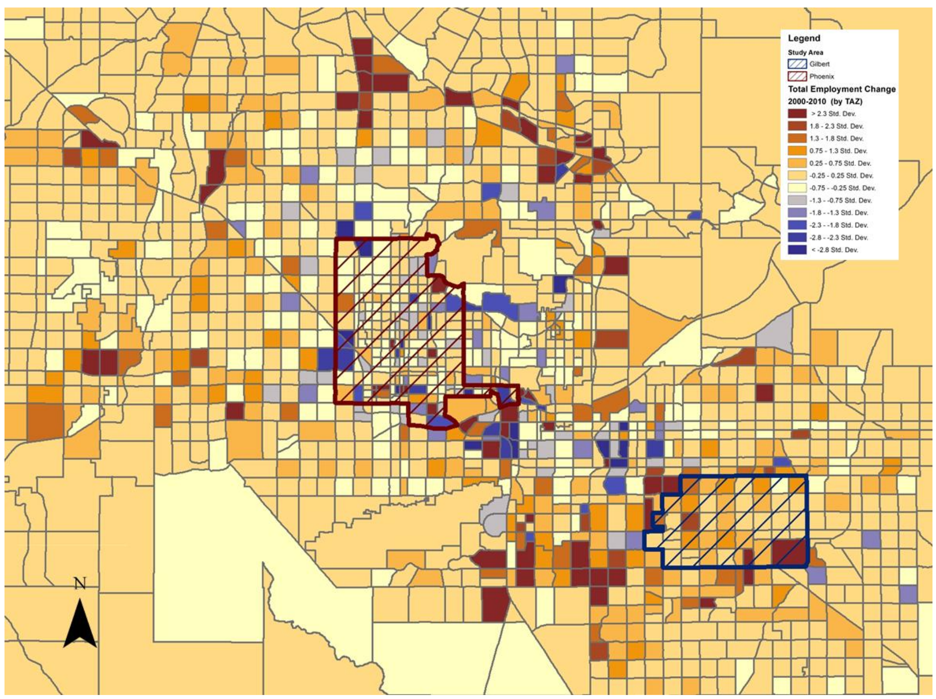


Figure 5.2: Total Employment Change in Phoenix and Gilbert

Source: Adapted by author based on 2001 and 2009 employment data from MAG

5.1.2. Retail Employment Spatial Distribution Change

In the last decade, the variation patterns of retail service were quite similar with the variation pattern for total employment, as shown in Figure 5.3. The growth rate for retail service within the region was 130%, which almost tripled that for total employment. Additionally, compared with total employment change, the retail employment sprawled farther into remote suburban area and the growth was more evenly distributed in the urban peripheral area.

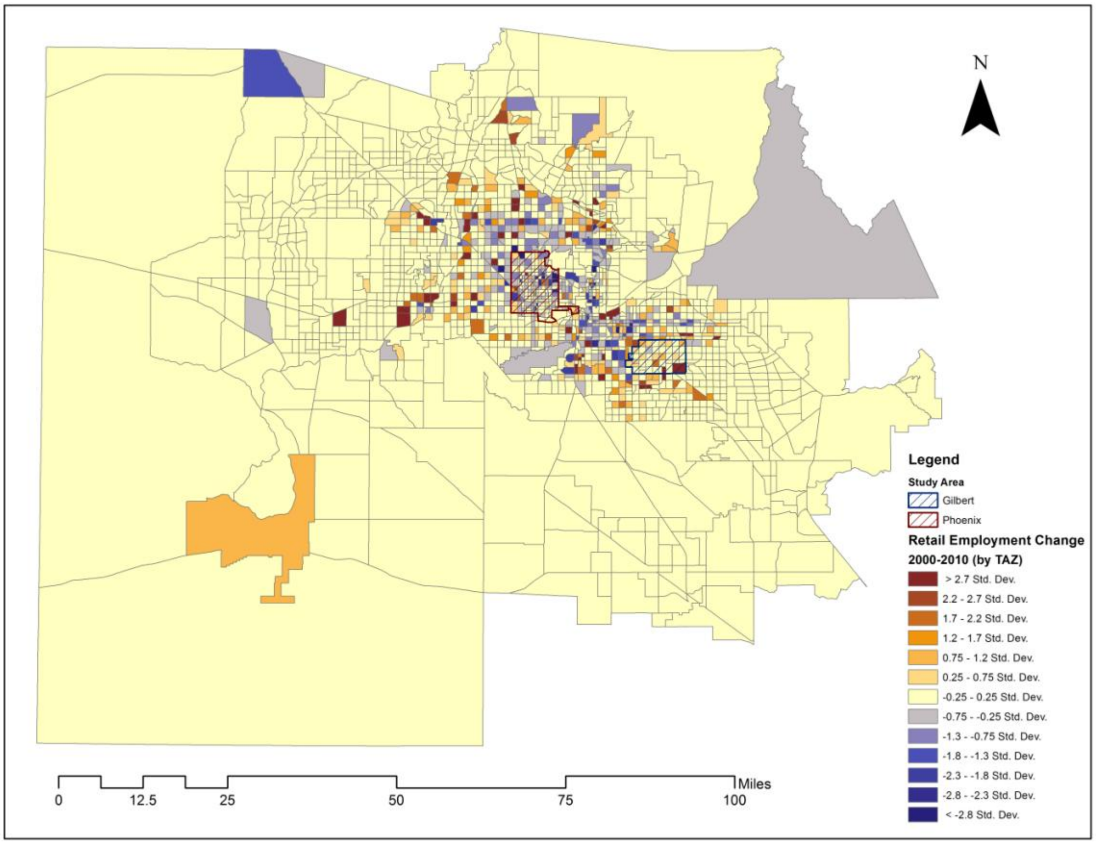


Figure 5.3: Retail Employment Change from 2001 to 2009

Source: Adapted by author based on 2001 and 2009 employment data from MAG

Gilbert has witnessed a dramatic growth in retail service during the study period. The total number of retail employment in Gilbert increased from 1.8 thousands to 5.7 thousands. The service in Phoenix, however, deteriorated significantly by 21.3% from 21 thousands to around 17 thousands. As illustrated in Figure 5.4, almost no TAZ level retail service in central Phoenix has been intensified during the study period. Meanwhile, the southeastern part of Gilbert, with the most significant growth has become the new retail service center for residents in the southern part of the region.

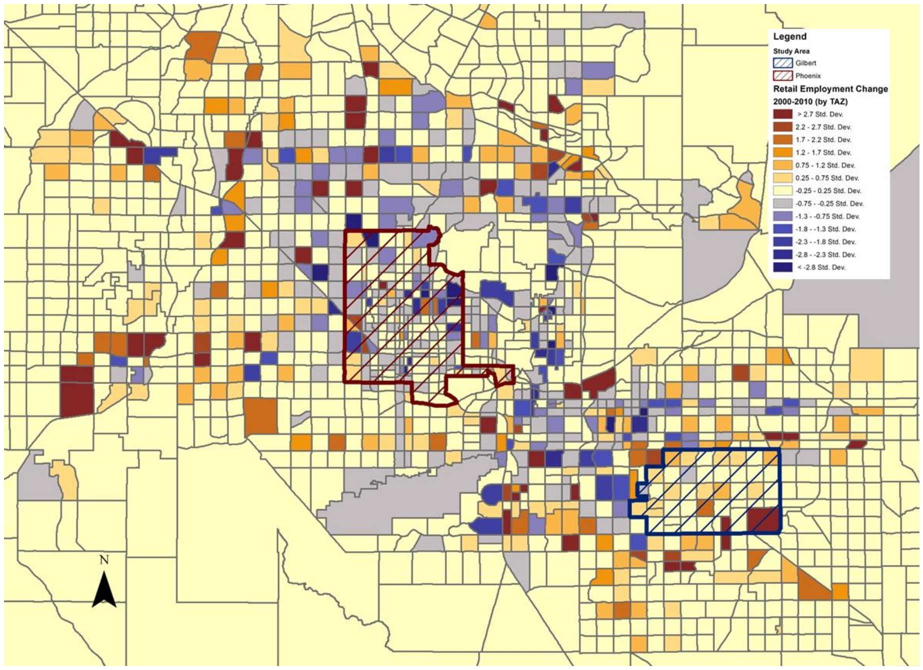


Figure 5.4: Total Employment Change in Phoenix and Gilbert

Source: Adapted by author based on 2001 and 2009 employment data from MAG

Due to the slight difference in the variation patterns for total employment and retail service employment, the HBW and HBSH travel behaviors were also expected to evolve in different manners. The travel behavior variation patterns for commuting and shopping trips are further discussed separately in the following two sections.

5.2. HBW Variation Analysis for Phoenix and Gilbert

5.2.1. HBW Travel Pattern Variation Analysis

From the regional perspective, the HBW trips from non-local inhabitants and study area local residents were compared to reveal if the suburban development changed the attractiveness of TAZs within central city and suburban area over the study period. The compositions of trip number associated with both study areas are shown in Figure 5.5. The number of HBW trip increased for both areas. However, the growth speed for

Gilbert area was 108.1%, which was significantly larger than central Phoenix. The majority of trip growth for central Phoenix was contributed by the population growth outside of central Phoenix area, as the total number of HBW generated by local residents dropped slightly during the study period. Despite the fact that the proportion of HBW inter-in trip number increased for both areas, the increase was 45% in Gilbert area, more dramatic than the 12.5% in central Phoenix. This indicated that Gilbert has become more attractive to adjacent inhabitants as a work destination. Whereas, Phoenix was still more attractive to people regionally, as the average commuting trip length from outside for central Phoenix was longer in 2009. Trip composition difference between the two study areas, however, has been reduced.

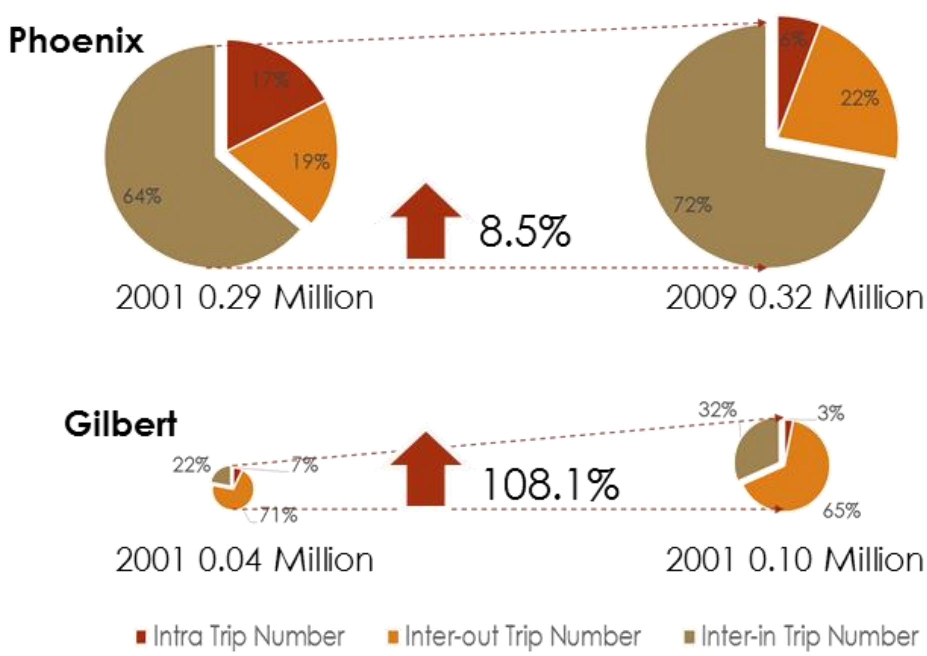


Figure 5.5: HBW Travel Pattern for Local and Non-local Residents

Source: Adapted by author

In addition to the trip frequency variation, the average trip number has also changed significantly. As illustrated in Figure 5.6, for central Phoenix area, the commuting trip length generated by local residents was more than doubled, from 7.31

mile to 17.4 mile. Meanwhile, for non-local residents the average trip length increased by 36%. In Gilbert, on contrary, most of the change came from non-local commuting trips, the length of which increased from 12.65 to 18.92 miles. Such results suggested that the suburbanization of employment might have a potential to inflate the trip length for both urban and suburban neighborhoods. Additionally residents in central city could be the ones who suffered the most during such process.

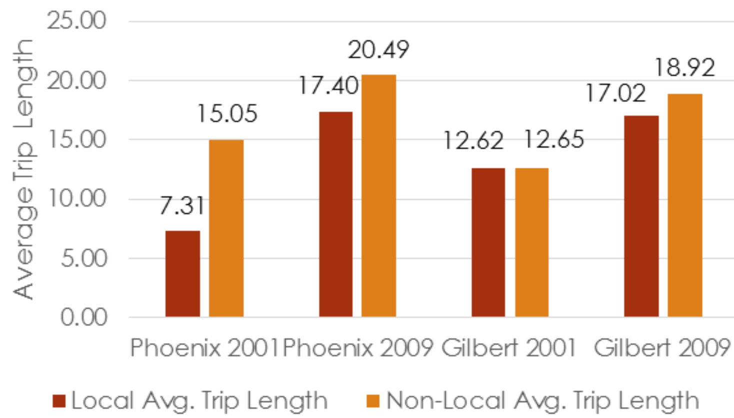


Figure 5.6: Average HBW Trip Length Change for Local and Non-local Inhabitants

Source: Adapted by author

The results for local residents within Phoenix and Gilbert from 2001 to 2009 are tabulated in Table 5.6 and 5.7 separately. The result indicated that compared with central urban area, Gilbert was likely to generate more inter-out trips than intra trips, as the ratios between two kinds of trips for Gilbert were always higher than that from central Phoenix. Moreover, the suburbanization process seemed to have encouraged more inter-out trips for both study areas, as the ratios increased from 2001 to 2009. However, the difference between the two areas was slightly smaller over the study period. In 2001 the inter-out and intra trips ratio in Gilbert was eight times larger than that in Phoenix, while in 2009 Gilbert was only around six times larger. Additionally, the average HBW generation rate in central Phoenix decreased from 0.32 to 0.25, while it increased in Gilbert from 0.32 to 0.58, indicating that more workers might have moved to the suburban areas. Such variation may also be attributed to the different trip production methods used for 2001 and 2009, due to data quality limitation. The 2009 results were considered as more reasonable, as the average individual income in Gilbert was approximately 58% higher than central Phoenix.

Table 5.1: 2001 HBW Travel Pattern Result Summary for Local Inhabitants

Zone	Trip number	Avg. Trip Length	Total VMT	Trip /Person	VMT/ Person	Ratio (Inter-out/Intra)
Phoenix	108003.57	7.31	789811.56	0.32	2.32	1.08
Gilbert	37439.40	12.62	472595.91	0.32	3.98	9.65

Source: Adapted by author

Table 5.2: 2009 HBW Travel Pattern Result Summary for Local Inhabitants

Zone	Trip number	Avg. Trip Length	Total VMT	Trip /Person	VMT /Person	Ratio (Inter-out/Intra)
Phoenix	90168.00	17.40	1569177.87	0.26	4.60	3.79
Gilbert	68328.93	17.02	1162856.29	0.58	9.80	21.10

Source: Adapted by author

The average trip length for intra-zonal commuting trip generated in central Phoenix area was inflated by 262.1%, from 4.12 mile to 14.92 mile. This speed was two times faster than that for Gilbert. One of the most dominant factors to such rapid growth was the increase of length for intra trips. The HBW trip flow distributions for intra trips are illustrated in Figure 5.7. For central Phoenix area, the HBW intra trips used to be evenly distributed. Whereas, in 2009 there was fewer intra-zonal trips and the most prevailing ones were the diagonal flows from the northwest TAZs to the middle southern TAZs. Therefore, the trip length tripled in 2009. Compared with Phoenix, the trips in Gilbert were more evenly distributed in 2009. As a result, even though there were more diagonal trips due to the upsurge of TAZs in the southeastern corner, the average trip length growth rate was not as dramatic as central urban area. The detailed HBW results tables are attached in Appendix D.

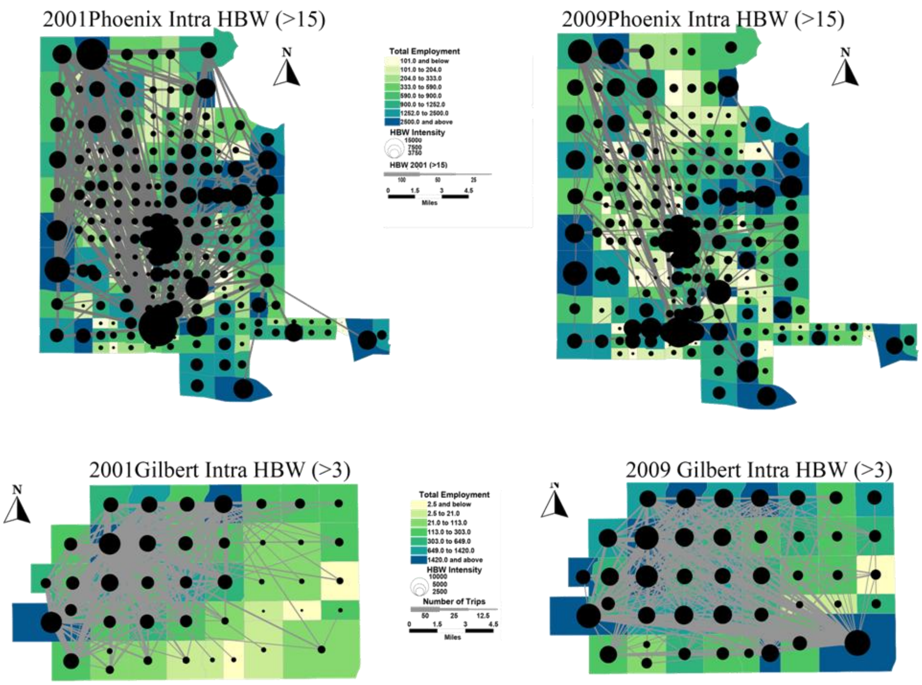


Figure 5.7: Intra HBW Trips Distribution

Source: Adapted by author

5.2.2. HBW Energy Consumption Variation Analysis

Similar with the travel pattern change, the energy consumption associated with Gilbert magnified at a faster speed (149%) compared with Phoenix (49%). Additionally, the portion of energy flow generated by inter-in trips declined from 78% to 75%. Such variation indicated that despite the fact that the number of trip increased due to population growth in suburban areas, the attractiveness of central Phoenix area as work destination has comparatively declined. In other words, more suburban residents were attracted by adjacent suburban employments. While Gilbert successfully attracted residents from farther distance, as the portion of inter-in energy increased from 22% to 34%. It is also interesting to notice that regardless that the employment density within

Gilbert has increased, the portion of intra-zonal energy still declined by 1% over the decade. This indicated that the effect of local compact development might be offset of the regional suburban growth. In sum, the variation in Gilbert could be attributed by two major facts: 1) there was a more competitive suburban employment area adjacent to Gilbert, who attracted many inter-out trips from Gilbert; 2) the employment growth in Gilbert was not sufficient to satisfy local needs.

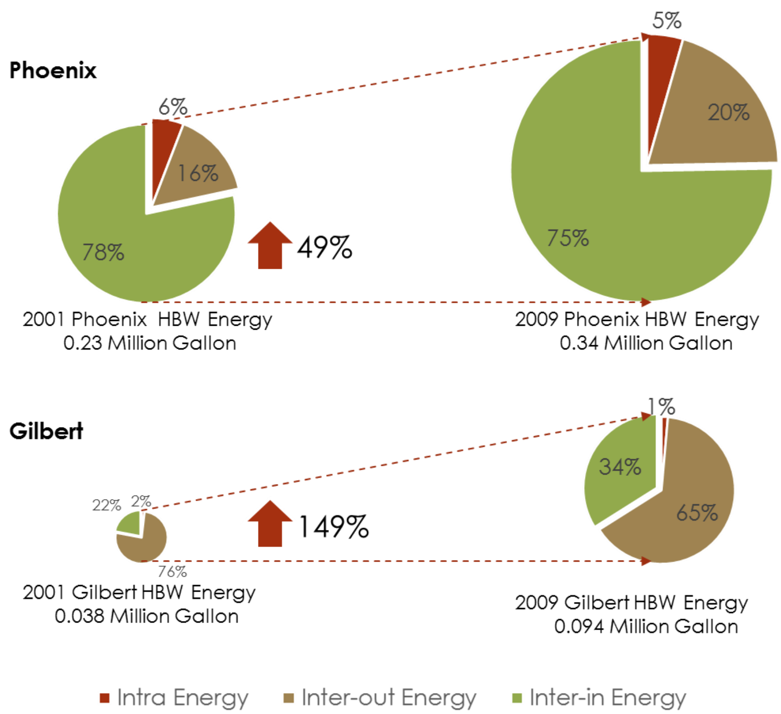


Figure 5.8: HBW Energy Consumption for Local and Non-local Residents

Source: Adapted by author

The energy consumption results for local inhabitants are tabulated in Table 5.3. The result indicated that suburban residents might be more energy intensive compared with those from central urban area. It is surprising that instead of controlling the difference between the two study areas, the suburbanization process actually widened the gap between them. In 2001 Gilbert area was 78.6% more energy intensive, while in 2009 it became 116.7% more intensive. One of the major underlying reasons could be the higher average income in Gilbert throughout the study period. If indeed there were substantially more workers in Gilbert, the individual HBW energy consumption could be higher compared with central Phoenix.

Table 5.3: 2001 and 2009 HBW Energy Consumption Result for Local Residents

Zone	Total Energy Consumption (Gallon of Gasoline)		Energy/Person	
	2001	2009	2001	2009
Phoenix	48954.81	83510.35	0.14	0.24
Gilbert	29292.86	61886.25	0.25	0.52

Source: Adapted by author

The energy consumption for local residents was then further classified into two categories: intra zonal energy consumption and inter-out zonal energy consumption, as illustrated in Figure 5.9 below. During the past decade, more local energy consumption in central Phoenix was allocated to inter-zonal travel. The portion of inter-out energy flow increased from 73% to 82%. However, in Gilbert the energy composition didn't vary much over study period. This result indicated that the compact development in Gilbert area to some extent helped the area to stabilize the portion of intra-zonal energy flow. One of the possible reasons that the portion of intra-zonal energy flow was not improved during the study period was that many TAZs close by Gilbert have also been significantly developed. Those TAZs attracted many commuting trips from the western part of Gilbert study area.

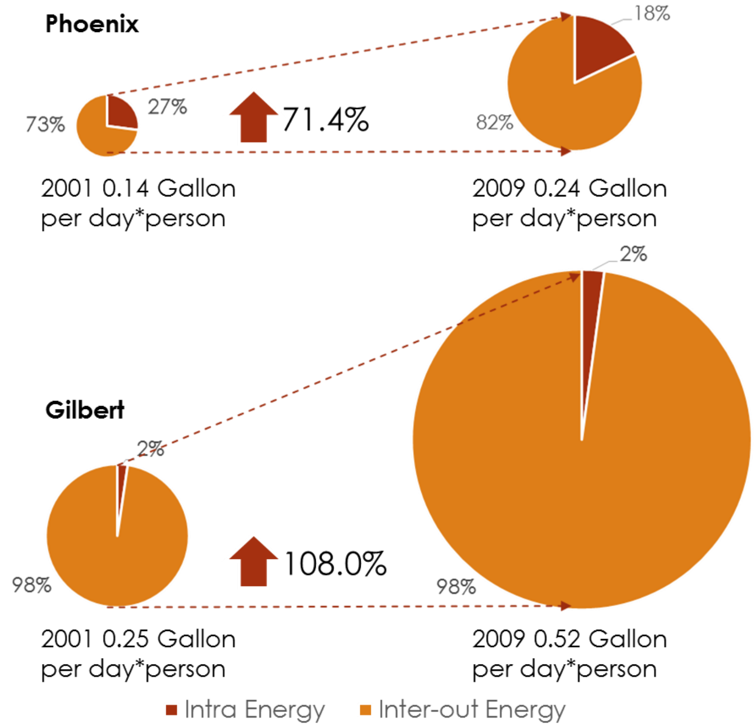


Figure 5.9: HBW Energy Consumption for Local Residents from Gilbert and Phoenix

Source: Adapted by author

In addition to the variation in quantity of energy consumption, the spatial distributions of different type of energy consumption also varied dramatically. The spatial patterns of intra-zonal energy flows are illustrated in Figure 5.10. For central Phoenix, due to the slight decline of total employment within the area, there were fewer intra-energy flows in 2009. The energy flow was more intensive from northwest to southern TAZs within central Phoenix. While, the flow in the east part of central Phoenix declined substantially. In Gilbert, most of the energy flows converged at the new employment center located at the southeastern corner of the study area.

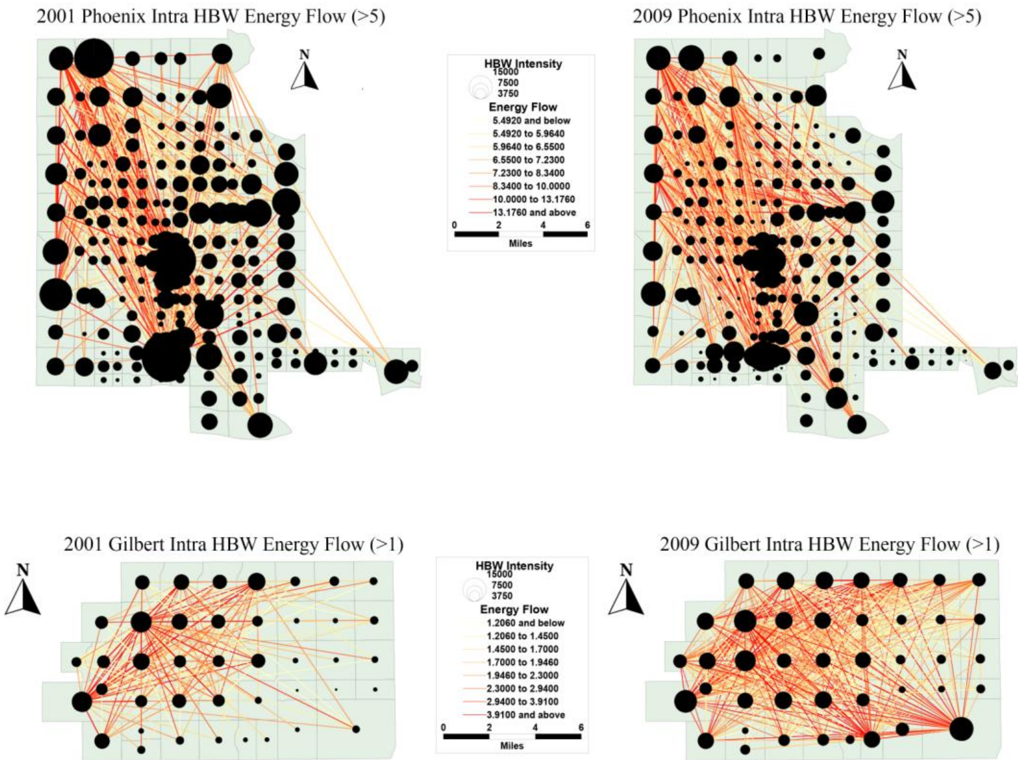


Figure 5.10: Spatial Distribution of Intra HBW Energy flow from 2001 to 2009

Source: Adapted by author

The spatial distributions of inter-out energy flows are illustrated in Figure 5.11. The results for Phoenix area indicated that compared with 2001 distributions, the 2009 distributions were more widely spread spatially, reflecting the suburbanization of employment within the region. In 2009, more energy flowed out of Phoenix to the remote west TAZs. Compared with Phoenix, the inter-out energy flows in Gilbert were more directional, as illustrated in Figure 5.13. Most energy flowed out of Gilbert to the western and northern TAZs in the region, as there was almost no employment located in TAZs that were southern and eastern to Gilbert. More energy flowed out from Gilbert to areas 20 to 30 miles away, due to the employment upsurges in those areas.

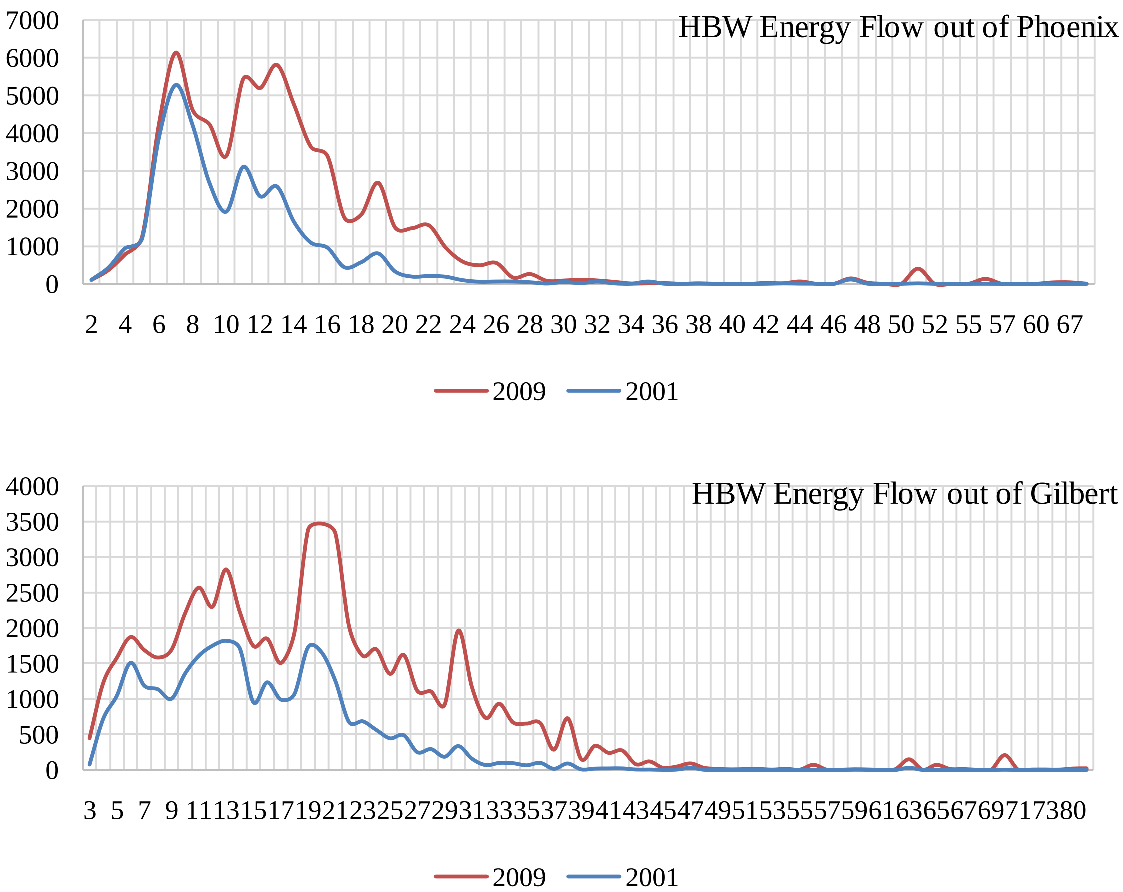


Figure 5.11: HBW Energy Flow out of Study area

Source: Adapted by author

Although the spatial distribution variation for inter-in flows was not as significant as that for inter-out flows, the intensity of energy flow from different directions still changed dramatically, as displayed in Figure 5.14. For central Phoenix area, comparatively less energy was attracted from remote TAZs in 2009, as shown in Figure 5.12. While for Gilbert area, there was an increase for the quantity of inter-in flows over the study period, which was reflected directly in the color in Figure 5.14. The results indicated that Gilbert has become more appealing to western and southern inhabitants, especially those 20 to 30 miles from Gilbert. However, the amount of energy flow into Gilbert from the eastern part of region declined. Residents in those TAZs were attracted to other closer by suburban TAZs

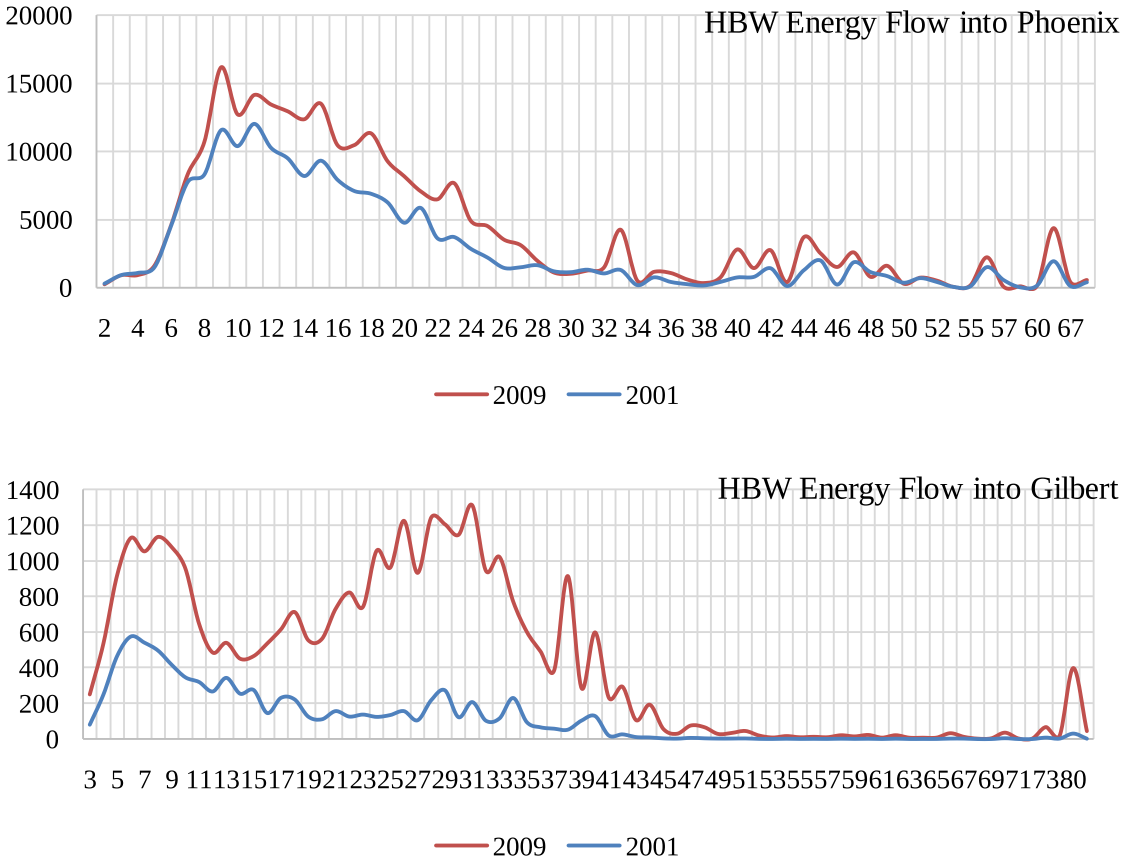


Figure 5.12: HBW Energy Flow into Study Area

Source: Adapted by author

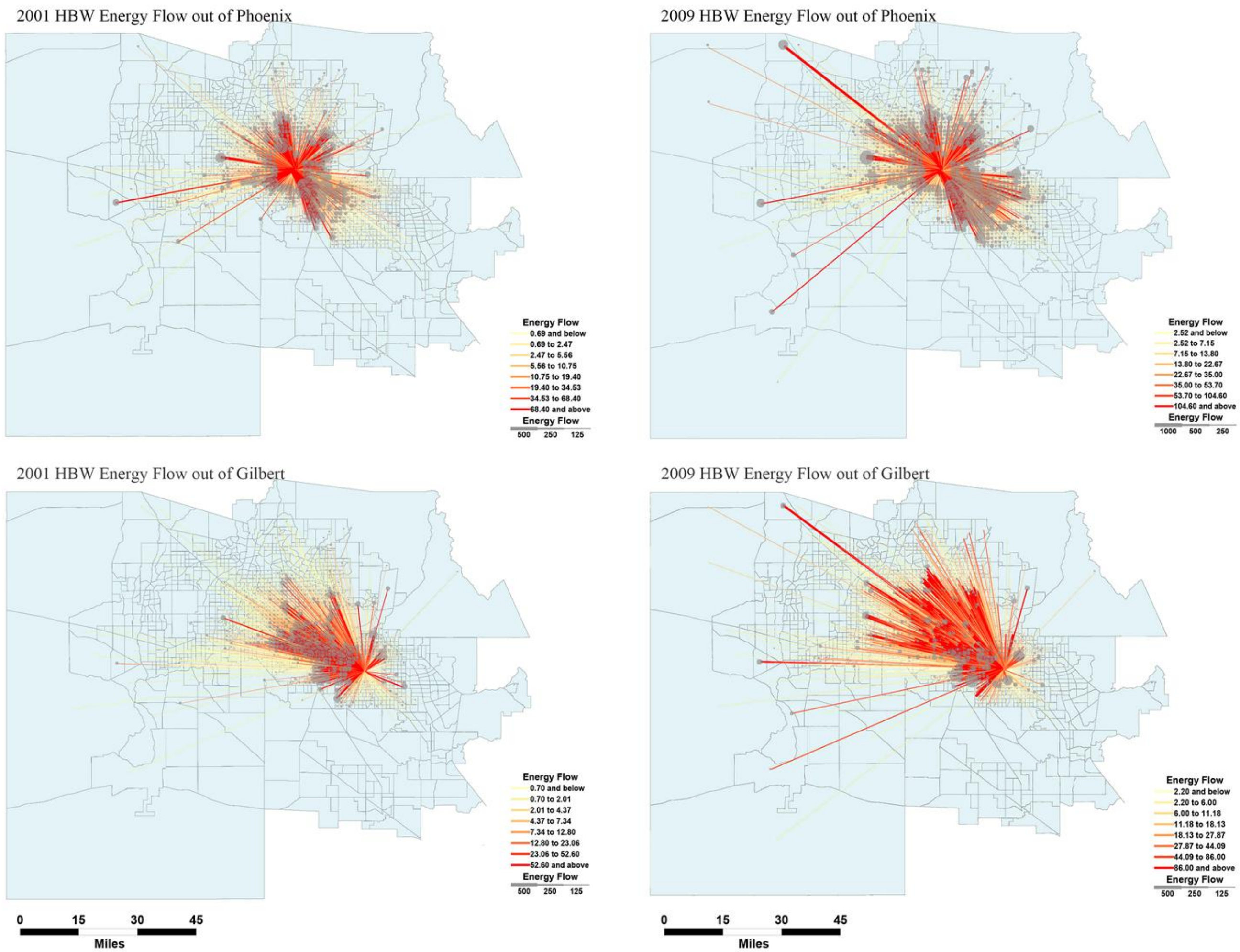


Figure 5.13: Distribution of HBW Inter-out Energy Flow for Phoenix and Gilbert from 2001 to 2009

Source: Adapted by author

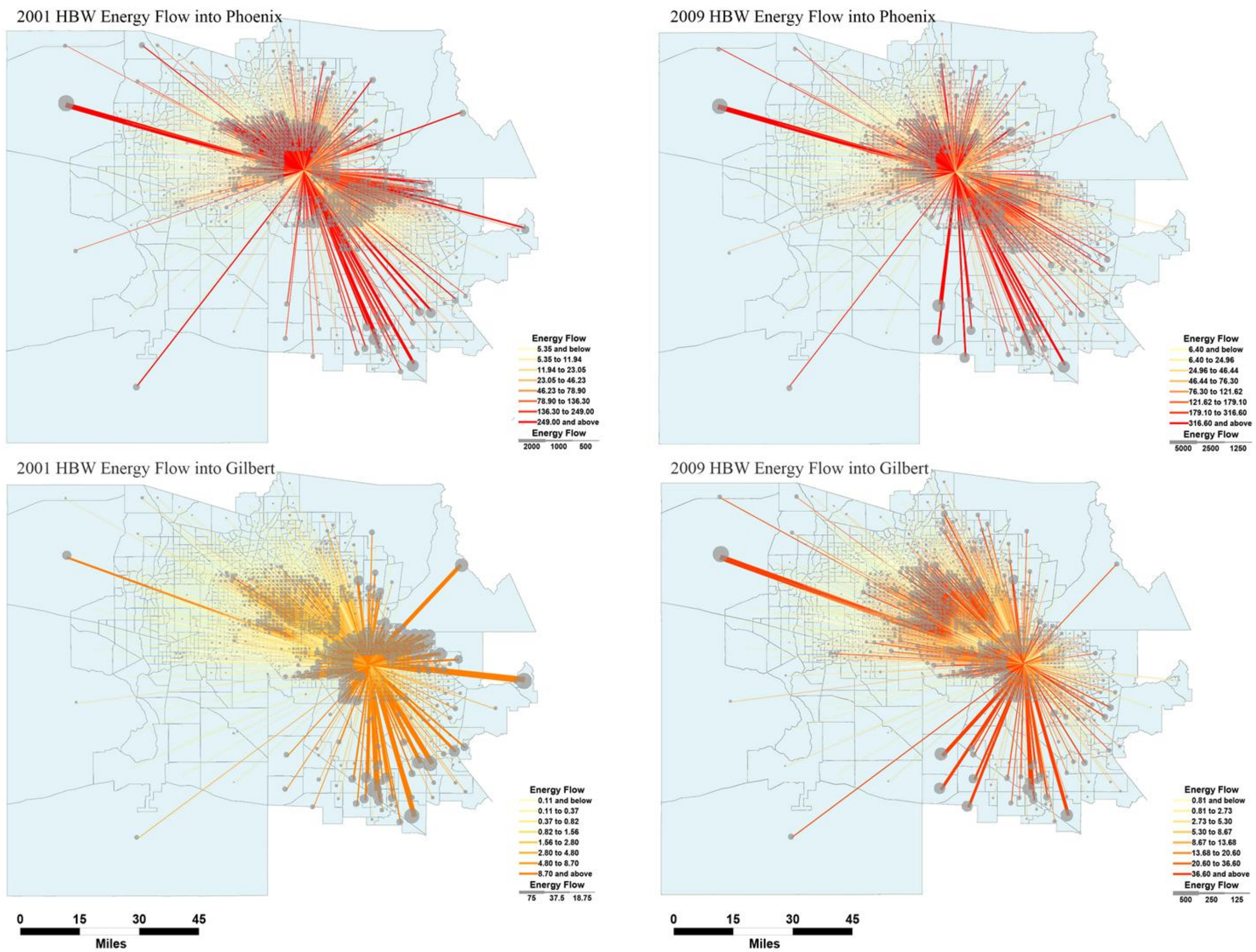


Figure 5.14: Distribution of Inter-in Energy Flow for Phoenix and Gilbert from 2001 to 2009

Source: Adapted by author

5.2.3. HBW GHG Emissions Variation Analysis

The GHG emissions associated with the two study areas have also increased. The pattern was quite similar with the energy consumption growth. From 2001 to 2009, the total CO_2e related with central Phoenix area increased by around 50%, from 2.1 million kg to 3.1 Million kg. While in Gilbert study area the amount was improved by150%, from 0.34 million kg 0.86 million kg.

Gilbert inhabitants seemed to emit more GHG compared with Phoenix inhabitants and such pattern didn't change over the 8-year study period, based on the results tabulated in Table 5.4. Additionally, the difference between Gilbert and Central Phoenix was slightly larger in 2009. In 2001, Gilbert inhabitants emitted 71% more GHG per person, while in 2009 they tended to emit approximately 112% more per person. Although, compared with Phoenix area the average commuting trip length growth in Gilbert was smaller, such reduction was offset by the higher HBW frequency within the area. Therefore, the GHG emissions per person for Gilbert grew at a faster speed compared with Phoenix area. Fortunately, the GHG emissions growth rate was around 39% slower than the VMT growth speed over the study period, due to the improvements in vehicle emission control technology, see Table 5.4.

Table 5.4: HBW GHG emissions Result for Local Residents from 2001 to 2009

Zone	GHG (CO2e (kg/day))		GHG/Person		Growth	
	2001	2009	2001	2009	GHG/person growth	VMT growth
Phoenix	445350.99	763333.21	1.31	2.24	71%	99%
Gilbert	266482.62	565676.36	2.24	4.77	112%	146%

Source: Adapted by author

5.2.4. HBW Regression Models

The results of OLS for different location of TAZs as well as the Spatial-Lag Regression Model for 2001 HBW VMT per person are tabulated in Table 5.5. The incremental segmentation test was performed and the result was significant, indicating that the null hypothesis could be rejected and different models should be used for urban and non-urban areas. The detailed test procedures and results are attached in Appendix E. Employment accessibilities calculated with distance thresholds from 10 to 60 minutes of travel distance were all tested in the regression separately. Models with 50 minutes travel distance threshold had the best explanatory power. Therefore, it was selected as the distance threshold for this case study. The household numbers within different travel distances were also calculated and included into the model. However, this variable was not included in the final output result, as the calculated VIF indicated that it was always highly correlated with employment accessibility, which led to multicollinearity problem (VIF larger than 5).

In 2001, compared with suburban area, land use variables such as road density and entropy index were dramatically less significant. While, the estimated coefficients for average household income in urban area was substantially larger than that in suburban area. Such result also revealed that there may be spatial autocorrelation for the residuals. Due to the fact that the result from Robust LM (Lag) test was less significant than Robust LM (error) test, spatial Lag model was built for the entire area. The result from spatial-lag model indicated that the VMT per person in one specific TAZ was highly related with the VMT per person in the surrounding TAZs, as the Rho for spatial regression was 0.838, which was highly significant. Additionally, neither road density nor entropy index was significant in spatial regression model. TAZ level of Average household income remains significant in the spatial model and 1% of increase in average income will lead to 0.04% of increase in the VMT per person. The employment accessibility was significant in all types of the models indicating the job-housing balance could play an important role in commuting trip VMT reduction.

Table 5.5: 2001 HBW VMT/Person Regression Models

	OLS			**Spatial-Lag Regression**
	All Sample	Urban	Non-Urban	All Sample
Lag_2001 HBW VMT	---	---	---	0.831***
Distance Weighted Sum of Total Employment within 50 minutes travel Distance (Ln)	-1.073***	-1.085***	-1.102***	-0.159***
Road Density (Ln)	-0.003**	-2.4E-4	-0.003**	-0.0004
Entropy Index	-0.055***	-0.016	-0.081***	-0.010
Average Household Income (Ln)	0.176***	0.259***	0.142***	0.043***
TAZ Dominate Service Type	-0.070***	-0.025***	-0.118***	-0.034***
Constant	10.983***	10.186***	11.668***	1.845***
Sample Number	1864	744	1120	1864
R-Square	0.827	0.613	0.815	0.911
F-Statistic for OLS/Rho for spatial regression	1776.708	234.109	980.679	0.838
SSE	100.758	43.622	54.239	---
Max VIF	1.565	1.330	1.286	---

Source: Adapted by author

The above discussed variables had less explanatory power in all 2009 models. However, the R-squares for those models were still around 0.7, as shown in Table 5.6, indicating that a majority of the variation in HBW VMT per person could still be explained by these models. Compared with 2001 models, the explanatory power of road density and entropy index declined especially in suburban areas. As the development patterns in urban and suburban area have become more comparable, the significance levels for road density and entropy index in suburban model have become more similar with those in urban models. Despite the fact that both areas have become more similar, the incremental segment test result still indicated that two separate models should be used for those areas. Again, as the Robust LM (lag) test was less significant, the spatial lag regression was developed for year 2009. Compared with OLS models, the R-Square for spatial regression model has been improved to 0.744. The lagged form of 2009 HBW VMT per person was still one of the most dominant explanatory variables in spatial regression model. Like that in 2001, the accessibility of employment within 50 minutes travel distance was still the key factor for VMT reduction. Based on the regression model, 1% improvement in employment accessibility would help control the commuting VMT by 0.04%. The reduction effect was substantially smaller than the 0.16% in 2001. On the other hand, the average income was likely to encourage more VMT in 2009, as the elasticity of which increased dramatically from 0.04% to 0.55%.

Table 5.6: 2009 HBW VMT/Person Regression Models

	OLS			**Spatial-Lag Regression**
	All Sample	Urban	Non-Urban	All Sample
Lag_2009 HBW VMT	---	---	---	0.491***
Distance Weighted Sum of Total Employment within 50 minutes travel Distance (Ln)	-0.408***	-0.349***	-0.576***	-0.043***
Road Density (Ln)	-0.002	-0.087*	0.000	0.003
Entropy Index	-0.083**	0.010	-0.093**	-0.043
Average Household Income (Ln)	0.583***	0.726***	0.584***	0.551***
TAZ Dominate Service Type	-0.293***	-0.547***	-0.101***	-0.231***
Constant	-0.206	-9.858***	1.513***	-4.729***
Sample Number	1864	803	1061	1864
R-Square	0.682	0.419	0.781	0.744

F-Statistic for OLS/Rho for spatial regression	795.163	106.457	793.292	0.491
SSE	348.064	166.142	154.846	---
Max VIF	1.472	1.288	1.268	---

Source: Adapted by author

Moreover, the results from OLS and Spatial regression models for both study years indicated that development patterns such as road density and diversity were likely to have a smaller explanatory power for VMT reduction, if the regional location of studied household was controlled in the model. Whereas, the accessibility of employment within a certain distance, in other words the job-housing balance, became a more critical factor in controlling VMT.

5.3.HBSH Variation Analysis for Phoenix and Gilbert

5.2.1. HBSH Travel Pattern Variation Analysis

The total number of HBSH trips associated with the two study area grew from 2001 to 2009, as shown in Figure 5.15. In central Phoenix area, the number has increased by around 74.1%, from 0.27 million to 0.47 million. Meanwhile, the portion of trips generated by non-local residents declined slightly from 49% to 48%. This indicated the deterioration of retail service function within central Phoenix area. In Gilbert area, the increase was more significant, as the total number of trips tripled from 0.05 million to 0.2 million during the study period. The growth was primarily contributed by the fast growing rate for inter-in trips. The portion of inter-in trips for Gilbert area was improved from 17% to 47%, as a result of the more intensive retail development pattern in Gilbert.

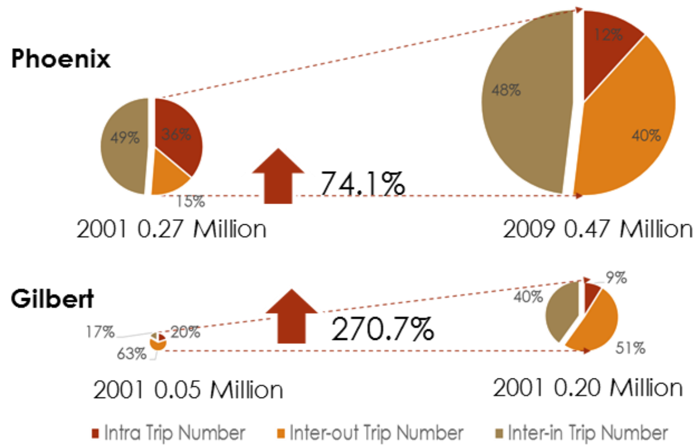


Figure 5.15: HBSH Travel Pattern for Local and Non-local Residents

Source: Adapted by author

Although the two study areas shared the similar variation patterns for shopping trip frequency, the average trip length change patterns were completely different between two areas, as displayed in Figure 5.16. From 2001 to 2009, the average length of HBSH trips generated by local residents in phoenix has almost been doubled, while the average length for central Phoenix attracted non-local trips decreased by 28.5%. Shopping trip length generated by local inhabitants in Gilbert study area declined slightly from 7.5 to 6.74 miles. While, residents living further away from Gilbert study area started to make more shopping trips into Gilbert in 2009.

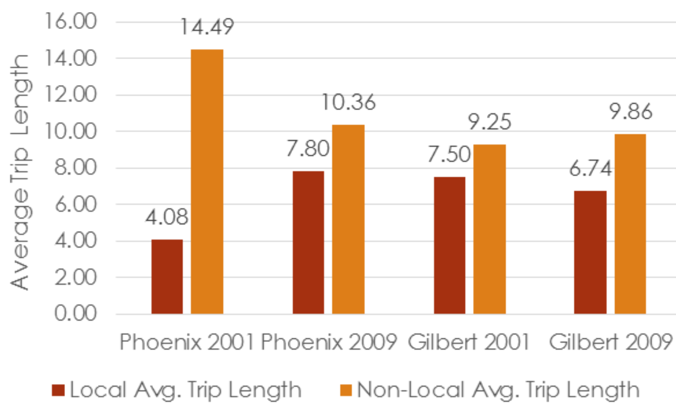


Figure 5.16: Average HBSH Trip Length Change for Local and Non-local Inhabitants

Source: Adapted by author

The suburbanization of retail service reversed the HBSH travel patterns for local urban and suburban inhabitants during the last decade, as shown in Table 5.7 and 5.8 separately. In 2001, central city inhabitants generated more individual shopping trips. The shopping trip generation rate in Gilbert surpassed that in central Phoenix in 2009. Additionally, the average trip length for Phoenix increased by 91%, while in Gilbert it dropped by approximately 11%. However, despite those variations, residents in Gilbert still generated more individual shopping VMT. On the other hand, the gap between Phoenix and Gilbert was indeed reduced. In 2001 Gilbert residents produced 69% more shopping VMT per person, while in 2009, inhabitants in Gilbert produced merely 20% more. Additionally, the suburbanization process encouraged the inter-out trips for both study area, as the ratios between inter-out and intra trips were increased.

Table 5.7: 2001 HBSH Travel Pattern Result Summary for Local Inhabitants

Zone	Trip number	Avg. Trip Length	Total VMT	Trip/Person	VMT/Person	Ratio (Inter-out/Intra)
Phoenix	139406.35	4.08	568457.04	0.41	1.67	0.42
Gilbert	44636.27	7.50	334763.23	0.38	2.82	3.19

Source: Adapted by author

Table 5.8: 2009 HBSH Travel Pattern Result Summary for Local Inhabitants

Zone	Trip number	Avg. Trip Length	Total VMT	Trip/Person	VMT/Person	Ratio (Inter-out/Intra)
Phoenix	246423.83	7.80	1921889.56	0.72	5.64	3.42
Gilbert	118891.44	6.74	801035.68	1.00	6.75	5.75

Source: Adapted by author

In central Phoenix area, the average trip length for intra-zonal shopping trip increased by 58.9%, slower than the 70.6% in Gilbert. As shown in Figure 5.17, after the decline of retail service in central Phoenix, most of the left service supplier located at the center of the study area. Whereas, in Gilbert the retail service supplier located at the southeastern corner of the area, which encouraged diagonal shopping trips within the zone. The detailed HBSH results tables can be viewed in Appendix D.

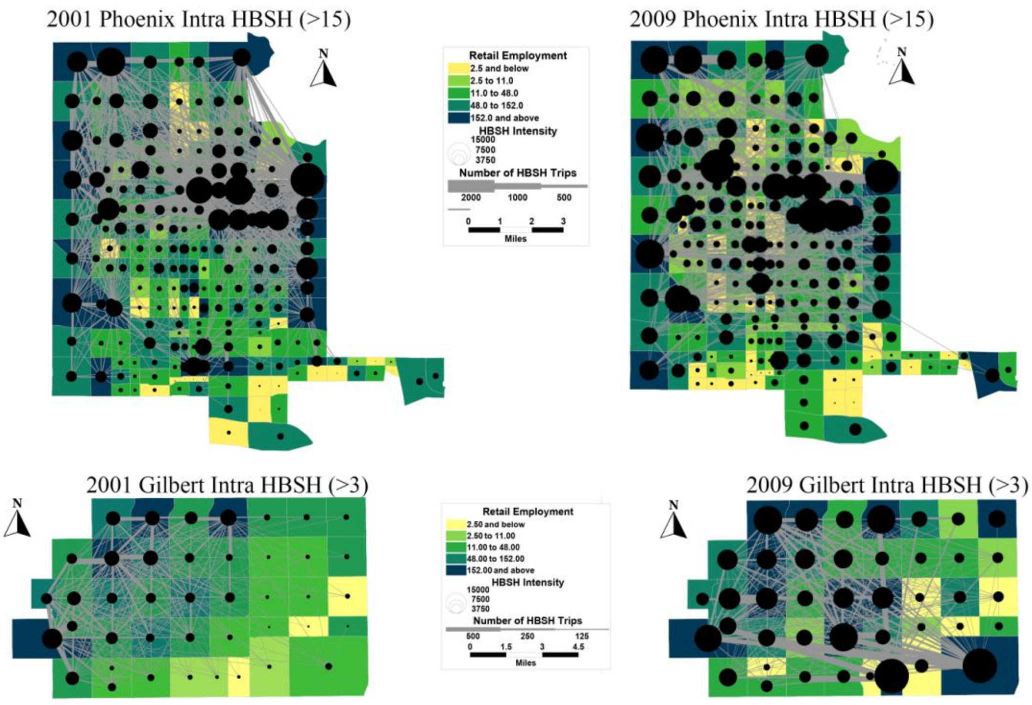


Figure 5.17: Intra HBSH Trips Distribution.

Source: Adapted by author

5.2.2. HBSH Energy Consumption Variation Analysis

The relationship between local and non-local energy consumption changed substantially in central Phoenix and Gilbert, as shown in Figure 5.18. The portion of non-local energy consumption in Phoenix declined from 77% to 55%, despite the fact that the portion of number of non-local shopping trips dropped merely from 49% to 48%. Meanwhile, the proportion of non-local energy consumption has been increased from 20% to 49%. Generally speaking, the shopping energy consumptions associated with both study areas have increased and Gilbert grew at a much faster rate.

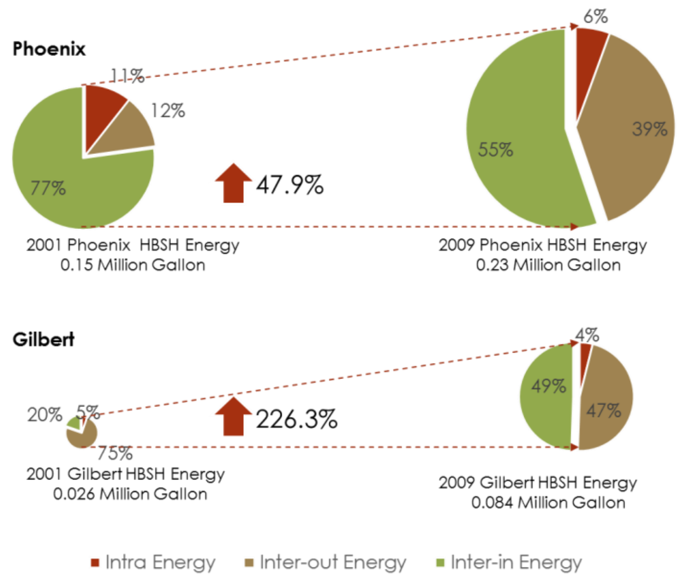


Figure 5.18: HBSH Energy Consumption for Local and Non-local Residents

Source: Adapted by author

Compared with HBW trips, energy consumption per person was smaller for HBSH trips, due to the fact that shopping trips were more sensitive to travel time impedance. The results, as tabulated in Table 5.9, indicated that suburban inhabitants were, again, more energy intensive over study period. However, results from both study areas converged at a higher consumption level.

Table 5.9: 2001 and 2009 HBSH Energy Consumption Result for Local Residents

Zone	Total Energy Consumption (Gallon of Gasoline)		Energy/Person	
	2001	2009	2001	2009
Phoenix	35234.62	102281.38	0.10	0.30
Gilbert	20749.60	42630.46	0.17	0.36

Source: Adapted by author

The intra and inter-out HBSH trips results for local residents revealed that intensified retail service within the zone can cast a dramatic effect on local people's energy consumption patterns. Central Phoenix area lost 35% of its intra-zonal energy consumption during the study period, due to retail service deterioration. As a result, the local energy consumption per person in central Phoenix increased by two times from 2001 to 2009. The final results are illustrated in Figure 5.19. Compared with central Phoenix, the individual energy consumption in Gilbert increased at much slower speed. This difference in growth patterns indicated that intensified development could help control local shopping energy consumption

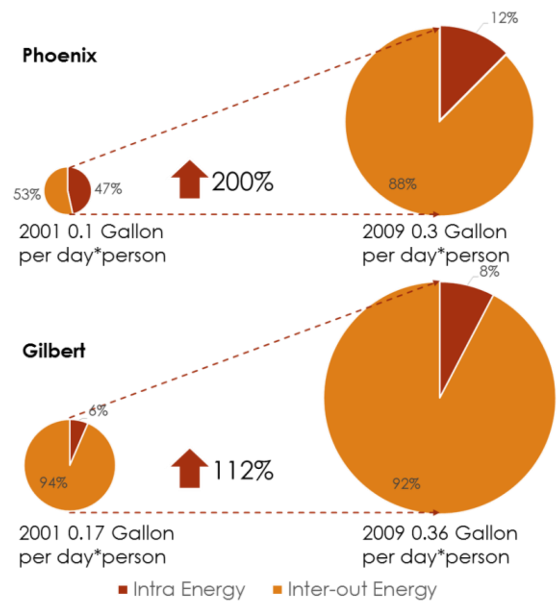


Figure 5.19: HBSH Energy Consumption for Local Residents from Gilbert and Phoenix

Source: Adapted by author

The retail service suburbanization process redistributed the intra-zonal HBSH energy flows in both study areas, especially those in Central Phoenix area. In 2001, most of the energy flows concentrated between residential oriented TAZs, located at the northern part of study area, and retail oriented TAZs, situated at the center of study area. Whereas, in 2009 more flows occurred in the southern part of central Phoenix, while fewer flows were produced from northern boundary TAZs. It seems that more shopping trips from those TAZs were attracted to the new shopping malls in the northern suburban areas. In Gilbert, the change pattern was parallel with the intra-zonal energy flow change pattern for HBW, as the flows were more evenly distributed spatially.

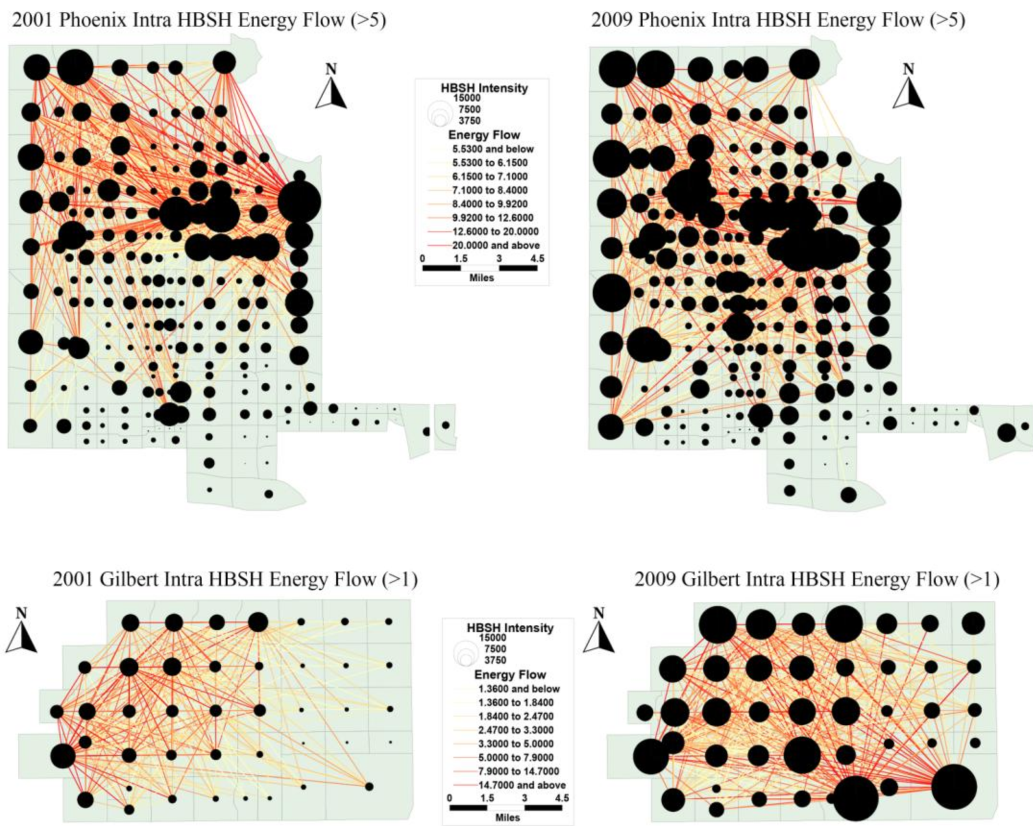


Figure 5.20: Spatial Distribution of Intra HBSH Energy Flow from 2001 to 2009

Source: Adapted by author

The HBSH inter-out energy flows were more widely dispersed spatially for both study areas in 2009, as illustrated in Figure 5.23. However, the magnitudes of the change were different for central Phoenix and Gilbert study areas. In central urban area, more energy flowed out to suburban areas, especially to the southern part of the region, where Gilbert was located. Based on chart 5.21, a majority of inter-out energy flows in central Phoenix area was attracted by retail facilities within 18 miles circle radius. While for Gilbert, more energy flowed to suburban TAZs in the northern part of region, which were around 45 miles away from the study area. However, inter-out energy flows from Gilbert study area, especially those ended within 20 miles radius circle, were controlled by the more intensive retail service within Gilbert.

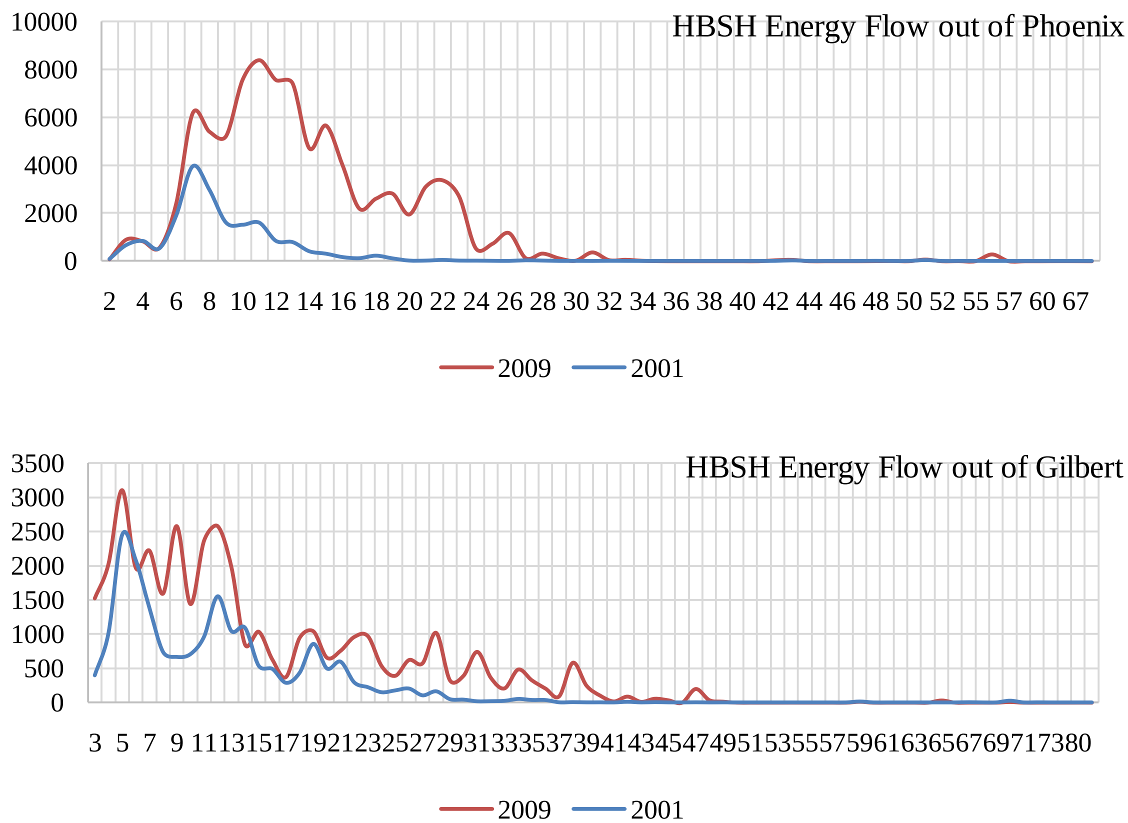
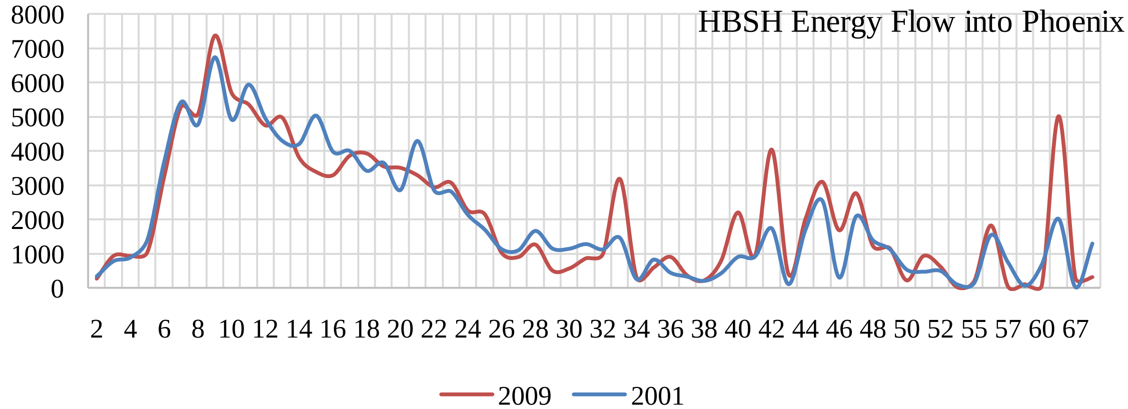


Figure 5.21: Energy Flow out of Study Areas

The decline of retail service within central Phoenix area also led to a decrease of growth rate for inter-in energy flows, as shown in Figure 5.24. The detailed distributions of energy flow are plotted in Figure 5.22. For central Phoenix area, the amount of energy flow rate within 30 miles circle remained the same over the study period. The majority growth occurred in the remote suburban areas, which are 40 or 60 miles away. The reason for such growth was the residential suburbanization process. Compared with 2001, a larger portion of population lived in remote suburban areas in 2009. Unlike Phoenix area, Gilbert area has become more attractive to the residents in surrounding TAZs, especially to those within the radius circle of 40 miles. A substantially larger portion of regional shopping energy flowed into Gilbert in 2009. However, compared with the central Phoenix area, the total amount of energy that flowed into Gilbert was still comparatively small, indicating that Phoenix area was still the major shopping center for the entire region.



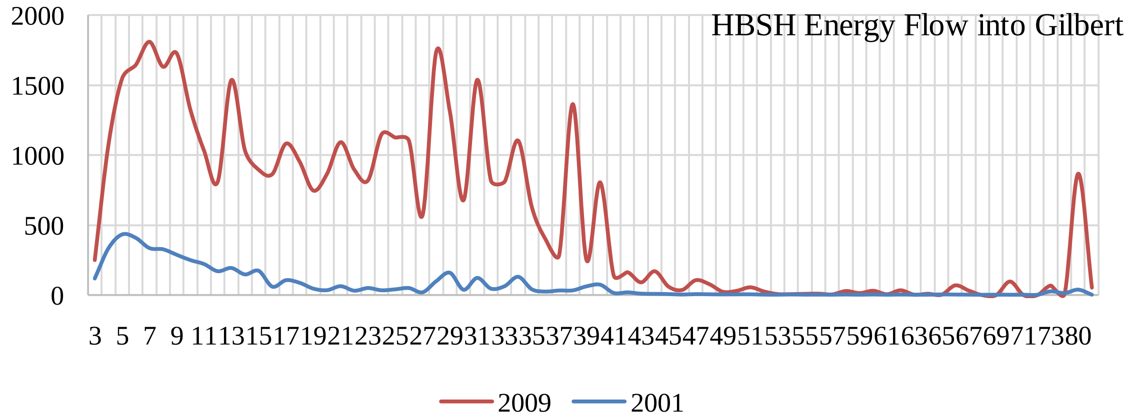


Figure 5.22: Energy Flow out of Study Areas

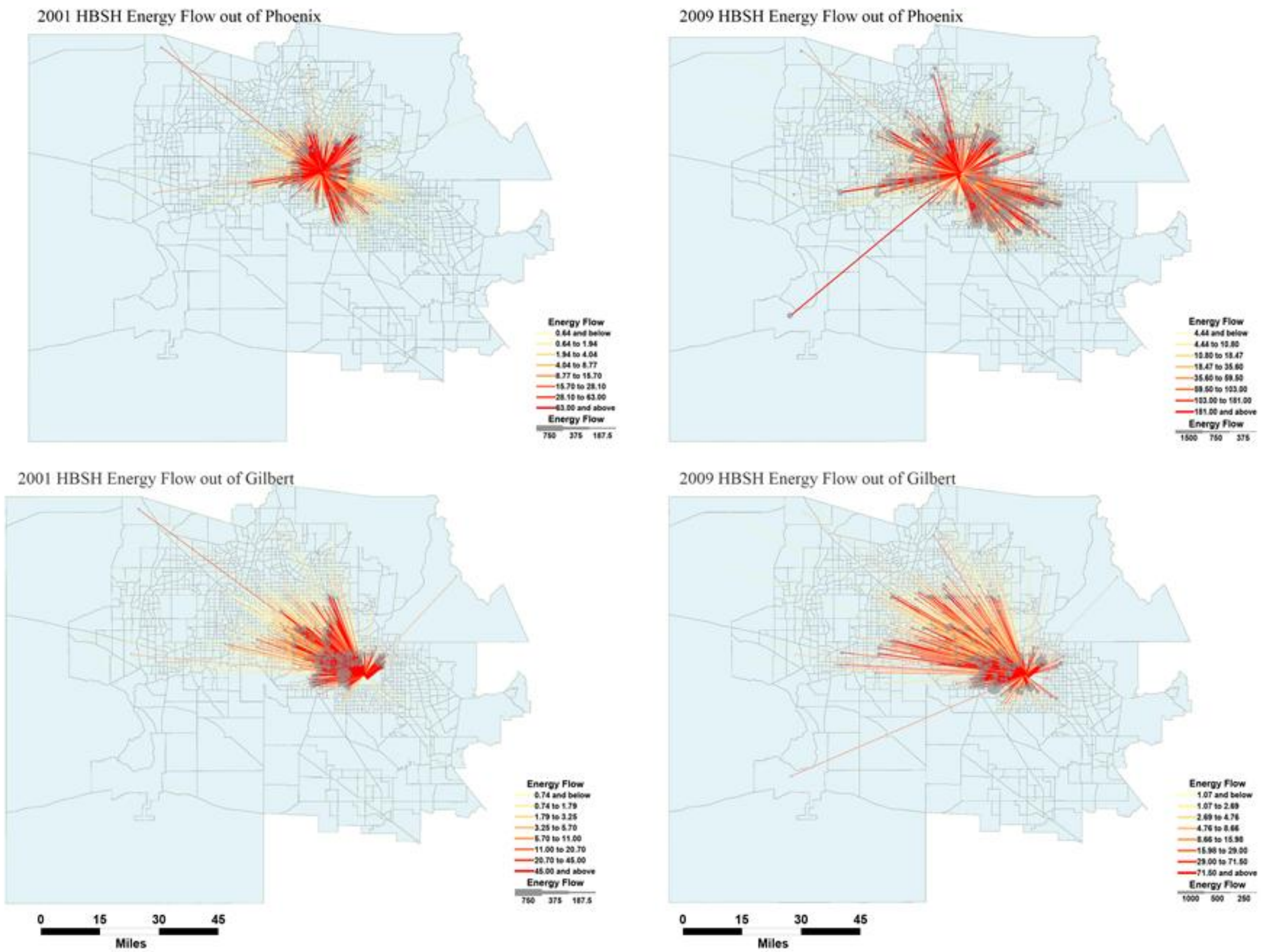


Figure 5.23: Distribution of HBW Inter-out Energy Flow for Phoenix and Gilbert from 2001 to 2009

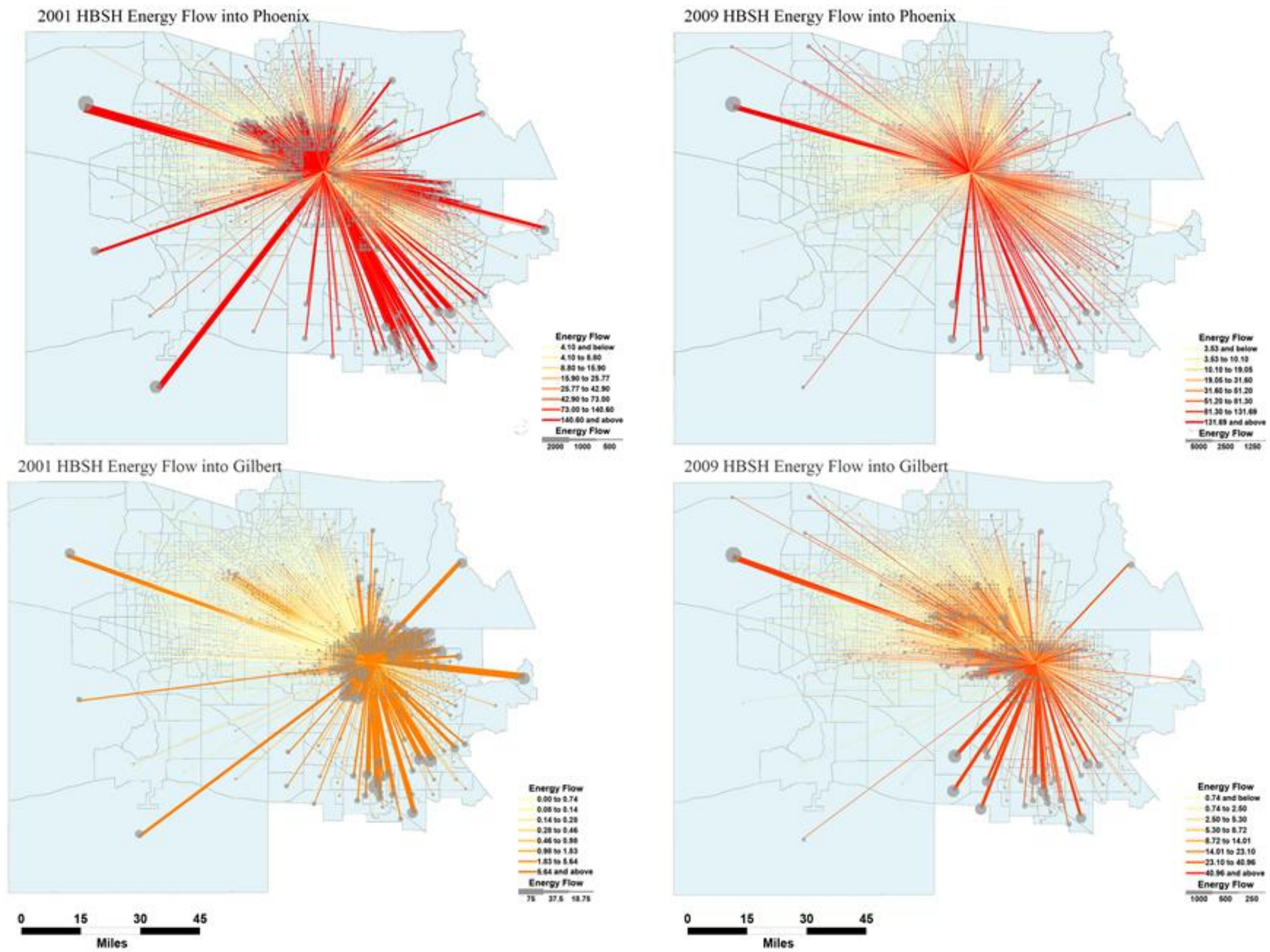


Figure 5.24: Distribution of HBW Inter-in Energy Flow for Phoenix and Gilbert from 2001 to 2009

5.2.3. HBSH GHG Emissions Comparison

The GHG emissions associated with both local and non-local HBSH trips increased significantly for both areas, especially for Gilbert. In central Phoenix, the total GHG consumption was increased by 50%, while in Gilbert, the total consumption was amplified by 221%. Most of the GHG emissions increase in Gilbert area was attributed by non-local residents. The proportion of inter-in GHG emissions increased dramatically, as more shopping trips were attracted to Gilbert.

From the local perspective, Gilbert inhabitants turned out to be the ones with larger GHG footprint. However, the GHG emissions per person in Phoenix increased at a rate of 167%, which was around 10% larger than that from Gilbert. As a result, the difference of GHG footprint became smaller in 2009. In 2001, Gilbert residents produced 51% more GHG per person, while in 2009, they generated only around 19% more GHG per person compared with inhabitants from central Phoenix. The detailed variations are tabulated in Table 5.10.

Table 5.10: HBSH GHG emissions Result Summary

Zone	GHG (CO2e (kg/day))		GHG/Person		Growth	
	2001	2009	2001	2009	GHG/person growth	VMT growth
Phoenix	350349.15	934911.30	1.03	2.74	167%	238%
Gilbert	188762.92	389667.20	1.59	3.28	106%	139%

Source: Adapted by author

5.2.4. HBSH Regression Models

Compared with 2009, the models for 2001 had a much stronger explanatory power, as the R-squares form those models were higher, as shown in Table 5.11 and 5.12. This indicated that the density related variables have become less important factor for HBSH VMT generation pattern estimation. While the regional retail service accessibility remained significant for both study years. But the magnitude of the estimated coefficients declined over study period.

The results from incremental segment test were significant for both years, suggesting that separate models should be employed to explain the travel behaviors in urban and non-urban areas. The difference between those areas might indicate that when TAZs were intensively developed, one of the major factors for VMT reduction was the spatial distribution relationship between retail service and residence. The VMT reduction effect for retail service accessibility was quite dominant compared with other variables. In 2001, by improving the accessibility by 1%, the individual shopping VMT was likely to be reduced by 0.297% percent. In 2009, the elasticity declined by 0.141%, however, it was still significant.

Table 5.11: 2001 HBSH VMT/Person Regression Results

	OLS			**Spatial-Lag Regression**
	All Sample	Urban	Non-Urban	All Sample
Lag_2001 HBSH VMT	---	---	---	0.738***
Distance Weighted Sum of Total Employment within 50 minutes travel Distance (Ln)	-1.506***	-1.557 ***	-1.508***	-0.297***
Road Density (Ln)	-0.003	-0.008	-0.003	0.000
Entropy Index	-0.144***	-0.034	-0.177***	-0.036
Average Household Income (Ln)	0.135***	0.170***	0.121***	0.038***
TAZ Dominate Service Type	-0.270***	-0.166***	-0.466***	-0.190***
Constant	12.693***	12.775***	12.862***	2.643***
Sample Number	1864	744	1120	1864
R-Square	0.829	0.518	0.815	0.894
F-Statistic for OLS/Rho for spatial regression	1501.950	131.771	815.603	0.738
SSE	224.319	92.403	124.103	---
Max VIF	4.989	2.106	4.087	---

Source: Adapted by author

Table 5.12: 2009 HBSH VMT/Person Regression Results

	OLS			Spatial-Lag Regression
	All Sample	Urban	Non-Urban	All Sample
Lag_2009 HBW VMT	---	---	---	0.560***
Distance Weighted Sum of Total Employment within 50 minutes travel Distance (Ln)	-0.724***	-0.615***	-0.794***	-0.141***
Road Density (Ln)	-0.001	-0.000	-0.001	0.000
Entropy Index	-0.164	-0.145	-0.136***	-0.128
Average Household Income (Ln)	0.599***	0.774***	0.590***	0.556***
TAZ Dominate Service Type	-0.066***	-0.089***	-0.089***	-0.058***
Constant	1.229***	-3.628***	1.930***	-4.152***
Sample Number	1864	803	1061	1864
R-Square	0.651	0.282	0.776	0.726
F-Statistic for OLS/Rho for spatial regression	577.239	48.159	644.431	0.560
SSE	381.444	205.431	157.841	---
Max VIF	4.884	2.149	3.989	---

Source: Adapted by author

The results from both 2001 and 2009 all indicated that the individual shopping VMT generation was closely related with retail-housing balance and average household income. It has to be pointed out that although the land use variables included in the models were not significant, it didn't necessarily mean that compact development cannot help reduce shopping VMT generation, as the household density was not included in the model due to multicollinearity issues.

CHAPTER 6

CONCLUSIONS AND DISCUSSIONS

6.1. Conclusions

This thesis found that in Phoenix Metropolitan Region, suburban residents was likely to be more energy intensive in the case of HBW and HBSH travel, compared with central urban residents. Moreover, the suburban growth with more diverse land use patterns didn't change this fact during the study period. In both HBW and HBSH travel patterns, analyzed in this thesis, Gilbert residents tended to consume more gasoline and emitted more GHG than inhabitants in central Phoenix neighborhoods. Such results could likely be attributed to three major factors: 1) in 2001, Gilbert was less accessible to employment and retail faculties; 2) in 2009, the effect of improved suburban accessibilities on reducing trip lengths was likely to be offset by the more intensive growth in trip frequency; 3) As Cervero indicated in 1994, there is a large possibility that people who prefer to generate shorter trips would like to live in central urban area. Such 'self-selection' process may lead to smaller VMT in central urban area.

The results from this thesis also revealed that suburban growth did have an impact on people's travel behaviors. As suburbs grew and diversified, the difference in travel behaviors between residents in suburban and urban areas was likely to be smaller. In the case of commuting trips, the difference between average trip lengths decreased dramatically. In 2009, the average trip length in Phoenix surpassed that in Gilbert by around 0.9 mile per trip. In the case of shopping trips, the average trip length for suburban residents in 2009 was also slightly shorter than that for central city residents. However, for both kinds of trips, the reduction in trip length in the suburban area was offset by higher trip frequency. Therefore, in general, Gilbert inhabitants still produced higher VMT in 2009. The increased trip frequency can be explained not only by improved facility accessibilities but also by increased average income over the study period. In 2001 the HBW trip generation rates for both study areas were similar with approximately 0.32 trip per person. However, in 2009, the trip generation rate in central Phoenix area dropped to 0.26 trip per person and the rate increased to 0.58 in Gilbert. Therefore, over the study period, the trip frequency in Gilbert increased substantially while in central Phoenix it dropped slightly. This fact may be attributed to the difference in average individual income in both study areas. In 2001, the average annual income in Phoenix was around $16720, which was 65% of that in Gilbert. In 2009, the average annual income in central Phoenix increased to $19382, which was 62% of Gilbert's average income. From 2001 to 2009, the gap between average incomes in both study areas increased from eight thousands to over ten thousands. Therefore, the higher income in Gilbert may be one of the major reasons for its higher trip frequency rates.

The results from the study of HBW and HBSH trips also suggested that travel behavior for urban and suburban inhabitants in the Phoenix metropolitan region converged at longer travel distances and higher energy use. While in 2009 central city residents were not confining themselves to the jobs, shopping, and service opportunities available close by, suburban residents were finding more options to travel both near and far. Although increasing land use diversity in the suburban area could induce more intra-zonal trips, it didn't seem to be a check for the growth of inter-zonal trips that are increasing at a faster clip. Conversely, the density of developments in the urban core has not been instrumental in limiting growth in inter-zonal trips of Phoenix residents.

The regression models developed in this thesis indicated that spatial factor cannot be ignored when estimating the relationship between compact developments and motorized travel patterns. For both HBW and HBSH travel pattern analyses during the study period, the spatial-lag regression model has proven to be a better model to explain the relationship between compact development and VMT reduction based on Robust LM test results. This indicated that the VMT generation within one specific TAZ is highly correlated with the surrounding TAZs. Additionally, the incremental segments test also suggested that if OLS regression models were employed, separate models should be used for urban and non-urban areas in Phoenix Metropolitan Region, which could serve as an evidence that spatial location factors should be taken into consideration when explain the relationship between compact development and travel behaviors.

The results from spatial regression models also revealed the fact that employment and retail service accessibility was one of the most critical factors for individual HBW and HBSH VMT reduction. The four spatial-lag regression models all suggested that accessibility was highly significant, regardless its explanatory power declined from 2001 to 2009. Additionally, it was interesting to discover that the explanatory power of accessibility calculated with different threshold distance also varied much. In this study, the employment accessibility was calculated with the distance weighted sum of employment data within different distance thresholds (from 10 minute travel distance to 60 minute travel distance). These calculated accessibility variables were included in the models separately to check whether their explanatory power varied. In the case of Phoenix Metropolitan area, the accessibilities of employment and retail service within 50-minute travel time distance have best R-square models among all different distance thresholds. Whereas, the significance level of other land use factors such as road density and land use diversity (entropy index) faded away from 2001 to 2009. Such results indicated that simple encouragement of more compact growth at a certain development site may not be sufficient to reduce VMT. Rather, factors such as accessibility may need to be considered in land-use policy-making.

6.2. Limitation of This Research and Future Work

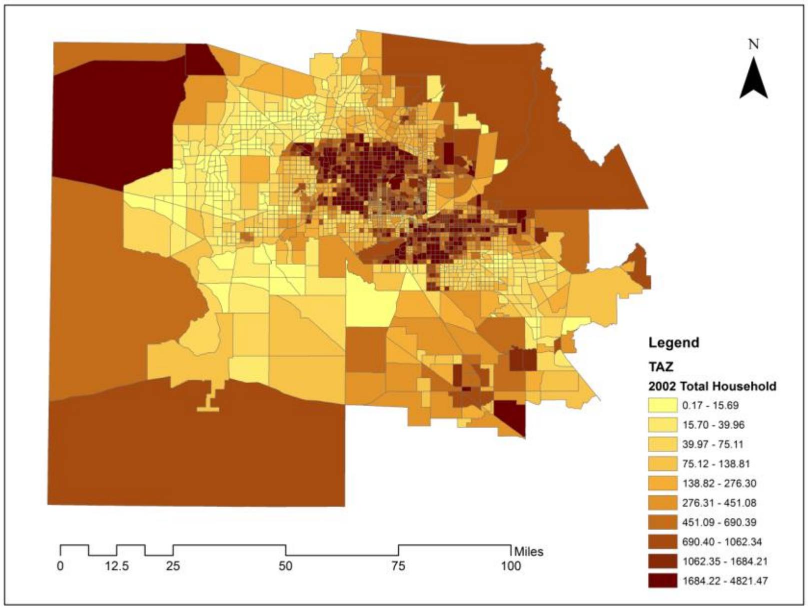
One of the major drawbacks of this research is that the data quality difference between the 2001 and 2009 is quite large. Compared with 2001 data, 2009 NHTS has more households and is quite proportionate to the entire population distribution within the metropolitan region. While for 2001, only 498 households within Arizona State were sampled in the survey. Therefore, the trip production methods for two study year are slightly different. For 2001, the cross classification table from transferred trip generation dataset prepared by FHWA is employed to obtain the trip production. According the FHWA dataset relevant documents, although the trip generation rates are offered at census tract level, the number is estimated based on national average data. While, the 2009 trip generation table is obtained using survey data. Such difference in data quality and trip production methods may lead to problems in longitudinal comparison process. However, the comparison between two study areas for the same study area will not be affected. In the future research, more efforts are needed to calibrate longitudinal data. As a matter of fact, it is still an unsolved problem in transportation study field. The issue is associated with how the surveys are designed in both years to alleviate the errors generated from different survey questions and procedures. Such problem may not be easily solved by data users but require national level of efforts to collect comparable longitudinal data.

Secondly, this research is conducted on the aggregated level of TAZs. The socio-economic variables are obtained by census tract level not household level and then reallocated to TAZs. The impedance matrix used to perform trips distribution is obtained by calculating the average travel time between the TAZ centroids. Such methodology will not deteriorate the results for travel flow between TAZs. Whereas, the results for travel within the same TAZ may be impacted, due to the lack of precise location of origins and destinations, rendering the research more intuitive for regional level analysis and decision making process, but may not be as accurate at the local level.

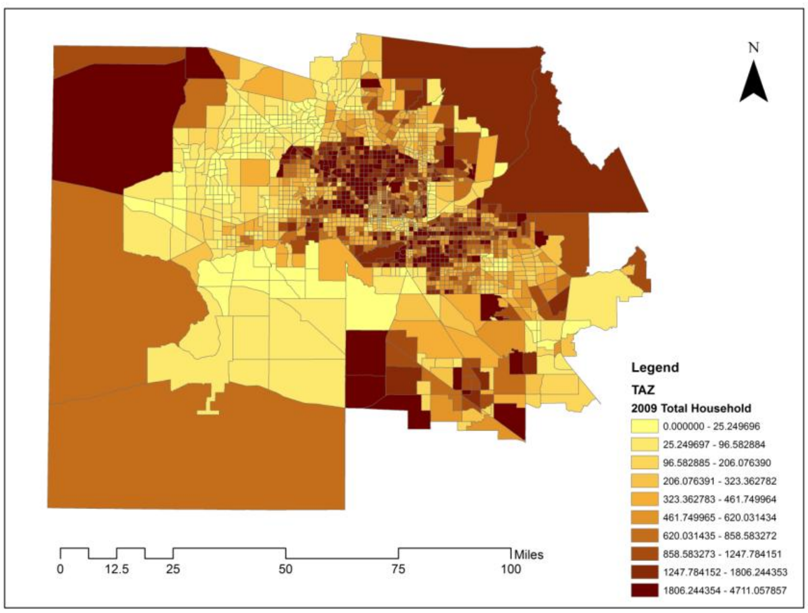
Lastly, the energy consumption and GHG calculation method employed in this research doesn't take factors such as congestion condition, weather condition, topology impacts into consideration, rendering the calculation results less accurate. However, the comparatively relationship between urban and suburban energy consumption and GHG emissions will remain solid. In the future, a more detailed bottom-up approach in which energy consumption and GHG emissions are estimated from observed vehicle activity rather than from average fuel economy may be introduced to calibrate the energy consumption and GHG emission results.

APPENDIX A

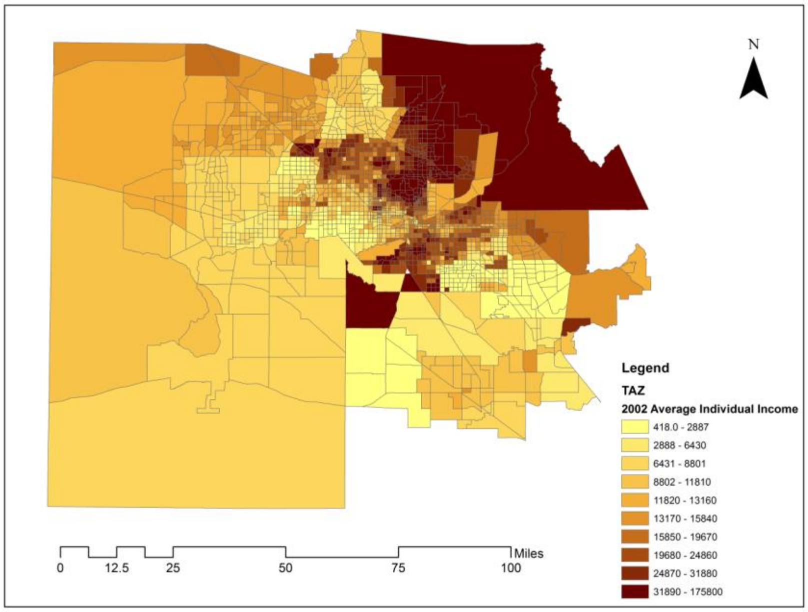
TAZ Level Socio-economic Variables



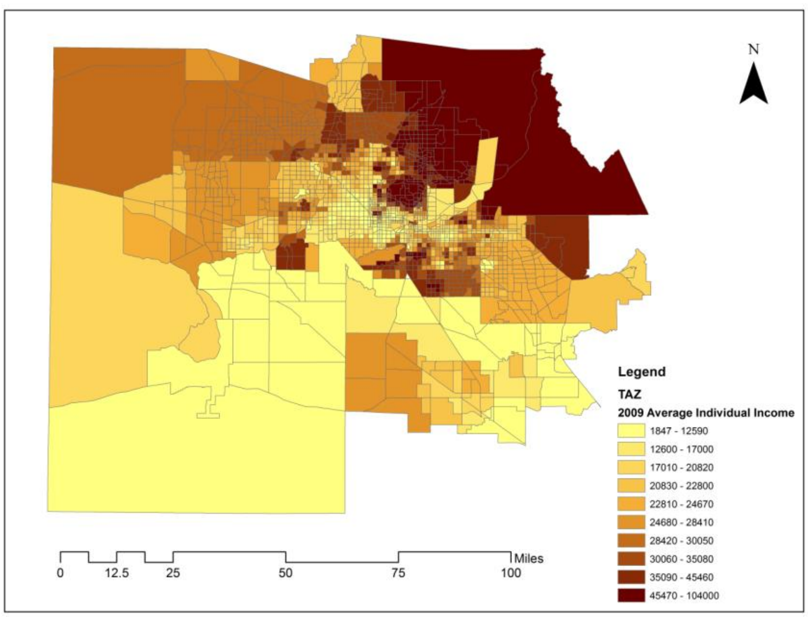
2002 TAZ Level Household Number



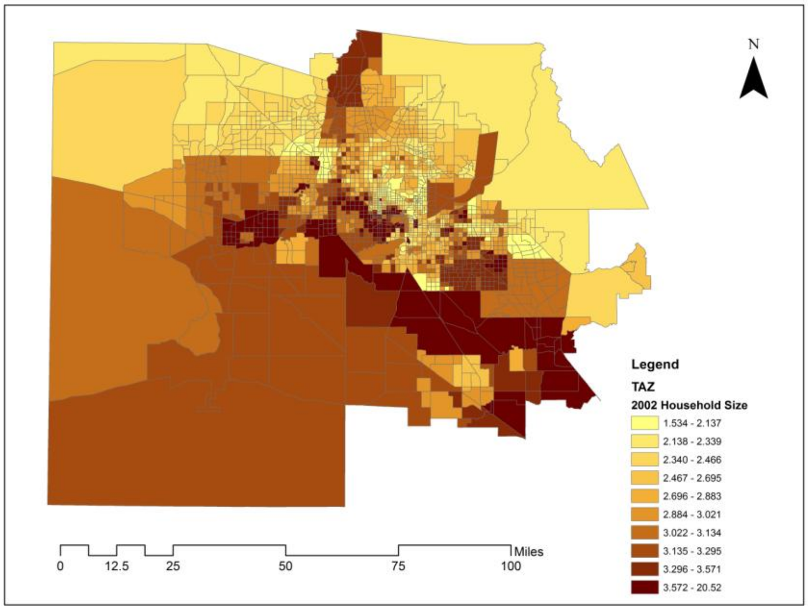
2009 TAZ Level Household Number



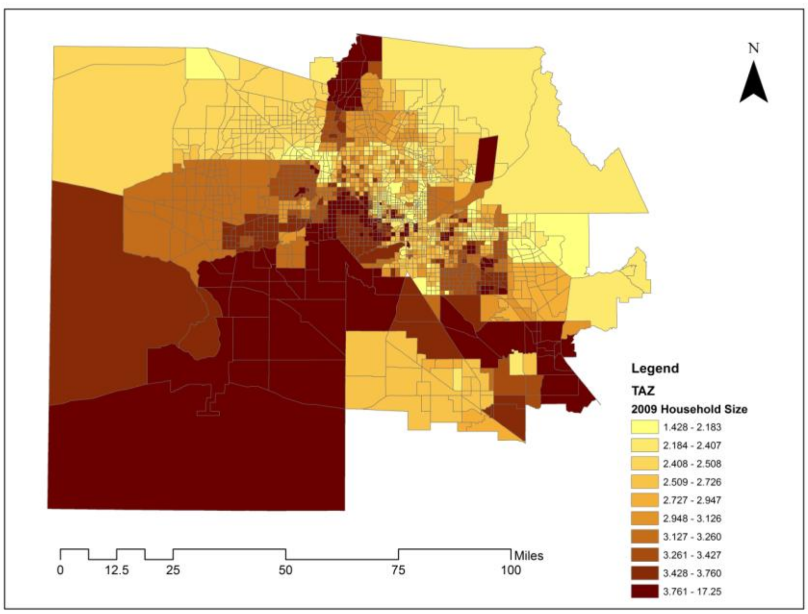
2002 Average Individual Income



2009 Average Individual Income



2002 Average Household Size



2002 Average Household Size

APPENDIX B

Trip Production Rate Tables

Table B.1: Example of 2001HBW Trip Generation Rate Table by Census Tract

ID	VT10	VT11	VT12	VT13	VT14	VT20	VT21	VT22	VT23	VT24	VT30	VT31	VT32	VT33	VT34	VT40	VT41	VT42	VT43	VT44	VT50	VT51	VT52	VT53	VT54
04007000300	0.39384597	0.571588	0.745602	0.915935	1.082635	0.447733	0.611531	0.771836	0.928696	1.082155	0.49114	0.641917	0.789431	0.933724	1.074842	0.525171	0.663817	0.799418	0.932015	1.061653	0.550865	0.67823	0.802759	0.924492	1.043471
04007000700	0.29455506	0.398301	0.500356	0.600737	0.699464	0.371426	0.470215	0.567378	0.662931	0.756893	0.441447	0.53548	0.62795	0.718873	0.808267	0.504996	0.59447	0.682442	0.768927	0.853943	0.562441	0.647545	0.731207	0.813442	0.894266
04007000800	0.31944814	0.421695	0.52227	0.621192	0.718476	0.394195	0.491545	0.587288	0.681441	0.77402	0.462207	0.554861	0.645969	0.73555	0.823618	0.523859	0.612011	0.698678	0.783876	0.867623	0.579514	0.663352	0.745764	0.826768	0.906377
04012020100	0.28816159	0.391514	0.493181	0.59318	0.69153	0.364912	0.463324	0.560115	0.655303	0.748904	0.434831	0.528503	0.620618	0.711191	0.800239	0.498296	0.587424	0.675055	0.761206	0.845892	0.555672	0.640446	0.723783	0.805698	0.886207
04013010100	0.41280612	0.507143	0.599913	0.691134	0.780823	0.477595	0.56736	0.655621	0.742393	0.827693	0.536231	0.621616	0.705556	0.788067	0.869165	0.58907	0.67026	0.750063	0.828495	0.90557	0.636453	0.713628	0.789473	0.864002	0.93723
04013020201	0.38162611	0.536164	0.687381	0.835321	0.980028	0.42512	0.567273	0.706325	0.84232	0.9753	0.459573	0.590201	0.717941	0.842833	0.964919	0.485989	0.605915	0.723154	0.837747	0.94973	0.505307	0.615311	0.72282	0.827872	0.930504
04013020202	0.41589894	0.600456	0.781169	0.958084	1.13125	0.471602	0.641771	0.808335	0.97134	1.130834	0.516482	0.673203	0.82655	0.97657	1.123306	0.551668	0.695846	0.836875	0.974796	1.109655	0.578223	0.710727	0.840296	0.96697	1.090791
04013030302	0.52016306	0.701886	0.879803	1.05396	1.224408	0.567416	0.734929	0.898875	1.059298	1.216247	0.604419	0.758656	0.909556	1.057163	1.201523	0.632278	0.774138	0.912883	1.048556	1.181199	0.652032	0.782377	0.90982	1.034401	1.156162
04013030303	0.42764895	0.606756	0.782108	0.953753	1.121739	0.479898	0.644969	0.806523	0.964606	1.119263	0.521711	0.673675	0.82235	0.967781	1.110012	0.554194	0.693942	0.830622	0.964276	1.094946	0.578386	0.706774	0.832303	0.955014	1.07495
04013030304	0.5305024	0.714087	0.893833	1.069788	1.242001	0.577976	0.747229	0.912884	1.074986	1.233583	0.615119	0.770979	0.923473	1.072644	1.218539	0.643044	0.786416	0.926643	1.06377	1.19784	0.662797	0.794547	0.923366	1.049297	1.17238
04013030307	0.60309785	0.787633	0.968307	1.145169	1.318267	0.646141	0.816281	0.9828	1.145745	1.305163	0.679065	0.835749	0.989045	1.138998	1.285654	0.702977	0.847112	0.988083	1.125934	1.260707	0.718921	0.851376	0.980883	1.107482	1.231215
04013030308	0.5200933	0.697321	0.870818	1.040632	1.20681	0.565133	0.728443	0.88826	1.044627	1.197593	0.60021	0.750527	0.897578	1.041407	1.182058	0.626413	0.764624	0.899789	1.031948	1.161146	0.644762	0.771718	0.895836	1.017157	1.135721
04013030309	0.56763967	0.748179	0.924927	1.097932	1.267242	0.61109	0.777494	0.940345	1.099689	1.255574	0.644546	0.797746	0.947623	1.094222	1.237588	0.669103	0.809996	0.947786	1.082519	1.214237	0.685791	0.815235	0.941789	1.065495	1.186395
04013030310	0.46042545	0.63904	0.813904	0.985068	1.152578	0.510204	0.674814	0.835911	0.993542	1.147753	0.549704	0.701236	0.849483	0.994492	1.136306	0.580025	0.719369	0.85565	0.988909	1.11919	0.6022	0.730211	0.855368	0.977712	1.097284
04013030311	0.3628699	0.528786	0.69118	0.8501	1.00559	0.413157	0.565915	0.71538	0.861597	1.00461	0.453592	0.594085	0.731505	0.865896	0.9973	0.485233	0.614318	0.74054	0.863942	0.984564	0.509073	0.627565	0.743396	0.856606	0.967231
04013030312	0.35505945	0.523434	0.688245	0.849538	1.007361	0.407071	0.562122	0.713841	0.862271	1.007457	0.449042	0.591671	0.731189	0.867638	1.001062	0.482043	0.613113	0.741284	0.866597	0.989093	0.507078	0.627413	0.745051	0.860031	0.972394
04013030313	0.32311051	0.489459	0.652282	0.811625	0.967536	0.376348	0.529511	0.679377	0.825991	0.969399	0.419546	0.560418	0.698213	0.832976	0.964748	0.45377	0.583209	0.709782	0.833531	0.954496	0.480021	0.598843	0.715002	0.828534	0.93948
04013030314	0.46355319	0.644007	0.82068	0.993621	1.162877	0.514021	0.68035	0.843136	1.002426	1.158267	0.554104	0.707239	0.857062	1.003616	1.146947	0.584911	0.725748	0.863493	0.998189	1.12988	0.607482	0.736879	0.863395	0.987073	1.107952
04013030315	0.45534859	0.636281	0.813425	0.98683	1.156543	0.506607	0.673384	0.836611	0.996335	1.152602	0.547421	0.700974	0.851208	0.998166	1.141895	0.578898	0.720125	0.858253	0.993326	1.125387	0.602084	0.731844	0.858717	0.982744	1.103967
04013030316	0.52680889	0.703195	0.875863	1.044863	1.21024	0.570976	0.7335	0.892542	1.048149	1.200367	0.605261	0.754844	0.901173	1.044293	1.184248	0.630747	0.768275	0.902768	1.034269	1.162819	0.648451	0.774772	0.898266	1.018976	1.136939
04013030318	0.54802328	0.732812	0.913741	1.090858	1.26421	0.594909	0.765289	0.932048	1.095234	1.254894	0.631453	0.788364	0.941887	1.092068	1.238953	0.658771	0.80312	0.944306	1.082371	1.21736	0.677913	0.81057	0.940278	1.067079	1.191015
04013030319	0.56697316	0.746931	0.923107	1.09555	1.264308	0.61018	0.77604	0.938357	1.097176	1.252546	0.643427	0.79612	0.945499	1.091609	1.234496	0.667809	0.808229	0.945556	1.079834	1.211106	0.684351	0.813356	0.93948	1.062764	1.18325
04013030322	0.53791367	0.719153	0.896593	1.07028	1.240264	0.583725	0.750786	0.914284	1.074268	1.230783	0.619385	0.773199	0.923681	1.070877	1.214832	0.645994	0.78746	0.925815	1.061105	1.193371	0.66459	0.794567	0.921647	1.045872	1.167281
04013030323	0.52626512	0.706521	0.882994	1.055733	1.224785	0.57238	0.738521	0.901117	1.060216	1.215862	0.608362	0.761319	0.91096	1.057332	1.200479	0.63531	0.775978	0.913552	1.048075	1.179591	0.654257	0.783494	0.909849	1.033363	1.154077
04013030324	0.59122712	0.770214	0.945434	1.116936	1.284766	0.632307	0.797259	0.958681	1.11662	1.271123	0.663582	0.815426	0.96397	1.109259	1.251337	0.68614	0.825769	0.962318	1.095831	1.22635	0.701	0.829269	0.954669	1.077242	1.197028
04013030325	0.55136178	0.733319	0.911463	1.085842	1.256504	0.596618	0.764349	0.928505	1.089134	1.246281	0.631727	0.786166	0.937261	1.085057	1.2296	0.657792	0.799839	0.938764	1.074611	1.207423	0.675851	0.806368	0.933976	1.058717	1.180633
04013030326	0.5932789	0.775624	0.954145	1.128891	1.299911	0.635893	0.803984	0.968491	1.12946	1.286938	0.668492	0.823265	0.974684	1.122796	1.267645	0.692177	0.834532	0.973757	1.109896	1.24299	0.707981	0.838784	0.966669	1.091678	1.213853
04013030327	0.51185411	0.690122	0.864642	1.035462	1.20263	0.557967	0.72225	0.883022	1.04033	1.194219	0.594018	0.745243	0.893185	1.03789	1.179401	0.621103	0.760159	0.896153	1.029127	1.159124	0.640246	0.767987	0.892875	1.014952	1.134258
04013030328	0.51560741	0.694882	0.870391	1.042184	1.210306	0.561961	0.727185	0.888882	1.047096	1.201876	0.598204	0.750306	0.899109	1.044659	1.186999	0.625433	0.765306	0.9021	1.03586	1.166627	0.644678	0.773177	0.898809	1.021614	1.141634
04013030329	0.4063424	0.513282	0.618481	0.721957	0.823728	0.482185	0.584032	0.684204	0.782718	0.879593	0.551086	0.648045	0.743393	0.837147	0.929324	0.613429	0.7057	0.796422	0.885612	0.973287	0.669586	0.757363	0.843652	0.928469	1.011831
04013030330	0.49856646	0.680974	0.859564	1.034387	1.20549	0.547619	0.715773	0.88035	1.041396	1.198957	0.586297	0.741133	0.892623	1.040811	1.185743	0.61571	0.758129	0.897424	1.033638	1.166815	0.636904	0.76777	0.895724	1.020809	1.143065

Table B.2: Example of 2001 HBSH Trip Generation Rate Table by Census Tract

ID	VT10	VT11	VT12	VT13	VT14	VT20	VT21	VT22	VT23	VT24	VT30	VT31	VT32	VT33	VT34	VT40	VT41	VT42	VT43	VT44	VT50	VT51	VT52	VT53	VT54
04007000300	0.49217992	0.716962	0.93869	1.157362	1.351608	0.574473	0.787388	0.997248	1.204054	1.3848	0.645988	0.847085	1.045147	1.240181	1.006313	0.504186	0.642122	0.779111	0.915128	1.050151	0.558045	0.692012	0.82492	0.956748	1.087475
04007000700	0.3926585	0.532333	0.670451	0.807016	0.941315	0.501665	0.636684	0.770156	0.902083	1.031669	0.60384	0.734237	0.863099	0.990429	0.761033	0.478311	0.565984	0.653099	0.739649	0.825626	0.546929	0.632866	0.718218	0.802981	0.887146
04007000800	0.4275166	0.565801	0.702531	0.83771	0.970599	0.534441	0.668079	0.800172	0.930725	1.058912	0.634558	0.763586	0.891082	1.01705	0.781651	0.500096	0.58726	0.673858	0.759883	0.845328	0.567853	0.653257	0.73807	0.822286	0.905897
04012020100	0.38465252	0.523961	0.661715	0.797915	0.931856	0.493508	0.628164	0.761274	0.89284	1.022071	0.595538	0.725575	0.854078	0.981051	0.75552	0.473238	0.560776	0.647754	0.734164	0.819999	0.541763	0.627558	0.712767	0.797384	0.881401
04013010100	0.5645431	0.695234	0.82439	0.952013	1.077252	0.661194	0.787304	0.911893	1.034964	1.155587	0.751202	0.872784	0.992861	1.111439	0.86187	0.5874	0.671638	0.755269	0.838287	0.920688	0.650598	0.732958	0.81469	0.89579	0.976252
04013020201	0.49937252	0.703934	0.905454	1.103937	1.277388	0.569568	0.762401	0.95223	1.139065	1.299565	0.629499	0.810798	0.989149	1.164565	0.994746	0.512598	0.643495	0.773259	0.901873	1.029317	0.559629	0.6859	0.810954	0.934774	1.057347
04013020202	0.51258641	0.742892	0.970152	1.194363	1.394066	0.597255	0.815703	1.031094	1.243425	1.42952	0.671042	0.877635	1.081182	1.281685	1.021953	0.514978	0.654617	0.793368	0.931205	1.068104	0.570361	0.706242	0.841116	0.974961	1.107755
04013030302	0.64331651	0.871374	1.096382	1.318338	1.513782	0.720949	0.937139	1.150272	1.360347	1.542205	0.787709	0.992053	1.193354	1.391616	1.100971	0.594376	0.733355	0.871425	1.008563	1.144743	0.647462	0.782596	0.916704	1.049766	1.18176
04013030303	0.53262349	0.758533	0.981389	1.20119	1.396007	0.613792	0.827834	1.038819	1.246748	1.428037	0.684155	0.886368	1.085543	1.281687	1.031999	0.528424	0.666721	0.804084	0.940487	1.075909	0.582134	0.716504	0.849826	0.982078	1.113242
04013030304	0.65357236	0.883128	1.109638	1.333098	1.529976	0.731696	0.94939	1.164025	1.375601	1.558861	0.798913	1.004752	1.207544	1.407293	1.107682	0.599794	0.73923	0.877774	1.0154	1.152086	0.653286	0.788934	0.923572	1.057178	1.189729
04013030307	0.74054157	0.970875	1.198166	1.422407	1.618864	0.815433	1.033905	1.249319	1.461673	1.644481	0.879371	1.085983	1.289546	1.490063	1.160699	0.65131	0.790994	0.929797	1.067694	1.204661	0.704097	0.840024	0.97495	1.108853	1.241712
04013030308	0.64894004	0.873328	1.094661	1.312937	1.504442	0.724046	0.936564	1.146025	1.352432	1.530428	0.788363	0.989061	1.186724	1.381358	1.103136	0.599492	0.737327	0.874215	1.010132	1.145056	0.651216	0.785067	0.917859	1.049572	1.180185
04013030309	0.70299447	0.930105	1.154166	1.375173	1.568751	0.777441	0.992682	1.204866	1.413992	1.593993	0.841022	1.044422	1.244779	1.442099	1.137229	0.630736	0.769433	0.907215	1.044055	1.17993	0.682777	0.817592	0.951376	1.084106	1.215761
04013030310	0.57362004	0.799133	1.021594	1.240997	1.434795	0.652741	0.866386	1.076974	1.284507	1.464779	0.721058	0.922876	1.121657	1.317407	1.057111	0.553395	0.691574	0.828815	0.965095	1.10039	0.606457	0.740693	0.87388	1.005995	1.137018
04013030311	0.46445882	0.679212	0.890908	1.09955	1.283901	0.542181	0.745104	0.944988	1.141841	1.312935	0.609347	0.800563	0.988781	1.174011	0.981493	0.489123	0.623719	0.757269	0.889753	1.021149	0.54012	0.670399	0.799534	0.927506	1.054298
04013030312	0.45233557	0.669218	0.883043	1.093811	1.280528	0.531845	0.736884	0.93888	1.137839	1.311242	0.600745	0.794049	0.984347	1.171647	0.975579	0.481274	0.616603	0.750906	0.88416	1.016345	0.533141	0.664223	0.794178	0.922986	1.050629
04013030313	0.41355491	0.628677	0.840742	1.049752	1.235278	0.493862	0.697151	0.897403	1.094622	1.266881	0.563594	0.755173	0.943754	1.129345	0.949392	0.457377	0.592095	0.725769	0.858377	0.9899	0.509264	0.639677	0.768947	0.897056	1.023986
04013030314	0.57539426	0.80241	1.026374	1.247284	1.442626	0.655348	0.870496	1.082587	1.291621	1.473407	0.724466	0.927777	1.128047	1.325281	1.058904	0.553911	0.692559	0.830285	0.967065	1.102875	0.607458	0.74222	0.875946	1.008614	1.140203
04013030315	0.56477221	0.792174	1.016526	1.237823	1.433726	0.645425	0.860961	1.073439	1.28286	1.4652	0.715237	0.918933	1.119587	1.317205	1.052551	0.547358	0.686124	0.823971	0.960877	1.096816	0.601165	0.73606	0.869921	1.002728	1.134459
04013030316	0.65831854	0.882012	1.10265	1.32023	1.510868	0.732579	0.944402	1.15317	1.358884	1.536028	0.796066	0.996075	1.193051	1.387	1.108668	0.605502	0.743117	0.879778	1.015462	1.150146	0.656861	0.790465	0.923006	1.054461	1.184812
04013030318	0.67332537	0.903846	1.131323	1.355752	1.553368	0.751208	0.969869	1.185473	1.398017	1.581993	0.818157	1.024959	1.228712	1.42942	1.119941	0.611103	0.750831	0.889679	1.02762	1.16463	0.66471	0.800688	0.935667	1.069622	1.202533
04013030319	0.70298126	0.929619	1.153206	1.373738	1.566817	0.777129	0.991896	1.203606	1.412258	1.59177	0.840422	1.043351	1.243238	1.44009	1.137103	0.630989	0.76954	0.90717	1.043853	1.179567	0.682858	0.817509	0.951124	1.083681	1.215158
04013030322	0.66566338	0.893334	1.117956	1.339524	1.534237	0.742084	0.957888	1.170633	1.38032	1.56145	0.807636	1.011595	1.212511	1.410388	1.114528	0.607997	0.746861	0.884813	1.02183	1.157885	0.660683	0.795686	0.929662	1.062588	1.194444
04013030323	0.65266213	0.879532	1.103351	1.324116	1.518174	0.729148	0.944149	1.156093	1.364979	1.545473	0.794786	0.997949	1.19807	1.395155	1.106311	0.600569	0.739184	0.876878	1.013627	1.149407	0.653127	0.78785	0.921538	1.054169	1.185722
04013030324	0.7340917	0.959944	1.182745	1.40249	1.594285	0.806384	1.020365	1.231288	1.439154	1.617395	0.867834	1.069981	1.269088	1.465162	1.155997	0.650169	0.78848	0.925863	1.062293	1.197746	0.701376	0.835758	0.969096	1.101371	1.232561
04013030325	0.68115915	0.909413	1.134619	1.356773	1.551877	0.757275	0.973663	1.186992	1.397263	1.578769	0.822504	1.027044	1.228538	1.426993	1.124164	0.617	0.756046	0.894187	1.031397	1.167654	0.669712	0.804919	0.939104	1.072246	1.204322
04013030326	0.73176795	0.960346	1.185876	1.408355	1.60307	0.805906	1.022616	1.236269	1.446862	1.627965	0.869135	1.073994	1.275808	1.47458	1.155108	0.647149	0.786302	0.924555	1.061883	1.198262	0.699391	0.834717	0.969027	1.102297	1.234506
04013030327	0.63746151	0.862703	1.084892	1.304024	1.496594	0.713603	0.926975	1.13729	1.34455	1.523593	0.778937	0.980482	1.17899	1.374468	1.09638	0.592153	0.730256	0.867421	1.003624	1.138841	0.644322	0.778473	0.911573	1.043601	1.174536
04013030328	0.6408175	0.866885	1.0899	1.30986	1.503247	0.717323	0.93152	1.142661	1.350745	1.530588	0.783001	0.985366	1.184691	1.380984	1.098756	0.593804	0.732167	0.869601	1.00608	1.141583	0.646223	0.780664	0.914063	1.046396	1.177644
04013030329	0.53503609	0.67765	0.818703	0.958197	1.095323	0.643539	0.78148	0.917867	1.052701	1.185087	0.745171	0.878466	1.010215	1.140422	0.85357	0.566862	0.655608	0.743817	0.831482	0.918594	0.635705	0.722769	0.809268	0.895195	0.980543
04013030330	0.61604701	0.84465	1.070205	1.292708	1.489124	0.6952	0.911939	1.125619	1.336242	1.519064	0.763477	0.968367	1.170212	1.369018	1.084474	0.57774	0.716881	0.855119	0.992429	1.128786	0.631339	0.766655	0.900952	1.034206	1.166396
04013030331	0.6782158	0.910349	1.139443	1.365492	1.56475	0.75691	0.977191	1.194415	1.40858	1.594169	0.824635	1.033051	1.238415	1.440731	1.123238	0.613138	0.753344	0.892687	1.03114	1.168681	0.667262	0.803781	0.939317	1.073845	1.207344
04013030332	0.62649521	0.858212	1.086888	1.312518	1.512071	0.707129	0.926993	1.143799	1.357546	1.543446	0.77682	0.984822	1.189772	1.391675	1.091823	0.582557	0.722632	0.861838	1.000149	1.13754	0.637106	0.773479	0.908862	1.043232	1.176567
04013030333	0.7525626	0.976394	1.19717	1.414888	1.604277	0.822751	1.03471	1.243612	1.449461	1.625339	0.882148	1.082288	1.279394	1.473472	1.166904	0.66252	0.800195	0.93692	1.072673	1.20743	0.712746	0.846415	0.979024	1.110552	1.240978

Table B.3 2009 HBW and HBSH Trip Production Rate

Household Size	Household Vehicle	Household income	HBW production rate	HBSH production rate
1	<=1	1=<$10,000	0.1667	1.5417
		2=$10,000-$19,999	0.1399	1.3636
		3= $20,000 to $34,999	0.2879	1.2677
		4= $35,000 to $49,999	0.5797	1.2319
		5= $50,000 to $69,999	0.5769	1.2821
		6>= $70,000	0.5455	0.9545
	>1	1=<$10,000	0.2000	1.0000
		2=$10,000-$19,999	0.1818	1.0000
		3= $20,000 to $34,999	0.0909	2.3636
		4= $35,000 to $49,999	0.3043	1.1739
		5= $50,000 to $69,999	0.6471	1.1176
		6>= $70,000	0.5484	1.2903
2	<=1	1=<$10,000	0.1667	1.7500
		2=$10,000-$19,999	0.1860	2.2093
		3= $20,000 to $34,999	0.2115	2.4423
		4= $35,000 to $49,999	0.2846	2.3577
		5= $50,000 to $69,999	0.3803	2.2113
		6>= $70,000	0.4918	1.8033
	>1	1=<$10,000	0.0000	2.7143
		2=$10,000-$19,999	0.5306	1.9184
		3= $20,000 to $34,999	0.3798	2.4341
		4= $35,000 to $49,999	0.7045	2.0136
		5= $50,000 to $69,999	0.8068	2.2008
		6>= $70,000	0.9936	2.1426
3 or 4	<=1	1=<$10,000	1.3333	1.0000
		2=$10,000-$19,999	0.1875	2.6250
		3= $20,000 to $34,999	0.7143	1.8929
		4= $35,000 to $49,999	1.2857	1.6190
		5= $50,000 to $69,999	1.3889	1.1111
		6>= $70,000	0.7143	2.9048
	>1	1=<$10,000	0.5833	2.7500
		2=$10,000-$19,999	0.5938	1.6250
		3= $20,000 to $34,999	0.9259	2.3519
		4= $35,000 to $49,999	1.0667	2.2667
		5= $50,000 to $69,999	1.2778	2.4877
		6>= $70,000	1.3793	2.2879
>=4	<=1	1=<$10,000	0.0000	12.0000
		2=$10,000-$19,999	1.4286	1.7143
		3= $20,000 to $34,999	1.0000	2.6000
		4= $35,000 to $49,999	1.0000	1.6667
		5= $50,000 to $69,999	1.0000	2.0000
		6>= $70,000	1.0000	2.0000
	>1	1=<$10,000	2.0000	1.4286
		2=$10,000-$19,999	1.3333	3.4444
		3= $20,000 to $34,999	1.1765	3.1765
		4= $35,000 to $49,999	1.5122	3.2439
		5= $50,000 to $69,999	0.9091	3.1591
		6>= $70,000	1.2289	3.1807

APPENDIX C

Total Employment Change from 2001 to 2009

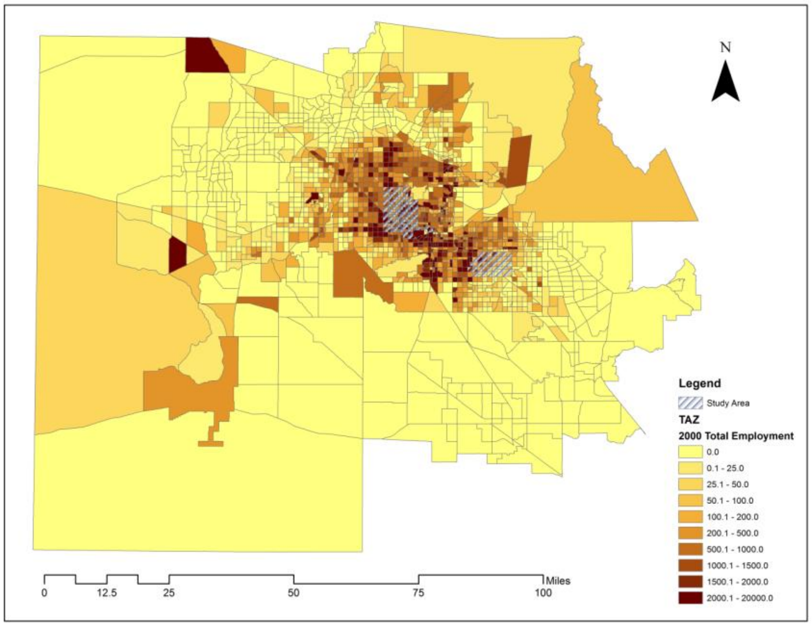


Figure C.1: 2000Total Employment Distribution

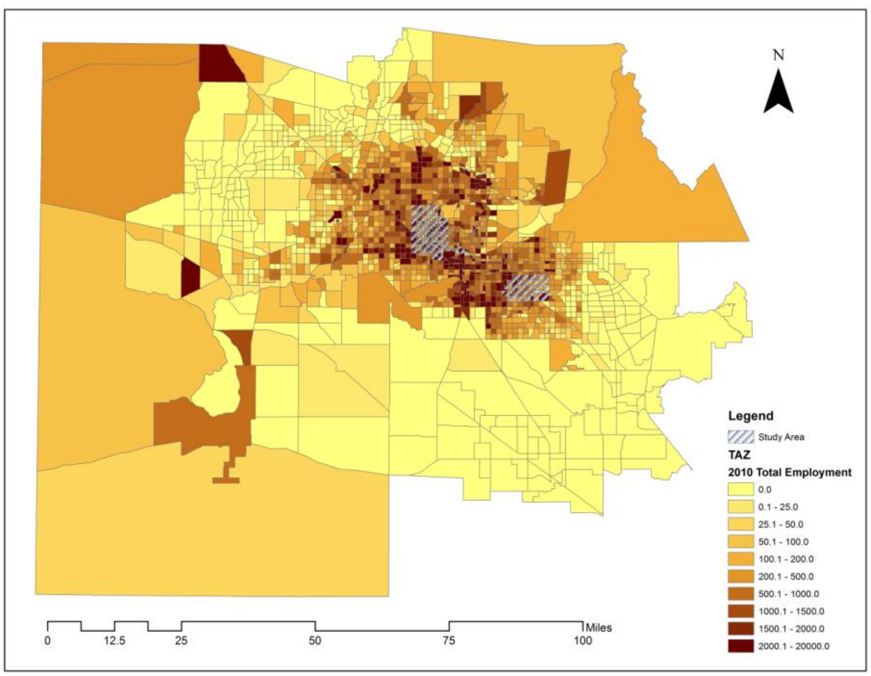


Figure C.2: 2010 Total Employment Distribution

Retail Employment Change from 2001 to 2009

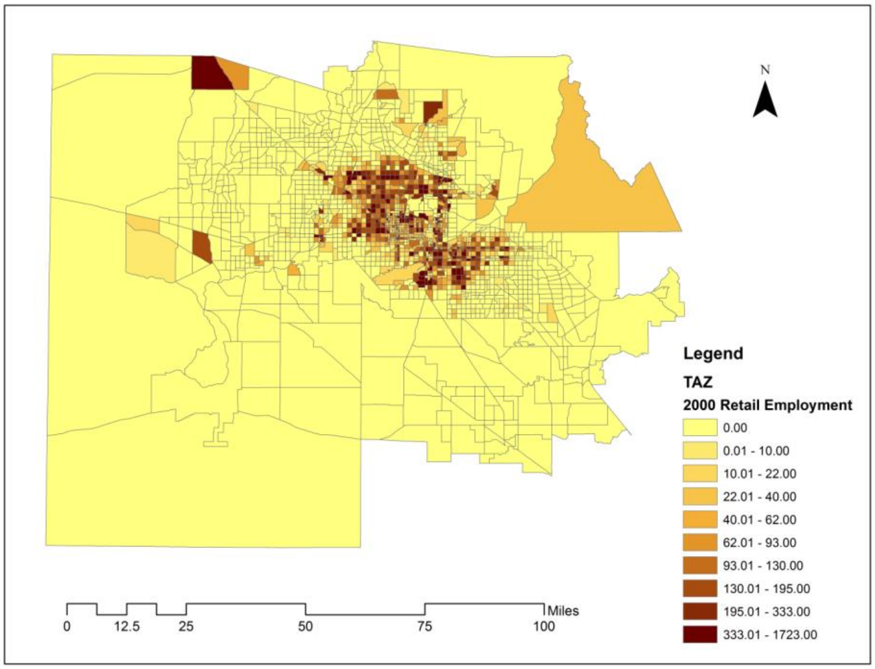


Figure C.3: 2000 Retail Employment Distribution

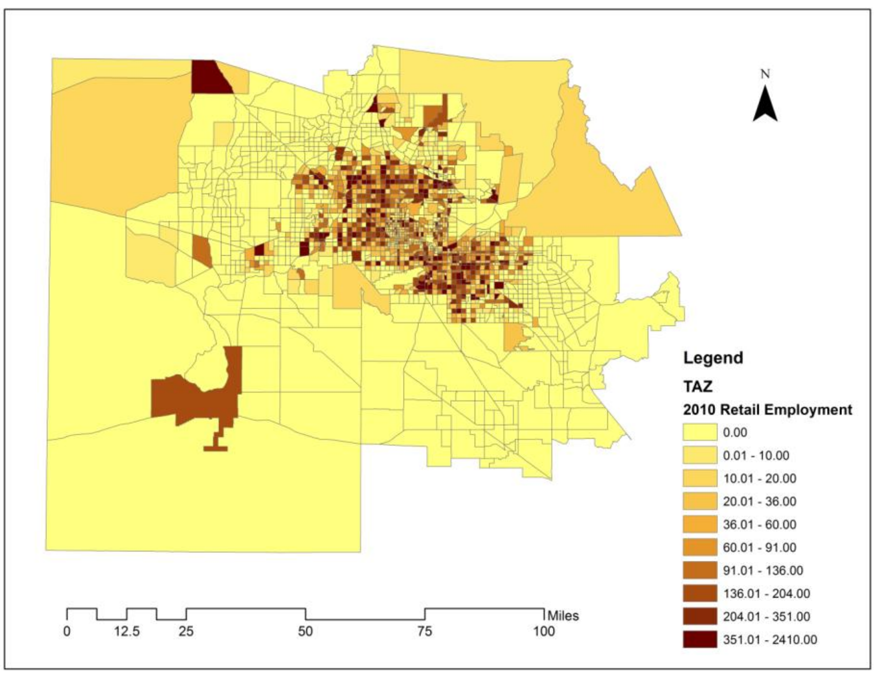


Figure C.4: 2010 Retail Employment Distribution

APPENDIX D

Detailed HBW Travel Pattern Results

2001 HBW Travel Pattern Result Summary by Trip Types

Trip Type	Zone	Trip number	Avg. Trip Length	Total VMT	Trip/Person	VMT/Person
Intra	Phoenix	51926.01	4.12	213686.81	0.15	0.63
Inter-out	Phoenix	56077.56	10.27	576124.75	0.16	1.69
Inter-in	Phoenix	190162.44	15.05	2861382.11	N/A	N/A
Intra	Gilbert	3516.16	3.12	10981.84	0.03	0.09
Inter-out	Gilbert	33923.24	13.61	461614.07	0.29	3.89
Inter-in	Gilbert	10550.80	12.65	133417.13	N/A	N/A

2009 HBW Travel Pattern Result Summary by Trip Types

Trip Type	Zone	Trip number	Avg. Trip Length	Total VMT	Trip/Person	VMT/Person
Intra	Phoenix	18816.00	14.92	280799.40	0.06	0.82
Inter-out	Phoenix	71352.00	18.06	1288378.47	0.21	3.78
Inter-in	Phoenix	233406.48	20.49	4783334.34	N/A	N/A
Intra	Gilbert	3091.96	8.00	24740.48	0.03	0.21
Inter-out	Gilbert	65236.97	17.45	1138115.81	0.55	9.59
Inter-in	Gilbert	31602.58	18.92	597794.69	N/A	N/A

Made by Local Habitants
Made by Outside Habitants

Detailed HBW Energy Consumption Results

2001 HBW Energy Result Summary by Trip Type

Trip Type	Zone	Energy Consumption (Gallon of Gasoline)	Energy/ person
Intra	Phoenix	13244.93	0.04
Inter-out	Phoenix	35709.88	0.10
Inter-in	Phoenix	177356.76	N/A
Intra	Gilbert	680.69	0.01
Inter-out	Gilbert	28612.18	0.24
Inter-in	Gilbert	8269.58	N/A

2009 HBW Energy Result Summary by Trip Type

Trip Type	Zone	Energy Consumption (Gallon of Gasoline)	Energy/ person
Intra	Phoenix	14943.91	0.04
Inter-out	Phoenix	68566.44	0.20
Inter-in	Phoenix	254565.12	N/A
Intra	Gilbert	1316.67	0.01
Inter-out	Gilbert	60569.59	0.51
Inter-in	Gilbert	31814.14	N/A

Made by Local Habitants
Made by Outside Habitants

Detailed HBW GHG Consumption Results

2001 HBW GHG Result Summary by Trip Type

Trip Type	Zone	GHG (CO2e (kg))	GHG/Person
Intra	Phoenix	120491.57	0.35
Inter-out	Phoenix	324859.42	0.95
Inter-in	Phoenix	1613447.33	N/A
Intra	Gilbert	6192.33	0.05
Inter-out	Gilbert	260290.29	2.19
Inter-in	Gilbert	75229.91	N/A

Made by Local Habitants
Made by Outside Habitants

2009 HBW GHG Result Summary by Trip Type

Trip Type	Zone	GHG (CO2e (kg))	GHG/Person
Intra	Phoenix	136596.06	0.40
Inter-out	Phoenix	626737.16	1.84
Inter-in	Phoenix	2326873.22	N/A
Intra	Gilbert	12035.11	0.10
Inter-out	Gilbert	553641.25	4.66
Inter-in	Gilbert	290799.75	N/A

Detailed HBSH Travel Pattern Results

2001 HBSH Travel Pattern Result Summary by Trip Types

Trip Type	Zone	Trip number	Avg. Trip Length	Total VMT	Trip/Person	VMT/Person
Intra	Phoenix	98187.33	2.70	264738.76	0.29	0.78
Inter-out	Phoenix	41219.02	7.37	303718.28	0.12	0.89
Inter-in	Phoenix	132648.58	14.49	1922210.93	N/A	N/A
Intra	Gilbert	10651.79	2.04	21742.36	0.09	0.18
Inter-out	Gilbert	33984.48	9.21	313020.87	0.29	2.64
Inter-in	Gilbert	8884.88	9.25	82216.11	N/A	N/A

2009 HBSH Travel Pattern Result Summary by Trip Types

Trip Type	Zone	Trip number	Avg. Trip Length	Total VMT	Trip/Person	VMT/Person
Intra	Phoenix	55789.03	4.29	239579.31	0.16	0.70
Inter-out	Phoenix	190634.80	8.82	1682310.25	0.56	4.93
Inter-in	Phoenix	228443.42	10.36	2367134.40	N/A	N/A
Intra	Gilbert	17601.10	3.48	61271.96	0.15	0.52
Inter-out	Gilbert	101290.34	7.30	739763.72	0.85	6.23
Inter-in	Gilbert	79504.78	9.86	783707.83	N/A	N/A

Made by Local Habitants
Made by Outside Habitants

Detailed HBSH Energy Consumption Results

2001 HBSH Energy Result Summary by Trip Type

Trip Type	Zone	Energy Consumption (Gallon of Gasoline)	Energy/ person
Intra	Phoenix	16409.28	0.05
Inter-out	Phoenix	18825.34	0.06
Inter-in	Phoenix	119144.21	N/A
Intra	Gilbert	1347.65	0.01
Inter-out	Gilbert	19401.94	0.16
Inter-in	Gilbert	5095.99	N/A

2009 HBSH Energy Result Summary by Trip Type

Trip Type	Zone	Energy Consumption (Gallon of Gasoline)	Energy/ person
Intra	Phoenix	12750.21	0.04
Inter-out	Phoenix	89531.17	0.26
Inter-in	Phoenix	125976.94	N/A
Intra	Gilbert	3260.84	0.03
Inter-out	Gilbert	39369.62	0.33
Inter-in	Gilbert	41708.29	N/A

Made by Local Habitants
Made by Outside Habitants

Detailed HBSH GHG Consumption Results

2001 HBSH GHG Result Summary by Trip Type

Trip Type	Zone	GHG (CO2e (kg))	GHG/Person
Intra	Phoenix	149278.23	0.44
Inter-out	Phoenix	201070.92	0.59
Inter-in	Phoenix	1083876.94	N/A
Intra	Gilbert	12259.86	0.10
Inter-out	Gilbert	176503.06	1.49
Inter-in	Gilbert	46359.19	N/A

2009 HBSH GHG Result Summary by Trip Type

Trip Type	Zone	GHG (CO2e (kg))	GHG/Person
Intra	Phoenix	116544.37	0.34
Inter-out	Phoenix	818366.94	2.40
Inter-in	Phoenix	1151502.54	N/A
Intra	Gilbert	29806.01	0.25
Inter-out	Gilbert	359861.19	3.03
Inter-in	Gilbert	381237.99	N/A

Made by Local Habitants
Made by Outside Habitants

APPENDIX E

Market Incremental Segment Test for 2001 HBW

H_0: Individual HBW VMT generation patterns are similar in urban and non-urban areas;

H_1: Individual HBW VMT generation patterns are different in urban and non-urban areas.

$$F_0 = \frac{\left[SSE_p - (SSE_1 + SSE_2)\right]/(J+1)}{(SSE_1 + SSE_2)/[(N_1 - J - 1) + (N_2 - J - 1)]}$$

$$= \frac{[100.758 - (43.622 + 54.239)]/(5+1)}{(43.622 + 54.239)/[(744 - 5 - 1) + (1120 - 5 - 1)]} = 9.138$$

$$> F_{0.05,5,1864} = 2.21$$

Where,

J is the number of variables used in the model, which is 5;

SSE_p is the SSE obtained from the regression for the entire region;

SSE_1 is the SSE obtained from the regression with only urban TAZs;

SSE_2 is the SSE obtained from the regression with only non-urban TAZs;

N_1 is the total number of sample for urban TAZs;

N_2 is the total number of sample for non-urban TAZs.

The result is highly significant, indicating that separate models should be used for urban and non-urban areas.

Market Incremental Segment Test for 2009 HBW

H_0: Individual HBW VMT generation patterns are similar in urban and non-urban areas;

H_1: Individual HBW VMT generation patterns are different in urban and non-urban areas.

$$F_0 = \frac{\left[SSE_p - (SSE_1 + SSE_2)\right]/(J+1)}{(SSE_1 + SSE_2)/[(N_1 - J - 1) + (N_2 - J - 1)]}$$

$$= \frac{[348.064 - (166.142 + 154.846)]/(5+1)}{(166.142 + 154.846)/[1864 - 12]} = 26.03667$$

$$> F_{0.05,5,1864} = 2.21$$

Where,

J is the number of variables used in the model, which is 5;

SSE_p is the SSE obtained from the regression for the entire region;

SSE_1 is the SSE obtained from the regression with only urban TAZs;

SSE_2 is the SSE obtained from the regression with only non-urban TAZs;

N_1 is the total number of sample for urban TAZs;

N_2 is the total number of sample for non-urban TAZs.

The result is highly significant, indicating that separate models should be used for urban and non-urban areas.

Market Incremental Segment Test for 2001 HBSH

H_0: Individual HBSH VMT generation patterns are similar in urban and non-urban areas;

H_1: Individual HBSH VMT generation patterns are different in urban and non-urban areas.

$$F_0 = \frac{\left[SSE_p - (SSE_1 + SSE_2)\right]/(J+1)}{(SSE_1 + SSE_2)/[(N_1 - J - 1) + (N_2 - J - 1)]}$$

$$= \frac{[224.319 - (92.403 + 124.103)]/(5+1)}{(92.403 + 124.103)/[1864 - 12]} = 11.139 > F_{0.05,5,1864}$$

$$= 2.21$$

Where,

J is the number of variables used in the model, which is 5;

SSE_p is the SSE obtained from the regression for the entire region;

SSE_1 is the SSE obtained from the regression with only urban TAZs;

SSE_2 is the SSE obtained from the regression with only non-urban TAZs;

N_1 is the total number of sample for urban TAZs;

N_2 is the total number of sample for non-urban TAZs.

The result is highly significant, indicating that separate models should be used for urban and non-urban areas.

Market Incremental Segment Test for 2009 HBSH

H_0: Individual HBSH VMT generation patterns are similar in urban and non-urban areas;

H_1: Individual HBSH VMT generation patterns are different in urban and non-urban areas.

$$F_0 = \frac{[SSE_p - (SSE_1 + SSE_2)]/(J+1)}{(SSE_1 + SSE_2)/[(N_1 - J - 1) + (N_2 - J - 1)]}$$

$$= \frac{[381.444 - (205.431 + 157.841)]/(5+1)}{(205.431 + 157.841)/[1864 - 12]} = 15.440 > F_{0.05,5,1864}$$

$$= 2.21$$

Where,

J is the number of variables used in the model, which is 5;

SSE_p is the SSE obtained from the regression for the entire region;

SSE_1 is the SSE obtained from the regression with only urban TAZs;

SSE_2 is the SSE obtained from the regression with only non-urban TAZs;

N_1 is the total number of sample for urban TAZs;

N_2 is the total number of sample for non-urban TAZs.

The result is highly significant, indicating that separate models should be used for urban and non-urban areas.

REFERENCES

Albrecht, W. (2006) *Experiences with Grids at Eurostat*, Nordic Forum for Geo-statistics, Kongsvinger, Norway.

Anslin, L. (2005) *Exploring Spatial Data with GeoDa: A Work Book.* Center for Spatially Integrated Social Science[online] Available at: <https://geodacenter.asu.edu/system/files/geodaworkbook.pdf>[Accessed 23 January 2013].

Bhat, C. R., & Guo, J. Y. (2007). A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. *Transportation Research: Part B*, *41*(5), 506-526.

Baht, C.R. & Sudeshna, S., & Naveen, E. (2009). The impact of demographics, built environment attributes, vehicle characteristics, and gasoline prices on household vehicle holdings and use. *Transportation Research Part B*, *43*1-18.

Bento, A., Cropper, M. L., Mobarak, A., & Vinha, K. (2003). The Impact of Urban Spatial Structure on Travel Demand in the United States.

Boarnet., M. G. (2011). A Broader Context for Land Use and Travel Behavior, and a Research Agenda. *Journal Of The American Planning Association*, *77*(3), 197-213.

Boarnet., M. G. & Crane, R. (2001). The influence of land use on travel behavior: specification and estimation strategies. *Transportation Research Part A*, *35*823-845.

Brownstone, D., & Golob, T. (2009). The impact of residential density on vehicle usage and energy consumption. *Journal Of Urban Economics*, *65*91-98.

Calthorpe, Peter. (1993). *The next American metropolis: ecology, community, and the American dream / Peter Calthorpe ; guidelines with Shelley Poticha*. New York: Princeton Architectural Press, c1993.

Cao, X. X., Mokhtarian, P. P., & Handy, S. S. (2009). Examining the Impacts of Residential Self-Selection on Travel Behaviour: A Focus on Empirical Findings. *Transport Reviews*, *29*(3), 359-395.

Cervero, R. (1994). Transit-based housing in California: evidence on ridership impacts. *Transport Policy*, 174-183.

Cervero, R., & Duncan, M. (1996). Which reduces vehicle travel more: Jobs-housing balance or retail-housing mixing?. *Journal Of The American Planning Association*, *72*(4), 475-490.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D-Transport And Environment*, *2*(3), 199-219.

Chatman, D. G. (2008). Deconstructing development density: Quality, quantity and price effects on household non-work travel. *Transportation Research Part A*, *42*1008-1030.

Crane, R. (1996). Cars and drivers in the new suburbs. *Journal Of The American Planning Association*, *62*(1), 51.

Crane, R.& Guo, Z. (2011). *Toward a second generation of land-use/travel models: theoretical and empirical frontiers.* Oxford University Press, c2013.

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment. *Journal Of The American Planning Association*, *76*(3), 265-294.

Ewing, R., Schroeer, W., & Greene, W. (2003). School location and student travel - Analysis of factors affecting mode choice. *Transportation Planning And Analysis 2004*, (1895), 55-63.

Frank, L., Kerr, J., Chapman, J., & Sallis, J. (2007). Urban form relationships with walk trip frequency and distance among youth. *American Journal Of Health Promotion*, *21*(4), 305-311.

Frank, L. D., & Pivo, G. G. (1995). Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and Walking. *Transportation Research Record*, (1466), 44.

Handy, S., Cao, X., & Mokhtarian, P. L. (2006). Self-Selection in the Relationship between the Built Environment and Walking. *Journal Of The American Planning Association*, *72*(1), 55-74.

Handy, S. L., & Niemeier, D. A. (1997). Measuring accessibility: an exploration of issues and alternatives. *Environment And Planning A*, *29*1175-1194.

Kockelman, K. M. (1997). Travel Behavior as Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from San Francisco Bay Area. *Transportation Research Record*, (1607), 116-125.

McNally, M. G., & Ryan, S. S. (1993). Comparative Assessment of Travel Characteristics for Neotraditional Designs. *Transportation Research Record*, (1400), 67.

National Research Council (U.S.). Transportation Research Board., & National Research Council (U.S.). Board on Energy and Environmental Systems. (2009). *Driving and the built environment: The effects of compact development on motorized travel, energy use, and CO2 emissions*. Washington, D.C.: Transportation Research Board.

Plessis, V., Beshiri, R. and Bollman, R. (2001) *Definitions of "Rural",* Statistics Canada, Ottawa, Canada.

Transportation Research Board. (1998). NCHRP Report 365: Travel Estimation Techniques for Urban Planning. [online] Available at: <http://ntl.bts.gov/lib/21000/21500/21563/PB99126724.pdf> [Accessed 23 January 2013].

Transportation Research Board. (2012). NCHRP Report 716: Travel Demand Forecasting: Parameters and Techniques [online] Available at: < http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_716.pdf> [Accessed 23 January 2013].

U.S. Department of Transportation. (2011). *Transportation Annual Report 2010*, 140-153.

Waddell, P., Ulfarsson, G. F., Franklin, J. P., Lobb, J. (2007). Incorporating Land Use in Metropolitan Transportation Planning. *Transportation Research Part A*. 41: 382-410.

Zegras, C. (2010). The Built Environment and Motor Vehicle Ownership and Use: Evidence from Santiago de Chile. *Urban Studies (Sage Publications, Ltd.)*, *47*(8), 1793-1817.