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Factors Explaining Changes in Household Vehicle Miles of Travel

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Factors Explaining Changes in Household Vehicle Miles of Travel

by

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DEDICATION

This thesis is dedicated to my mother and father, without whom I would never have been able to pursue higher education. They taught me the value of hard work and determination, and constantly challenge me to better myself.

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ABSTRACT

Vehicle miles of travel (VMT) is a key indicator of travel demand in the United States. Since 1995 total VMT and VMT per capita has fluctuated, with notable declines in the late 2000s and accelerated increases in the last 7 years. Since 1995, the National Household Travel Survey (NHTS) has tracked the household share of total VMT to shed light on the demographic and behavioral data behind personal vehicle travel. The household share of VMT, while still a majority, has declined every NHTS year since at least 1995. Meanwhile, household VMT has stagnated around 2.25 trillion miles since the 2001 survey. With such unprecedented travel demand changes, the current transportation technology revolution, and the climate of uncertainty, it is critical to understand why household VMT is changing and how this might affect future roadway demand.

This thesis examines demographic, socioeconomic and behavioral factors that influence VMT, including both factors with existing research and some untraditional factors, using new data and methodologies.

CHAPTER 1: INTRODUCTION

The roll of the automobile in creating mobility cannot be understated. Cars are the cornerstone of American transportation and are used in many facets including commuting, recreation, the transportation of commodities, and entertainment. Automobiles have become a critical function of everyday life. According to the Federal Highway Administration (FHWA), in 2017 Total Vehicle Miles of Travel (VMT) in the U.S. reached a record 3.21 trillion, the equivalent of nearly 9,900 miles per person [1]. This record setting story no longer holds true when examining household travel. The recent release of the National Household Travel Survey (NHTS) estimates 2017 household generated VMT, those miles not associated with travel for services or freight, at 2.26 trillion miles. While notably a large share of VMT is generated from household travel (a little more than two-thirds in 2017) the percent has been declining since 2001 and is showing little signs of stopping [2].

VMT is a measure of roadway demand and has been used as an important indicator of travel trends. Understanding the nature of VMT and how it changes is advantageous from both a planning and policy standpoint. For context, Figure 1-1 shows total national VMT and VMT per capita from 1995 to 2017 from the FHWA. Notably, VMT and VMT per capita have had nominal growth since 1995 and suffered from a period of decline between 2007 and 2014, but have since resumed growth [3]. VMT per capita has yet to return to pre-2007 levels, and may not if the slowed growth from 2016 to 2017 continues into 2018.

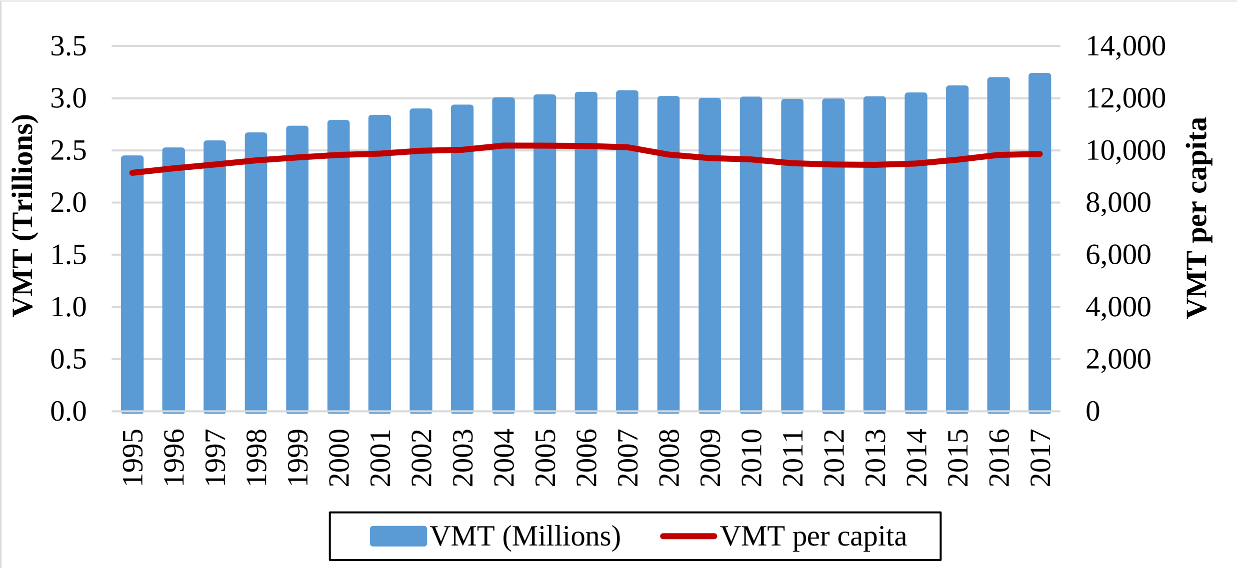

Figure 1-1 National VMT and VMT per capita

The FHWA count of VMT is inclusive of all traffic, but household VMT is not trending consistently with other components. Freight, commercial and public vehicle travel is not affected in the same way as household travel, and as such should be analyzed independently. The NHTS seeks to enrich our understanding of the household travel, which makes up the majority of all VMT. Figure 1-2 shows the VMT associated with household travel derived from the NHTS and the NHTS share of total VMT as calculated by FHWA. In 1995, NHTS derived VMT accounted for over 85% of total VMT. Every subsequent NHTS year this share has fallen, including another drop between 2009 and 2017 when it fell from 75% to 70%. Shockingly, despite a nominal increase in household VMT from 1995 to 2001 its share of total VMT decreased, so the trend is only exacerbated by the decrease in household VMT in 2009 and the very modest growth of 15.976 billion miles in 2017.

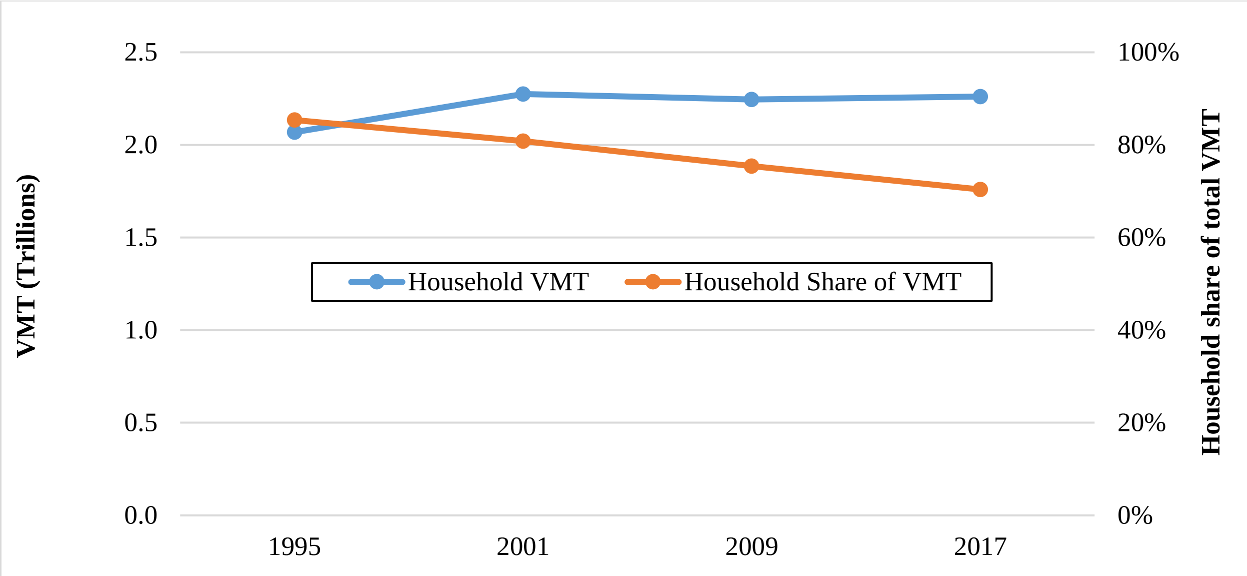

Figure 1-2 NHTS calculated VMT and NHTS share of total VMT

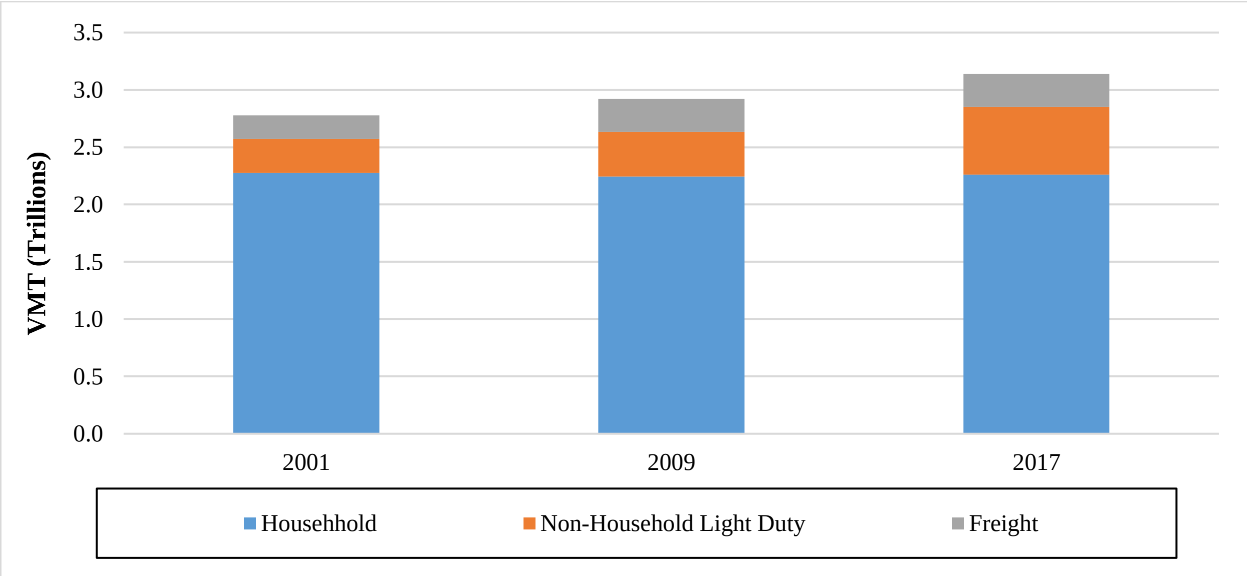

Figure 1-3 VMT by source

Figure 1-3 displays total VMT by source. It is surprising that not only has household generated VMT stagnated, so too has heavy freight related VMT indicating service trips constitute the majority of VMT growth between 2009 and 2017. These trips include TNCs, deliveries, maintenance and repair services, and other non-household and non-freight trips. Unfortunately, a data source doesn't exist that defines service VMT, and while the NHTS and other FHWA products help to fill in the picture slightly, it is not sufficient to explore completely. As communication continues to improve and the economy strengthens, people will be more willing to outsource getting food and groceries and doing housework to these services. This is a concept worth exploring when considering the implications to job specialization and off peak travel demand.

As total VMT has increased, so too has roadway supply as shown in Figure 1-4. Lane miles, as a measure of supply, have grown since 1995. In particular, urban lane miles have grown by about 50% in that time from just under 2 million to nearly 3 million miles according to the FHWA's Highway Statistic Series [4]. This is at least in part due to reclassification of roadways from rural to urban, but also the result of adding lanes to support demand. Demand, however, is evolving from traditional household dominated VMT to a more shared VMT landscape. It is important to understand how household VMT is changing to provide for the transportation needs of today rather than "business as usual".

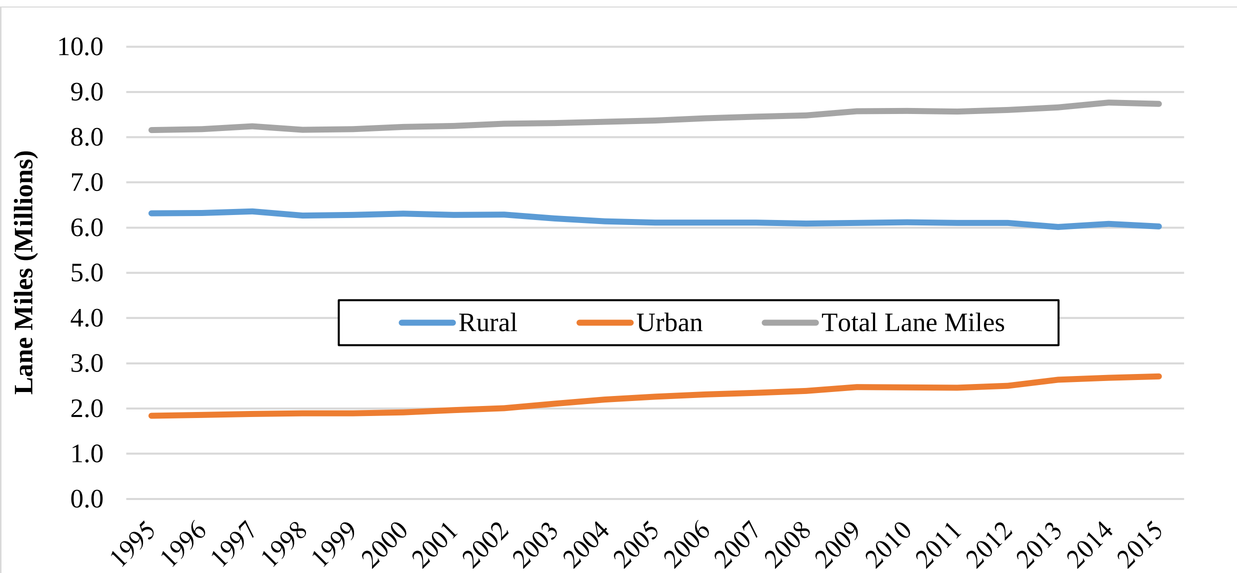

Figure 1-4 National lane miles

Factors influencing total VMT are not consistent with those factors affecting household VMT; and this phenomenon will only grow as the household share of total VMT continues to decrease. For this reason, it is important to identify how household VMT is changing, what travel trends have arisen since the early 2000s, and how this might influence future demand, and therefore policy and planning.

1.1 NHTS and Census Products

The bulk of the analysis presented in this paper utilizes NHTS behavioral data in regard to economic, demographic, and geographic conditions, as well as Census population data. The NHTS is a product of the FHWA distributed every 5 to 8 years and has been published for the years 2017, 2009, and 2001 with prior surveys conducted in 1995, 1990, 1983, 1977, and 1969 called the Nationwide Personal Transportation Surveys (NPTS). This paper focuses on the 2001, 2009, and 2017 years to draw conclusions about recent transportation trends within households. The 2017 NHTS data was collected using a stratified random sample of all U.S. households with and additional focus on 13 add-on areas [5]. These add-on areas include; Dallas-Ft. Worth, Texas; Des Moines, Iowa; Tulsa, Oklahoma; Waterloo, Iowa; New York; North Carolina; South Carolina; Texas; Arizona; Georgia; California; Maryland and Wisconsin. Prior surveys used list-assisted random digit dialing to collect responses. Of the 252,304 households recruited for the 2017 survey the final dataset includes 129,696 completed household surveys. A mix of online surveys and phone interviews were used to collect the data over a 14 month period spanning from March 2016 to May 2017.

Some important changes have been made to the 2017 NHTS particularly in regards to determining trip length. Historically, trip length was estimated using self-reported values by the household respondents. The 2017 NHTS incorporated Google Maps API to calculate the shortest distance between the trips origin and the trips destination as the new method to determine trip length. This methodology has resulted in an issuance of caution when using the data and comparing it to previous years. As of the download date of the data used in this paper, there has been corrections regarding the trip length based on mode of transport [6]. This updated data set required a confidentiality agreement, and adjusted trip lengths are not included in the publicly available data set. Thus, this same analysis with the publicly available data may result in different outcomes. While data refinements may continue to arise, it is important to understand that the analyses in this paper have consistently applied the trip length adjusted data.

The Census Bureau releases annual population estimates through the American Community Survey. The survey is compulsory and collects responses from county and county equivalents across the country. The 2016 data was comprised of 2,229,872 housing unit responses and 160,572 group quarters responses [7]. The main purpose for American Community Survey data in this paper is regarding population demographics to supplement the NHTS analysis. The broad sample size, compulsory nature, and extensive funding make it a reliable source for annual information. The release used in this paper is the 2016 dataset. The primary method of accessing the dataset is through the Factfinder online table search tool.

1.2 Nature of the Analysis

The primary objective of the paper is to explore the current travel trends in the NHTS with regards to household generated VMT. Human behavior is constantly changing, especially in an environment as complex and accelerated as the one presented by modern America. This can make determining any one reason for why VMT is changing difficult, let alone a combination of factors. For this reason the paper focuses on univariate analysis in combination with sensitivity analysis to see how particular factors affect or will affect VMT now and in the future. The analysis focuses exclusively on factors related to household VMT and does not include freight and/or service related vehicle mileage.

1.3 Note on Heterogeneity

Since this paper takes a univariate approach to the analysis of household VMT, there are likely to be factors that influence each other thereby masking the true individual impact of any given variable. This interaction, known as heterogeneity, means that performing an individual analysis of a variable to gain greater insight on it may unintentionally overplay the importance of the factor [8]. As a hypothetical example, if it were found that multi-person households have a higher tendency to make school related trips – and as a separate finding households with children in them had a higher tendency to make school related trips – then it could be the case that the multi-person finding is in fact partially caused by the presence of families with children. This does not mean that the multi-person household finding is wrong; on the contrary, it is a small portion of the reasoning for higher school trip rates, but is over emphasized if viewed independently. While this poses a dilemma for the quantitative impact of a factor, the univariate approach still outlines underlying details of the overall picture effectively while still maintaining quantitative relevance.

1.4 Outline

This thesis will proceed by first exploring some of the existing research with a literature review. The review serves to establish data and methods that have already been explored so as not to repeat research without warrant, and to develop a better overall understanding of total VMT and household VMT. This paper will then explore effects of demographics regarding housing density in the first analysis focused chapter. The second analysis chapter, while still focused on population, discusses the geographic distribution of peoples and population growth within MSAs. The third analysis chapter examines the national age profile and the implication of an aging population. The forth chapter of the analysis section explores Transportation Network Companies and how they are influencing modal VMT distribution. The last chapter explores share of VMT by trip length to help describe a more behavioral aspect of VMT. The final chapter of the thesis summarizes the findings of each analysis chapter, provides thoughts on policy and planning implications, and discusses some thoughts on future research.

CHAPTER 2: LITERATURE REVIEW

While the factors discussed in the paper have important implications in the grand scheme of household travel and VMT, there are many other factors that have been researched with profound impacts on VMT.

2.1 VMT and the Economy

One of the many well researched areas of VMT is the effect of the economy on transportation demand. It's a well understood phenomenon that the state of the economy, including factors like employment, GDP and consumer spending, have long been correlated to vehicle travel [9]. Additionally, VMT and the economy support into each other creating a positive feedback loop. In 2009, the Federal Surface Transportation Policy and Planning Act set a national goal to reduce per capita VMT and focus funding towards non-motorized modes of transportation in an effort to promote multimodal transportation and mitigate environmental impact, among other things. State governments have since established greenhouse gas and VMT reduction milestones, so understanding economic impact to motorized travel is a critical function of making these reductions. "Relationship Between Vehicle Miles Traveled and Economic Activity" by B. Starr McMullen and Nathan Eckstein highlights these goals and attempts to use time series data through a Granger causality analysis to determine how VMT and economic activity influence each other over time.

The McMullen/Eckstein paper focuses on both national data as well as urban metropolitan data [10]. The national dataset was pulled from the Bureau of Economic Analysis, which releases Gross Domestic Product (GDP) and personal income estimates, and the Federal Highway

Administration, which releases VMT estimates. Their findings suggest that using a 2-year lag length between economic indicators and VMT showed consistent Granger causality from the economy to VMT. They further concluded that that the causal relationship between VMT and GDP specifically is dependent on the business cycle. Macroeconomic upturns resulting in GDP growth were shown to increase VMT, and only during economic downturns did VMT decline precede GDP decline. This is not to suggest that VMT decline causes economic decline, but that it can be used as a preemptive indicator for decline.

Other studies have found similar cause-effect dualities regarding economic indicators and VMT. Liddle's 2009 study used co-integration to examine the time-series relationship between VMT and gasoline price, income, and vehicle ownership [11]. The paper focused on energy consumption as a function of GDP to determine methods to mitigate the negative impacts of fuel consumption. As part of the analysis, VMT was analyzed as a function of GDP as well. It was found that "U.S. mobility demand has a long-run systemic, mutually causal relationship with gasoline price, income, and vehicle ownership." [11]

Pozdena examines VMT in comparison to GDP as a means to better understand fuel consumption and carbon emissions [12]. The paper defines VMT in relation to GDP simplified as the production relationship and the consumption relationship. The production relationship represents the production of goods and services, including the movement of labor and raw materials among other things. The consumption relationship represents household's need to use energy and other resources to get them from origin to destination. The study found a response elasticity of 0.90% change in GDP per capita with a 1.0% change in VMT per capita over a 2-year period, and 0.45% change in GDP per capita over a 20-year period. On the other hand, VMT per capita responds negatively to changes in GDP per capita. Pozdena suggest the reason for the negative elasticity is from the notion that "VMT is less of a consumer good than it is an input to production or consumption." [12]

While there are some conflicting findings about how exactly the economy relates to VMT, it is evident there is a causality function between the two. The relationship influences how policy is implemented and what can be expected in terms of roadway demand in the future.

2.2 Gasoline Price

There seems to be a somewhat intuitive relationship between VMT and gasoline price that is confirmed by the literature. Brand's report on the "impacts of higher fuel costs" defines a negative elasticity between both short-term and long-term fuel price and VMT. The analysis found the short-term the price elasticity of VMT to be -0.12 between the months of July and October in 2007 and 2008. When adjusted for the "secular" trends (that is a 2.9% VMT increase and 1.2% fuel consumption increase between 2007 and 2008) the price elasticity is closer to -0.30 for the same four-month period. According to research conducted in the paper, other literature seems to come to a similar conclusion. What's important to note is there is a notable impact from fuel prices on travel behavior that leads to fewer VMT.

2.3 Gender

Pickrell notes in a 2013 presentation the differences in the average annual miles driven by men and by women by age group. The findings show that of men, nearly every age group except for men 65+ had declining annual miles driven while annual driving for women had only decreased in the 16-19 year group and the 20-34 year group between 2001 and 2009. Pickrell notes that the decline in driving "mirrors" the decline in employment among men and women alike. This being said, persons across all age groups are driving less regardless of the employment status. It is likely that behind the age and gender trends there are more integral explanations of declining travel demand [13].

2.4 Millennials

Millennial travel behavior is a major topic of interest in transportation research. "The impact of millennials' travel behavior on future personal vehicle travel" by Polzin uses 2009 and earlier NHTS trends to discuss some of the characteristics that distinguish millennials from prior generations [14]. The paper found that despite popular belief, millennials are only slightly more urbanized than previous generation. The share living in urban areas was 32% for this age range compared to the 28% for the baby boomers generation at that age. Daily VMT per capita for the millennials living in urban areas is smaller than that of non-urban residents. The paper also found that millennials in 2009 had the highest rates of college participation of any preceding generation, and while pursuance of a college degree decreased labor force participation (which coincides with less daily VMT per capita) the more educated individuals in this population segment tend to generate more daily VMT. Factors like income, debt, and employment put millennials under "significant economic stress", which has also dampened travel [14]. Intuitive measures like decreased licensure rate and lower vehicle availability have played against millennial VMT generation as well. Finally, millennial substitution of electronic media for trips and general changes in personal values also put downward pressure on VMT.

2.5 Baby Boomers

Baby boomers, similar to millennials, are getting research attention as they begin to enter retirement age. The baby boomer generation is the largest share of population over any other age group as of 2016 [15]. As the largest population segment in the U.S. it is important to understand baby boomer travel behavior [7]. In a Master's thesis out of the University of South Florida by J.

N. Samus Jr. examines the travel trends aspects of older individuals (persons 65 and older). Findings from the 2009 NHTS and prior show increased educational attainment as college educated seniors rose from 26% in 1990 to 48% in 2009. Additionally, seniors are choosing to stay employed longer with an increase share from 11% to 40% between 1990 and 2009. There was also noted increase in transit usage in the senior population. Several factors that may explain this rise include the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETY-LU) in 2005 which increased funding to transit and improved technology that is able to better communicate vehicle arrival, among other things [16]. These first of the baby boomers could be setting the precedence for the rest of their generation to defy the status quo travel of the older age cohorts.

2.6 VMT Forecasting

A presentation from the 9th annual New Partners for Smart Growth: Building Safe, Healthy, and Livable Communities by Polzin discusses the fundamental drivers of travel demand [17]. The presentation breaks down what drives travel demand into 3 steps: first, growth in income and knowledge; second, specialization in employment and consumption; and finally growth in person travel and commerce. Growth in travel demand in this way is self-promoting meaning that as people travel more they wind up fueling the desire to travel more; not only for themselves, but for others as well. Polzin presents three travel growth estimations as a basic concept. The 4-step model where population is converted to person trips, then person trips to person miles, then person miles to vehicle miles. The activity model where a population's travel time is budgeted to a certain number of hours per person and is then compared to travel speed by mode to determine the VMT. Lastly, the economist method that takes historical growth in population and personal income as a percent and determines the percent change in vehicle miles of travel. The methodologies presented by Polzin are similar to some presented in this paper.

CHAPTER 3: VMT AND POPULATION DENSITY

One of the major indicators of household VMT change is housing unit density at the block group level of geography. Density is an indicator for many transportation related studies, in particular those dealing with travel rates and trip distances. Increased housing density is correlated with greater economic activity and opportunity. This correlation suggests that the more people there are the more business that will exist. The assumption, therefore, is as housing units are spaced closer together they are more likely to take fewer vehicle trips, and those trips will tend to be shorter in length.

3.1 Housing Density

As part of this analysis, the number of households in a housing unit density per square mile is examined as a share of the total households. Housing unit density is categorized into 0 to 99; 100 to 499; 500 to 999; 1,000 to 1,999; 2,000 to 3,999; 4,000 to 9,999; 10,000 to 24,999; and 25,000 to 99,999 units per square mile. Figure 3-1 shows the distribution of households by density for 2009 and 2017.

Households in the 0 to 99 density per square mile range made up 18.3% of households in 2009, but this number has diminished to 16.7% in 2017. Household shares for the groups ranging from 100 to 3,999 units per square mile have remained relatively constant, only shifting by fractions of a percent between 2009 and 2017. This consistency suggests that most of the lost shares from the 0 to 99 density range has been absorbed by the 4,000 and greater density ranges. This is particularly true for the 4,000 to 9,999 density range whose share increased 1.0% from 2009 to 2017. Every density range grew in number of households with the exception of the 0 to 99 range, which fell from 20,661,000 to 19,720,000 households. The decrease in households for this range is likely due to either reclassification of the household to a higher order density range (from construction of more housing units in the block group), or the result of the residential growth occurring in the higher order ranges.

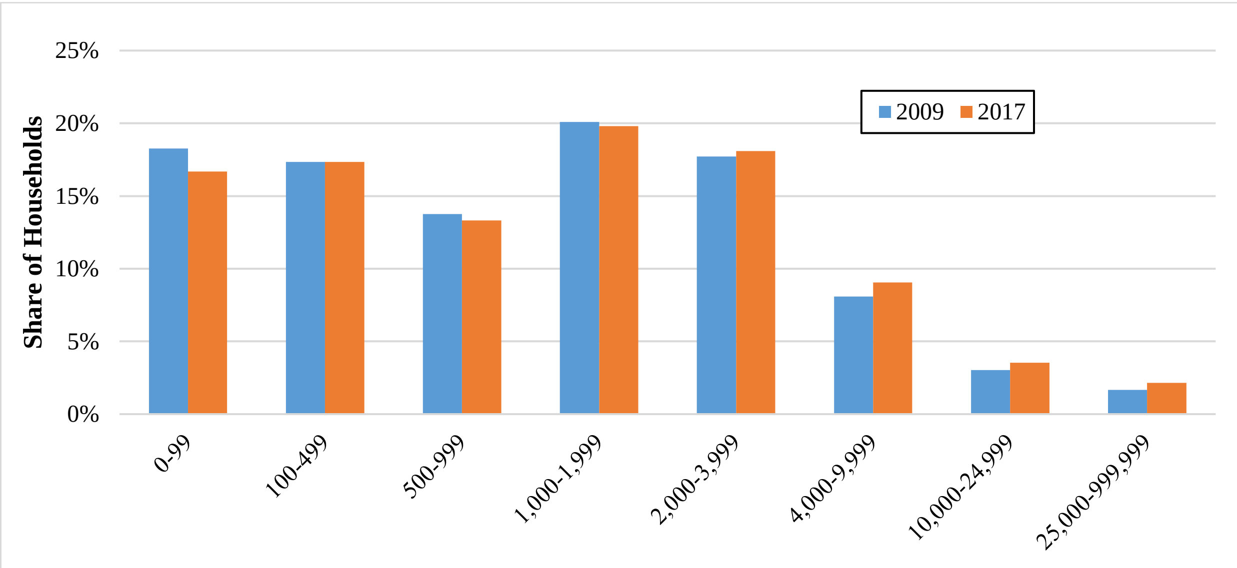

Figure 3-1 Share of households by housing unit density within block group

3.2 Trip Rate

The trip rate data used for this analysis was specific to vehicle trips and therefore did not include transit, walking, biking, or other forms of transportation. The survey categorizes vehicle trips as passenger cars, motorcycles, and light-duty trucks (i.e. pick-up trucks) where the respondent identified himself or herself as the driver. Figure 3-2 shows the vehicle trip share and Figure 3-3 shows the vehicle trip rate per household per year for both 2009 and 2017.

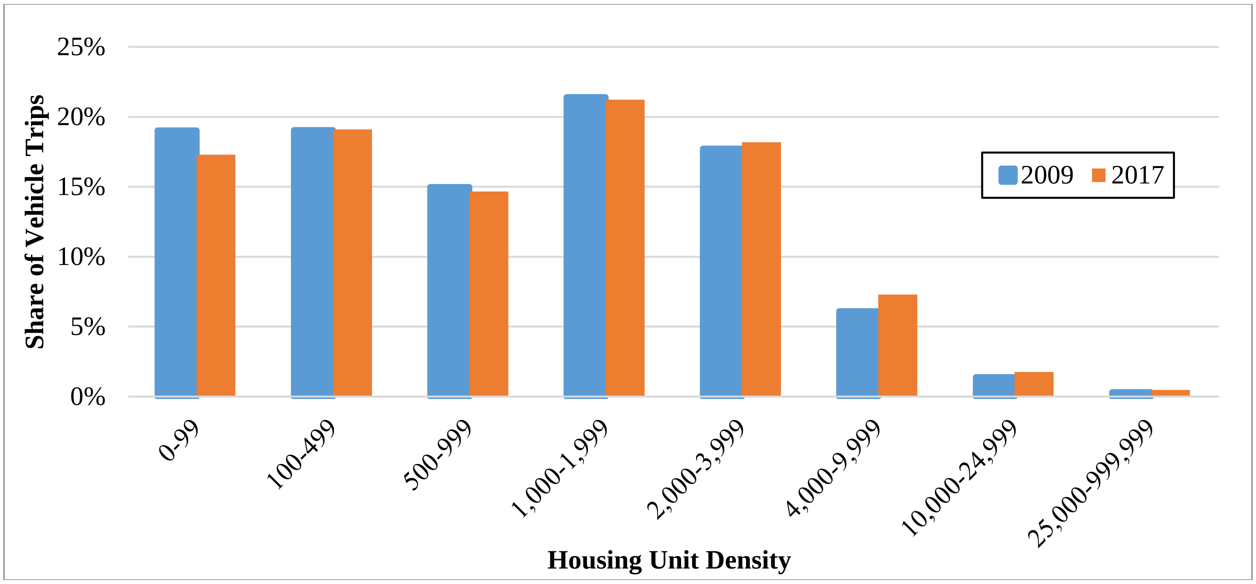

Figure 3-2 Share of vehicle trips by block group housing unit density

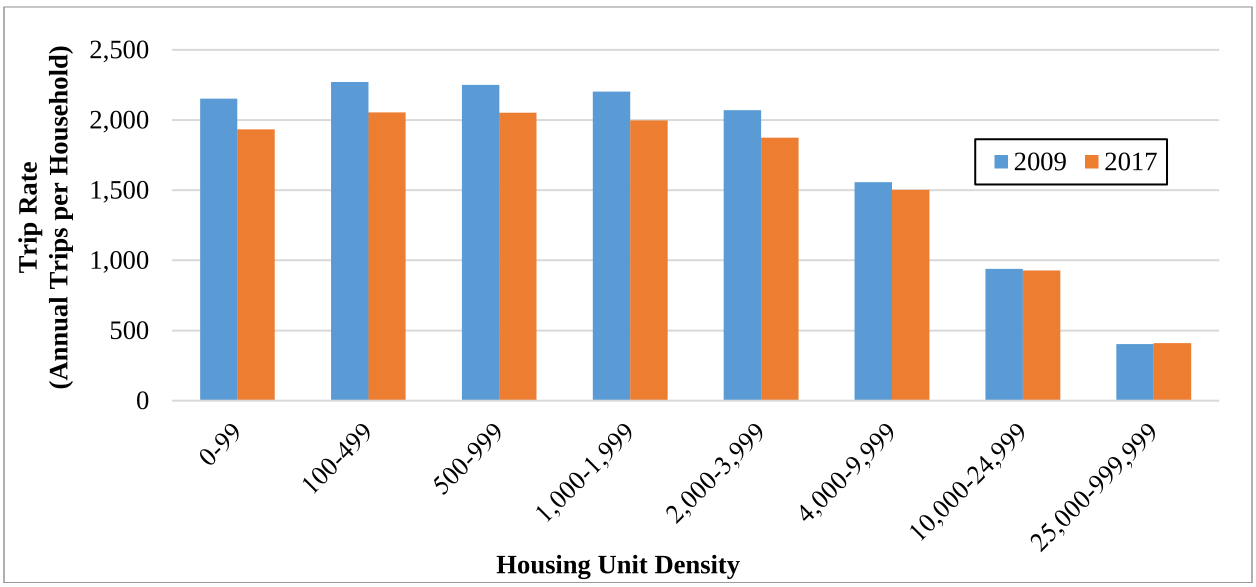

Figure 3-3 Vehicle trip rate per household per year by block group housing unit density

In 2009 the share of total vehicle trips taken by households in density less than 4,000 housing units per square mile was 92.2%. This share fell to 90.5% in 2017, but it is evident that the households in the lower density ranges make up the vast majority of vehicle trips taken annually. This number makes sense given the share of households that exist in the lower density ranges. Interestingly, the vehicle trip rate per household for the 5 lowest density ranges (those making up over 90% of all vehicle trips) has declined substantially from 2009 to 2017. The weighted average vehicle trip rate for the households in those density ranges dropped from 2,190 annual trips to 1,982 annual trips, a 9.5% decrease. Notably, the only density range that had increasing vehicle trip rate per household was the 25,000 to 999,999 density range, but only by 1.6% from 404 to 410 vehicle trips per household per year. As presumed, Figure 3-3 shows the vehicle trip rate dropping dramatically for the higher density ranges as many of those vehicle trips are served by other modes like transit and walking, or foregone all together.

3.3 Trip Length

A high density of housing units typically suggests households are in a city or downtown area. The number of vehicle trips is much lower for these areas, but it could be presumed that the trip length is longer because individuals electing to drive would only do so as a result of transit inaccessibility and/or travel time savings. It is unlikely that those households are located in such high density would not have access to public transit for a given trip. These same households also probably do not have the income to justify owning and driving a vehicle. Since this analysis examines vehicle trips exclusively, the length of the trip would likely be long for a household living in high density to justify driving. Figure 3-4 shows the average vehicle trip length by housing units per square mile.

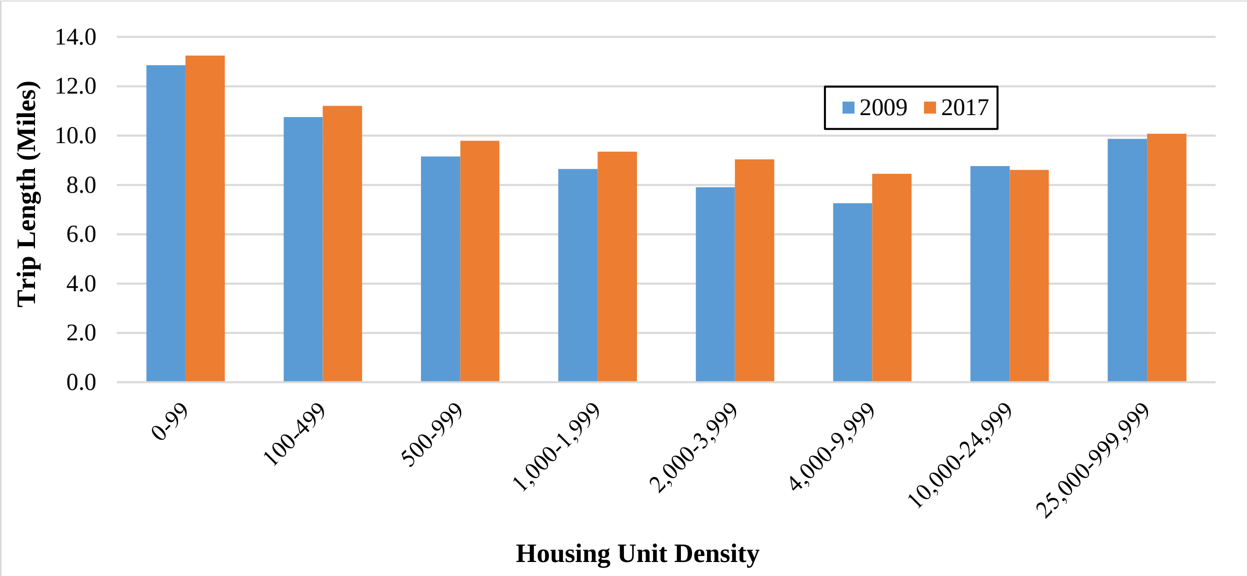

Figure 3-4 Average vehicle trip length by housing unit density within block group

The presumption that households in high density areas take long trips is proven by Figure 3-4, but average trip length for the low density ranges is still greater. This trend is likely the result of households being located in rural and remote areas with destinations like work, school, and even the nearest grocery store located farther away. There has been a slight increase from 12.85 miles per trip in 2009 to 13.24 miles in 2017 for the lowest density range. This is true for the higher density range as well with an increase from 9.87 to 10.07 miles per trip for the 25,000 to 999,999 range. There is also a very small dip from 8.76 to 8.60 miles per trip for the 10,000 to 24,999 density range. The most notable increase in average trip length is the 4,000 to 9,999 density range where length grew from 7.25 miles per trip in 2009 to 8.45 miles per trip in 2017. Average trip length is predictable with vehicle technology and fuel costs, but there may be other factor at play.

3.4 VMT Analysis

To determine the VMT generated by each density range, the number of trips taken is multiplied by the average trip length; the resulting VMT distribution is presented in Figure 3-5.

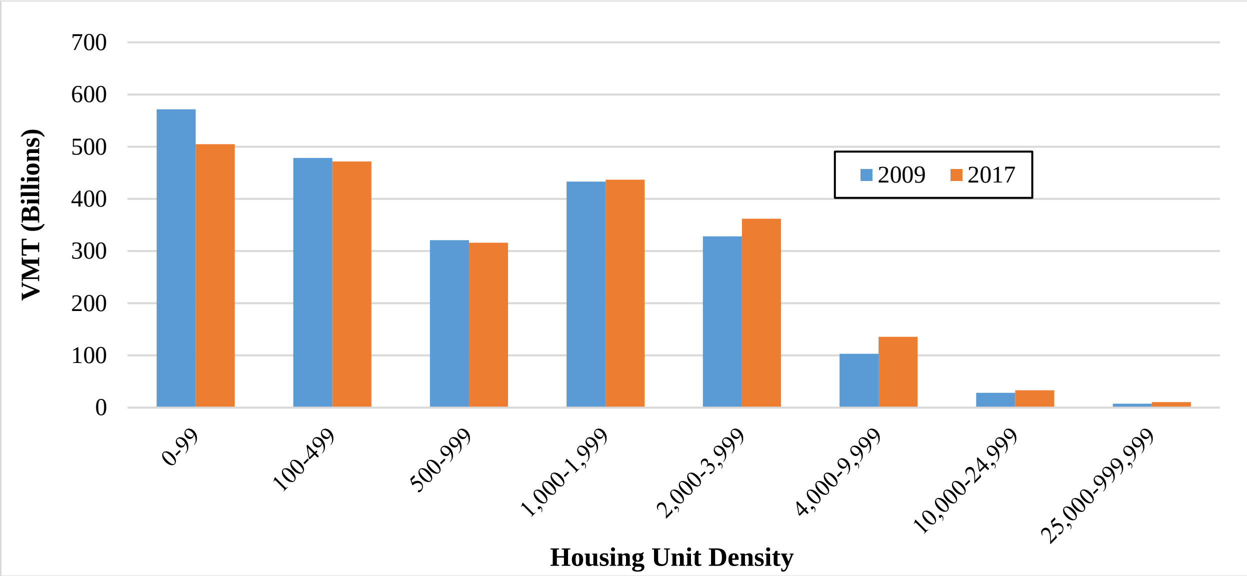

Figure 3-5 VMT by housing unit density within block group

VMT related to NHTS surveying grew from 2.245 trillion in 2009 to 2.261 trillion in 2017, an increase of 0.7% or 15.976 billion miles. The density ranges from 0 to 999 units per square mile lost VMT while the remaining density ranges increased in VMT. This trend suggests that the high-density areas have a higher propensity to maintain and grow their VMT. On the other hand, high density households do not contribute to VMT nearly as much as the lower density households do. Figure 3-6 and Figure 3-7 show VMT contribution on a per household basis and per driving age person basis respectively.

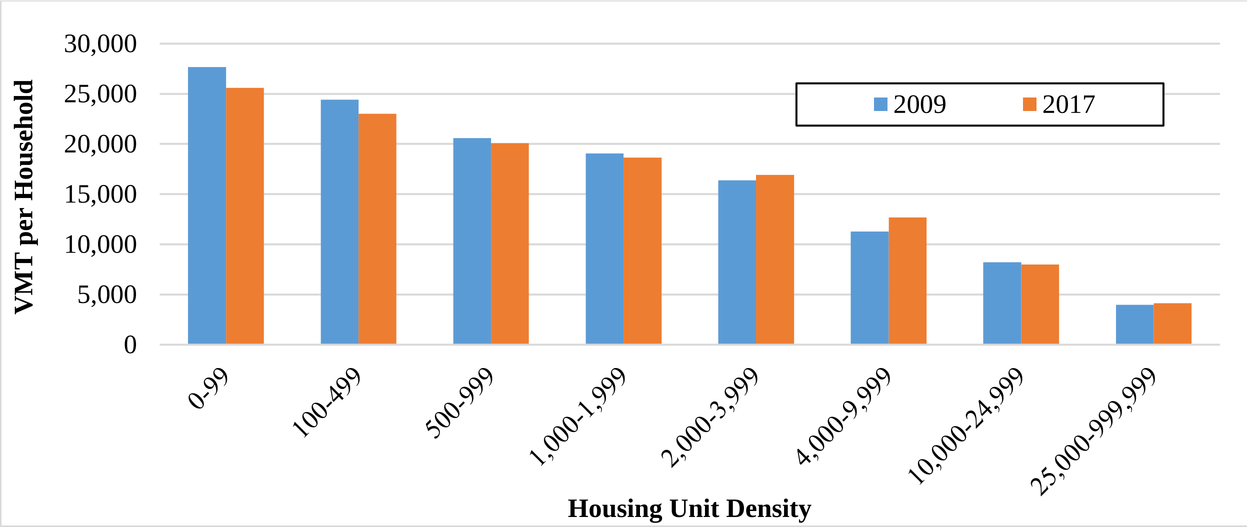

Figure 3-6 VMT per household by housing unit density

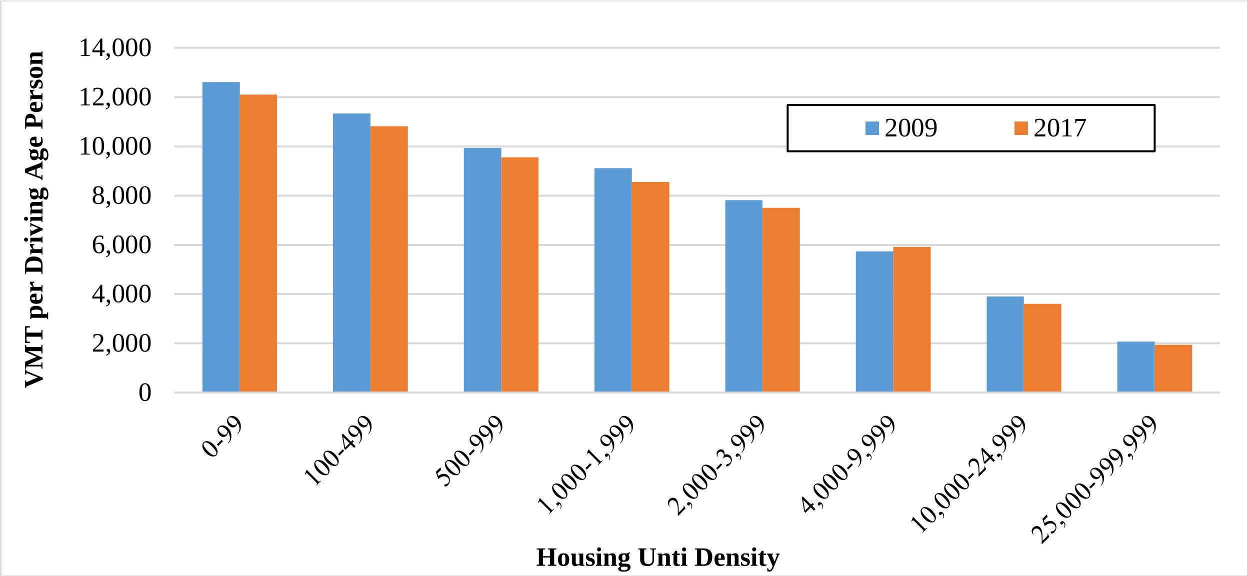

Figure 3-7 VMT per driving age person by housing unit density

The lowest housing unit density range contributes the most per household VMT at 25,600 miles in 2017 while the highest density range contributes the least per household VMT at 4,100 miles. The sum of decreases in VMT from 2009 to 2017 for those density groups with negative change is 78.8 billion miles, 66.9 billion of which is attributed to the 0 to 99 density group. The sum of the increases in VMT from 2009 to 2017 is 78.7 billion miles, 66.7 billion miles of which is attributable to the two density ranges between 2,000 to 9,999 units per square mile. When calculating VMT by multiplying average miles by number of trips, as is done in this analysis, results in a decline in VMT from 2009 to 2017. Household VMT in 2017, as presented in Figure 1-2 of the introduction, is 2.261 trillion miles compared to the calculated value in this analysis of 2.271 trillion miles. This discrepancy is likely due to a combination of internal error and rounding. This analysis will continue to use the calculated 2017 VMT of 2.271 trillion for consistency when comparing to the projected value presented in Figure 3-8.

In order to determine the underlying effect of households shifting to higher densities it is possible to project 2009 household distribution by housing unit density onto the 2017 travel behavior using the following equation:

$$\begin{matrix} Total\ Theoretical \\ 2017\ VMT \end{matrix} = \sum_X \begin{matrix} 2009\ household \\ share\ by\ desnsity \end{matrix}_X * \begin{matrix} total\ 2017 \\ households \end{matrix} * \begin{matrix} 2017\ trip \\ length \end{matrix}_X * \begin{matrix} 2017\ household \\ trip\ rate \end{matrix}_X \quad (3.1)$$

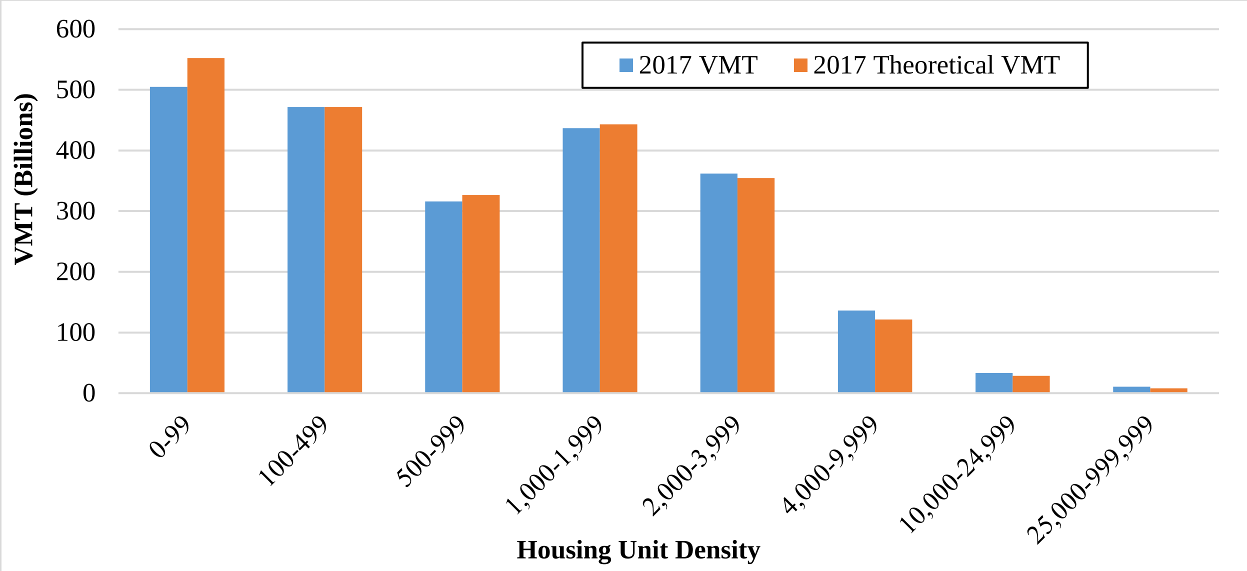

Figure 3-8 2017 VMT vs 2017 theoretical VMT by housing unit density within block group

Figure 3-8 show the theoretical 2017 VMT by housing unit density assuming the household distribution by density remained constant from 2009 to 2017. The share of households in lower densities had shrunk in 2017, and those densities are the ones with the highest propensity to generate VMT. The result of the analysis is an additional 35.6 billion miles generated using the 2009 density distribution. This means that the declining share of low-density households with the highest propensity to generate VMT and the subsequent increase in high-density households with the lowest propensity to generate VMT has resulted in a loss in potential VMT of 35.6 billion miles. This downward force may help to explain why the growth in VMT was so modest rather than of more significance. This represents 220% of the 2009 to 2017 change in VMT in a negative direction, but there are many other factors that are counteracting the downward pressure.

3.5 Behavior Analysis

In order to determine the underlying effect on VMT of density behavioral changes it is possible to project 2009 trip rates onto the 2017 household demographic using the following equation:

$$Theoretical\ 2017\ VMT = 2017\ household\ count * 2017\ trip\ length * 2009\ trip\ rate \quad (3.2)$$

Figure 3-9 shows the actual 2017 VMT given 2017 NHTS data, a theoretical 2017 VMT assuming trip rate goes unchanged from 2009 to 2017, and the percent difference between them.

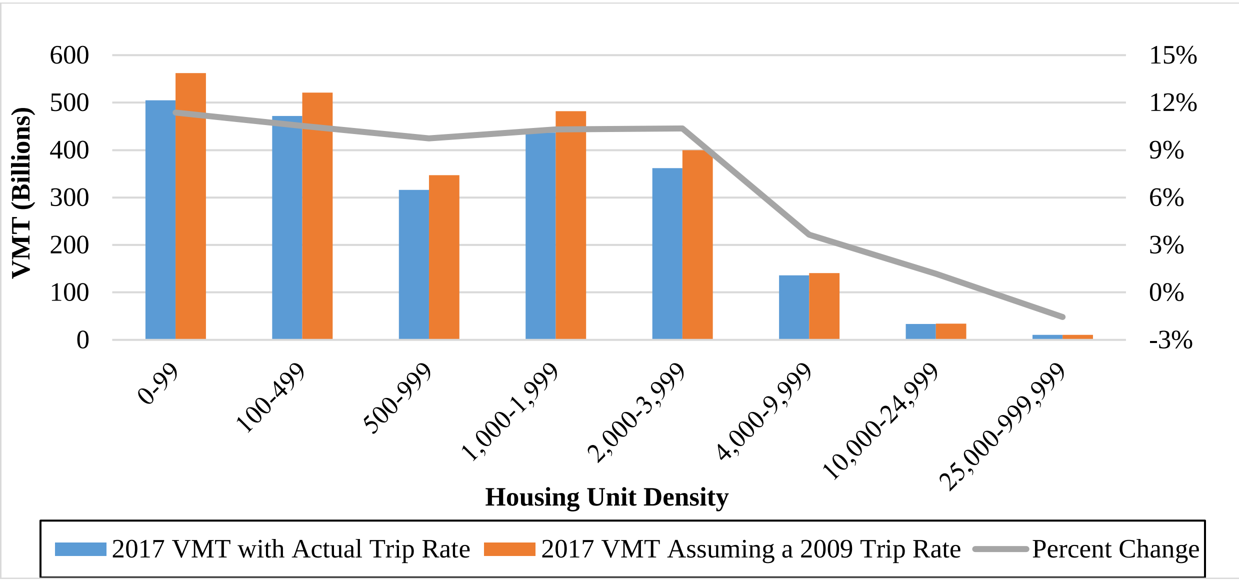

Figure 3-9 VMT by housing unit density within block group (actual vs. assuming 2009 trip rate)

The analysis shows an increase from actual 2017 VMT of 2.261 trillion to the theoretical 2017 VMT of 2.497 trillion, a difference of about 225 billion miles. What is substantial about this finding is that NHTS trip rate methodology has not changed from 2009 to 2017 so there is a certain amount of reliability in the findings. When applying 2009 trip rates, every density group increased their VMT with the exception of the 25,000 to 999,999 density range which lost 1.6% as compared to the actual 2017 VMT value. This density range has the smallest sample size with 885 responses. It is therefore subject to the highest error, but still sufficient enough to be used with some confidence.

In addition to projecting 2009 vehicle trip rates onto the 2017 household demographics it is possible to project 2009 vehicle trip lengths using the following equation:

$$Theoretical\ 2017\ VMT = 2017\ household\ count * 2009\ trip\ length * 2017\ trip\ rate \quad (3.3)$$

Figure 3-10 shows the actual 2017 VMT value calculated using NHTS variables, the theoretical VMT assuming vehicle trip length goes unchanged from 2009 to 2017, and the percent difference between them.

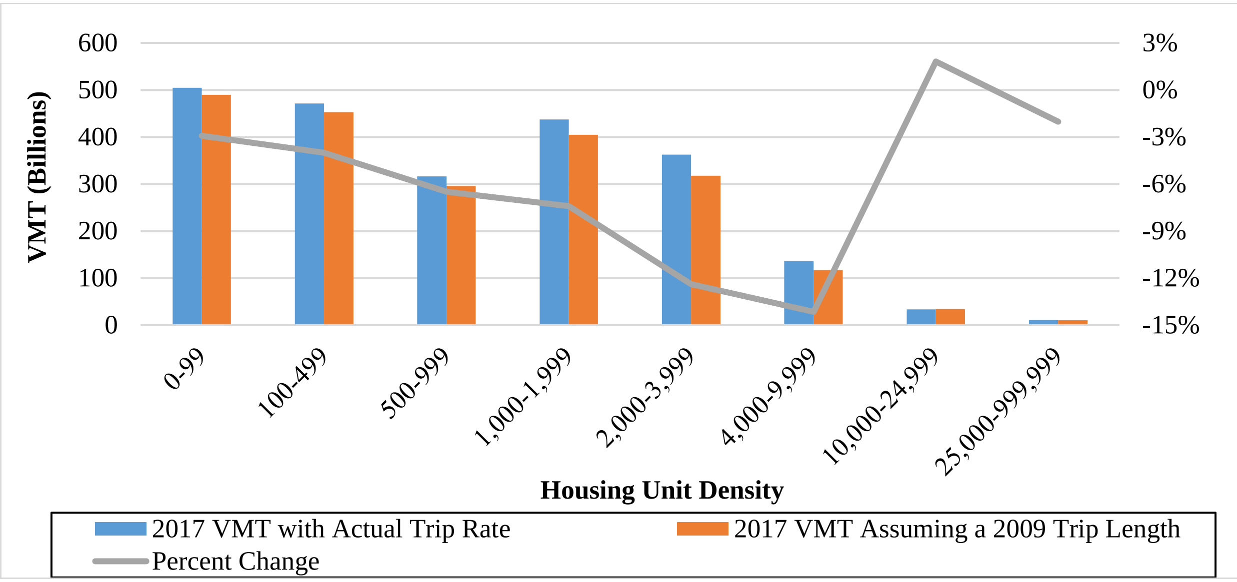

Figure 3-10 VMT by housing unit density within block group (actual vs. assuming 2009 trip length)

Holding vehicle trip length constant from 2009 to 2017 results in a net decrease in theoretical 2017 VMT of 150 billion miles as compared to the actual 2017 VMT. This suggests that the actual 2017 VMT is experiencing a growth effect from 2017 miles per trip. Most of this lifting effect is attributable to the 2,000 to 3,999 and 4,000 to 9,999 housing unit density ranges. While the lifting effect presented through trip length is minimal compared to the drag effect explained by trip rate, it is still an important source affecting VMT. Additionally, the combined effect of the two can help to describe the modest growth in VMT from 2009 to 2017. The two forces acting against each other results in a net drag effect that, when added to other forces pulling VMT up, can explain much of what is happening overall.

Between the lift from trip length and the decline from trip rate the net change in theoretical influence is 470% of the 15.976 billion mile change in VMT from 2009 to 2017. This side analysis is used to explore the behavioral changes to get a better grasp of how these factors are changing over time.

3.6 Implications

The objective of this section of the paper is to determine how travel behavior related to density has changed and how it might have affected household VMT. Conclusively, 2017 trip length seems to impart an increasing effect on VMT whereas 2017 trip rate has caused a dragging effect. This is also clear from visualization of the data where it is clear that average trip length has increased from 2009 and average trip rate has declined. It seems, however, that trip length increase has not compensated enough for trip rate decrease and thus there is a net drag effect. This may be a causal factor for why VMT grew so modestly between 2009 and 2017. Travel characteristics by housing unit density vary dramatically between density ranges, and as people continue to urbanize there will be important implications regarding roadway demand for specific densities. Mid-density ranges are seeing the highest trip length increases and relatively lower rate decline, so these areas are going to be important points of interest in the future.

CHAPTER 4: POPULATION DISTRIBUTION ACROSS MSAs

When examining changes in VMT it is important to understand the geographic location of mileage. There are many implications associated with geography including population change, economic activity and stability, local policy, and access to alternative modes to name a few key points. The 2017 NHTS gives insight into personal travel within specific Metropolitan Statistical Areas (MSAs). Since MSAs encompass areas with similar transportation needs and programs, knowing the VMT generated within these areas as well as the changes in population and trip rates can be informative in determining the future of personal vehicle travel demand.

4.1 VMT by MSA

Figure 4-1 depicts household VMT as a function of the respondent's MSA of residence. Not surprisingly, greater VMT is located in the heavily populated areas with the highest densities. High density areas tend to have more mobility options which would imply lower VMT, but the densest MSAs also have the most people. The Los Angeles, San Francisco, and New York City MSAs are excellent examples of high density areas in conjunction with high population resulting in the greatest total household VMT. It is important to understand the geographic location of travel as TNC's, automated vehicles, and transit, are more competitive in certain urban environments. This analysis provides some insights into markets where alternative mobility strategies might be viable.

Figure 4-1 shows VMT per capita as a function of the respondent's MSA of residence, calculated by dividing the 2017 NHTS VMT by the 2017 ACS population estimates. Per capita VMT can be used as a measure to differentiate between places where driving behaviors are contributing to a rise in VMT; however, there is little evidence that VMT per capita plays a role as a determinant of where VMT is greatest currently. In MSAs where VMT exceeds 50 billion, there is disparity in the VMT per capita. New York City's MSA ranks among the lowest in VMT per capita while Dallas-Fort Worth ranks in the middle of VMT per capita.

Figure 4-1 and Figure 4-2 show that there is not likely a relationship between the current VMT volume in any given MSA and the VMT per capita, but it does help to show that MSAs, while similar in size, do not necessarily behave the same. MSA per capita behavior is not uniform across the country and neither is population growth.

4.2 VMT and Population

In 2009 and 2017, VMT for the 52 NHTS MSAs summed to 1.138 and 1.180 trillion miles respectively. This data shows that in 2017 there were an additional 40 billion VMT from household travel on roadways in and around these MSAs. There were 27 MSAs with declining VMT totaling 96.1 billion while 24 MSAs gained a total of 129.3 billion miles (with one MSA having insufficient data from 2009 and thus contributed 8.4 billion miles). Of the 27 MSAs with declining VMT, nearly all of them are associated with either declining population or VMT per capita of less than the weighted average per capita VMT of 6,500. There are only 9 such examples where the population growth was not negative and the VMT per capita greater than 6,500. MSAs with growing VMT are those with positive population growth and/or better than average VMT per capita with the exception of only 4 of the 24.

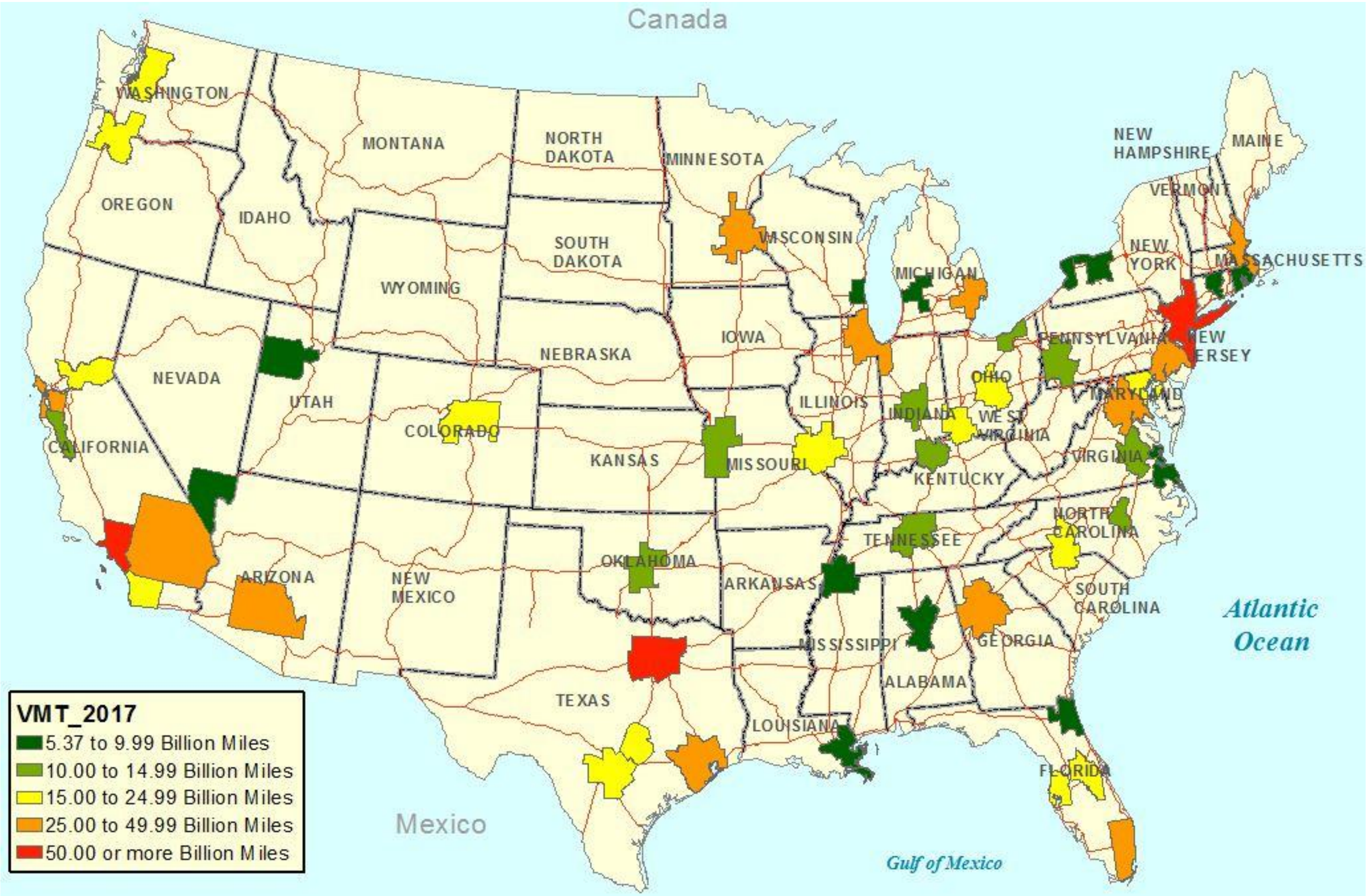

Figure 4-1 Household VMT for the 52 largest MSAs by population 2017

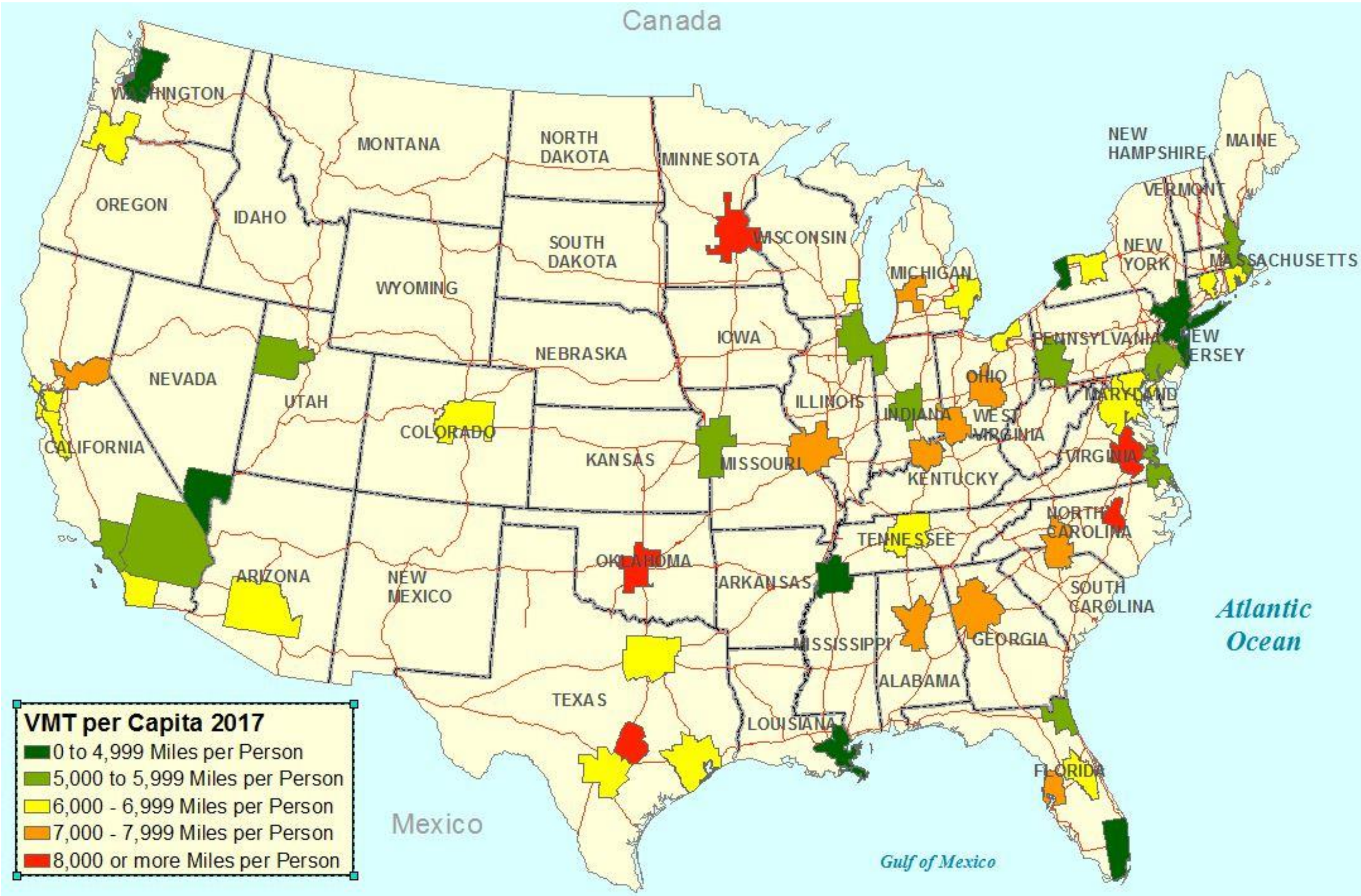

Figure 4-2 VMT per capita by MSA 2017

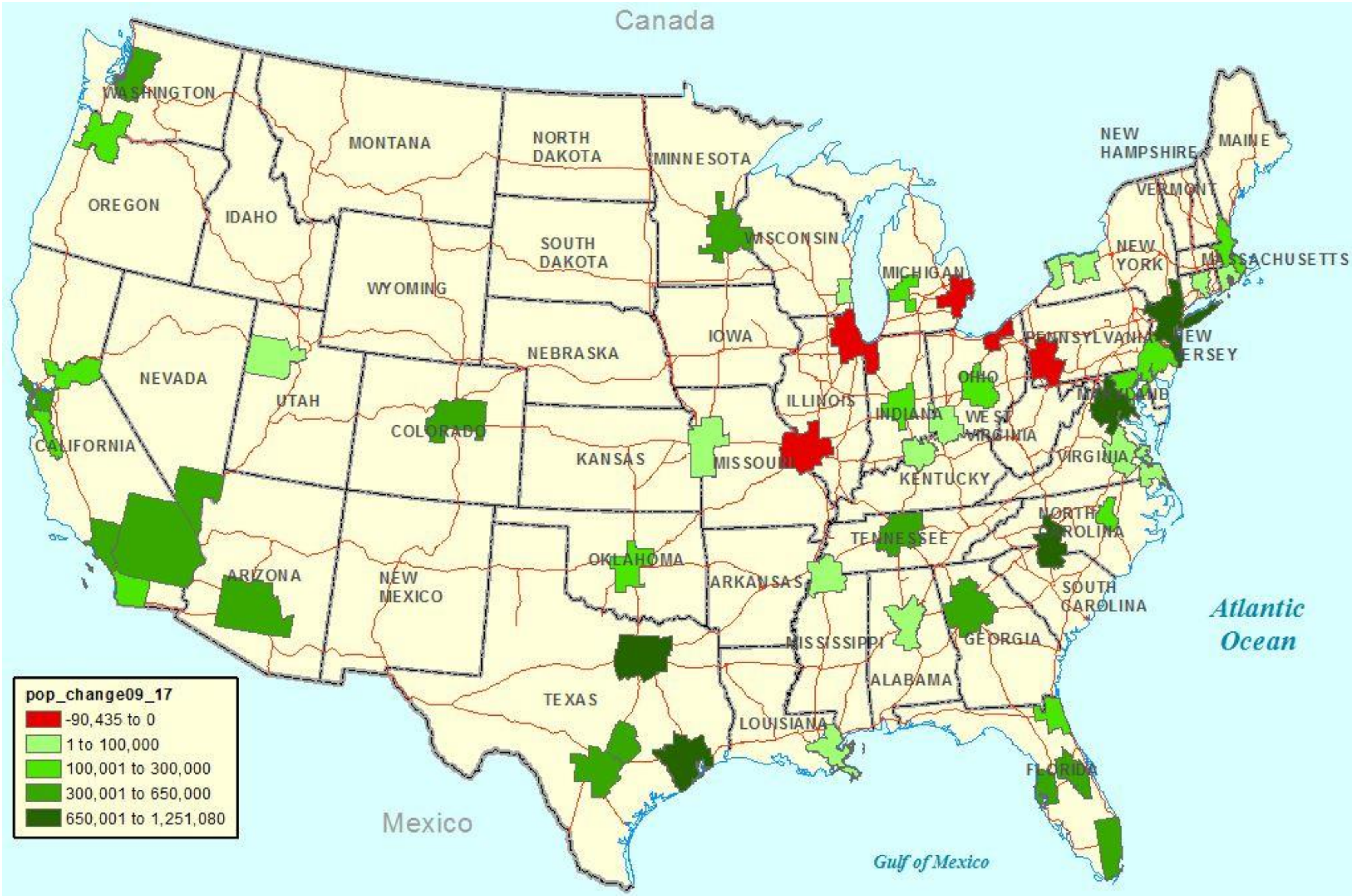

Figure 4-3 MSA population change 2009 to 2017

While there may not be a direct relationship between nominal 2017 VMT and VMT per capita for the 52 MSAs in question, there does seem to be a correlation between changes in VMT and VMT per capita based on where population growth is occurring. Figure 4-3 shows the population growth from 2009 to 2017 for these MSAs. It is possible to compare the changes in population and the 2017 VMT per capita for these areas to find the specific locations that may be contributing to the modest increase in VMT in these MSAs.

Table 4-1 and Table 4-2 show the 2017 VMT per capita by percent change in population. By examining the change in population as a percent, it is possible to remove anomalies, like the New York City area MSA, with the highest nominal population growth. The growth is sufficient to result in increases to VMT purely because so many people already live in the MSA. In this instance, small percent changes are still rather large nominal changes.

Table 4-1 2017 VMT per capita by largest percent change in population, 2009-2017

MSA	Population 2017	Population Change (Percent Change) 2009-2017	2017 VMT per Capita (Change in VMT Billions)
Charlotte-Concord-Gastonia, NC-SC	2,525,305	779,781 (44.7%)	7,639 (6.28)
Grand Rapids-Wyoming, MI	1,059,113	281,104 (36.1%)	7,973 (8.44)
Austin-Round Rock, TX	2,115,827	410,752 (24.1%)	9,471 (6.21)
Orlando-Kissimmee-Sanford, FL	2,509,831	427,410 (20.5%)	7,159 (3.42)
Nashville-Davidson-Murfreesboro-Franklin, TN	1,903,045	321,137 (20.3%)	6,837 (0.32)
San Antonio-New Braunfels, TX	2,473,974	400,882 (19.3%)	9,809 (6.10)
Raleigh, NC	1,335,079	209,252 (18.6%)	10,192 (2.56)
Houston-The Woodlands-Sugar Land, TX	6,892,427	1,027,341 (17.5%)	6,609 (9.26)
Indianapolis-Carmel-Anderson, IN	2,028,614	283,934 (16.3%)	5,502 (-1.36)
Las Vegas-Henderson-Paradise, NV	2,204,079	301,245 (15.8%)	4,290 (0.08)
Weighted Average:	-	-	7,298

Table 4-2 2017 VMT per capita by smallest percent change in population, 2009-2017

MSA	Population 2017	Population Change (Percent Change) 2009-2017	2017 VMT per Capita (Change in VMT Billions)
Detroit-Warren-Dearborn, MI	4,313,002	-90,435 (-2.1%)	6,472 (-6.60)
Cleveland-Elyria, OH	2,058,844	-32,442 (-1.6%)	7,424 (-0.47)
Pittsburgh, PA	2,333,367	-21,590 (-0.9%)	5,500 (-2.85)
St. Louis, MO-IL	2,807,338	-18,431 (-0.7%)	2,530 (-27.42)
Chicago-Naperville-Elgin, IL-IN-WI	9,533,040	-47,569 (-0.5%)	5,557 (-2.67)
Cincinnati, OH-KY-IN	2,179,082	8,254 (0.4%)	8,414 (-1.66)
Milwaukee-Waukesha-West Allis,	1,576,236	16,569 (1.1%)	6,476 (1.41)
Buffalo-Cheektowaga-Niagara Falls,	1,136,856	13,052 (1.2%)	5,071 (-0.34)
Hartford-West Hartford-East	1,210,259	14,261 (1.2%)	6,957 (-2.80)
Providence-Warwick, RI-MA	1,621,122	20,480 (1.3%)	6,599 (0.47)
Weighted Average:	-	-	5,893

Declining population frequently correlates with decreases in VMT. This correlation makes sense as fewer people lead to less VMT. “Rust Belt” MSAs like Detroit, Cleveland, and Pittsburgh show this to be the case. The opposite can be said for MSAs with growing population like Charlotte, Grand Rapids, Austin, and Orlando where there is large growth in VMT. The true implication from Table 4-1 and Table 4-2, however, is that people are moving away from places with a low propensity to travel in vehicles to places with a high propensity for this type of behavior. The weighted average 2017 VMT per capita for those MSAs with the smallest and even negative percent changes in population is only 5,900, well below the 52 MSA average 2017 VMT per capita of 6,500. Additionally, the weighted average 2017 VMT per capita for the fastest growing MSAs is 7,300, 800 miles per capita more than the average. To better represent this phenomenon Figure 4-4 plots each of the 52 MSAs by 2017 VMT per capita and percent population growth and provides delineators to identify the weighted averages for both variables.

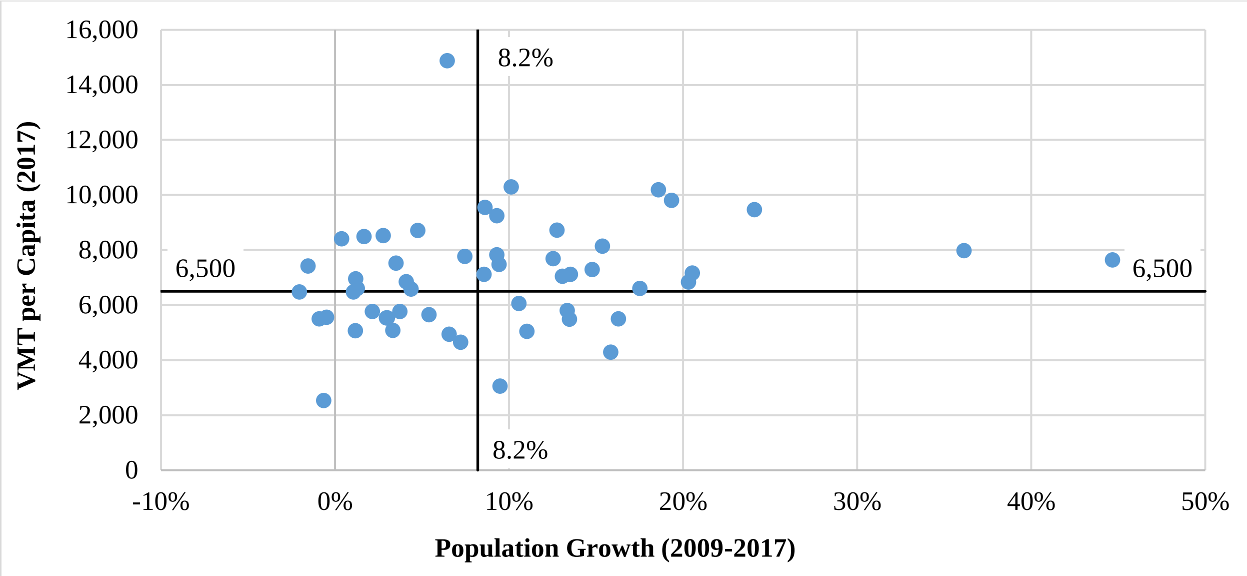

Figure 4-4 VMT per capita (2017) vs. population change (2009-2017)

4.3 Distribution Analysis

To understand the described phenomenon, it is possible to determine what VMT would have been if percent population growth had been uniform across the 52 MSAs. To do this, the percent growth sum from 2009 to 2017 for all MSAs is applied to the 2009 population estimates for each MSA to generate a "uniform growth" 2017 population estimate. The uniform growth 2017 population estimate is then multiplied by the 2017 VMT per capita derived by dividing nominal 2017 VMT by the nominal 2017 population. This method assumes the derived 2017 VMT per capita will have occurred regardless of population change. It holds constant the behavioral and changing overall population aspect of the equation and focuses solely on the population distribution to show that people are living in places where the propensity to drive is modestly higher. The equation to find uniform growth 2017 VMT is as follows:

$$\begin{matrix} Uniform\ Growth \\ 2017\ VMT \end{matrix} = \left(2009\ population * \left(1 + \begin{matrix} 09'\ to\ 17'\ percent \\ population\ growth \end{matrix}\right)\right) * \begin{matrix} 2017\ VMT \\ per\ Capita \end{matrix} \quad (4.1)$$

where 2009 to 2017 percent population growth is derived by dividing the difference between 2009 and 2017 total 52 MSA population by the 2009 summed population. The resulting population growth rate is 8.2% for the entire 8-year span, or 1.025% per year.

Prior to applying the equation, the summed 2017 VMT for the 52 MSAs in question, referred to as the nominal VMT, is 1.180 trillion miles. After applying the equation, the uniform growth 2017 VMT is 1.173 trillion miles. The disproportionate population growth in areas with a higher propensity to use vehicles resulted in an additional 7 billion VMT, or about 39% of the 15.976 billion mile change in household VMT from 2009 to 2017.

4.4 Implications

This analysis is limited by the assumption that 2017 VMT per capita would have remained the same regardless of population change. Since VMT per capita was derived by dividing 2017 VMT by 2017 population there is an error associated with behavioral aspects that change under certain population growth characteristics. The finding that population distribution represents 38.7% of the total household VMT change from 2009 to 2017 is likely overstated, but still important. People are motivated to move for economic, social, and various other reasons, but it seems that people are moving to areas where driving is a much larger part of everyday life. It is not the purpose of this paper to determine the exact factors influencing vehicle usage for each MSA mentioned, but there are implications associated with transportation initiatives. Areas at the forefront of population growth might find themselves battling congestion in the near future. Local governments might consider congestion pricing options or other driving disincentives, and providing more transportation options. Federal dollars may also need to be shifted towards areas with large population growth to preemptively combat extensive vehicle usage and curb travel behavior early.

CHAPTER 5: AGE DISTRIBUTION

Travel behavior differences across age groups is a well-observed phenomenon with implications on household VMT generation. The U.S. has experienced dramatic growth in the elderly population in the last decade, and these individuals are better equipped than previous generations to continue personal vehicle use well into retirement years. In addition to elderly persons impacting VMT, the younger driving age individuals have altered their personal vehicle use as well. Millennial travel behavior has been a topic of great interest as technology improves connectivity, preferences change, and consumer services expand. There are implications to trip rates for all age groups given the current socioeconomic climate.

5.1 Population Grouping

In an attempt to understand VMT as a function of age distribution, 5 classifications of driver are established: “non-licensed” age 15 and younger, “young” individuals age 16-25, young adults age 26-45, older adults age 46-65, and retirement age persons 65 years or older. This segmentation of the population is used to try to distinguish between different age cycles in an individual’s life that reflect the responsibility the individual might bear in terms of self, career, and family.

The population profile presented in Figure 5-1 are from the NHTS, but there is a notably smaller total population estimate when compared to the U.S. Census Bureau estimates. Part of the reason for the discrepancy between the two values stems from the NHTS not including persons under the age of 5 in the count, and the sample size for Census data is far larger than NHTS [18]. Using Census derived age distribution may be more accurate, but NHTS uses their population estimate as a basis for much of their calculations so using Census population numbers would substantially overestimate VMT.

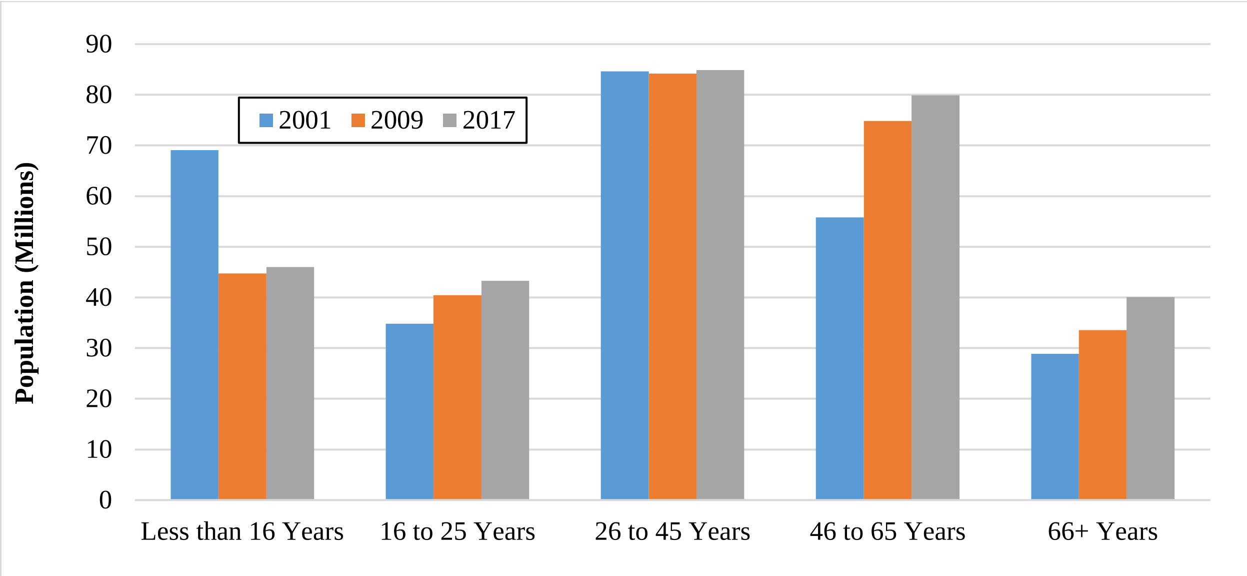

Figure 5-1 NHTS population distribution by age

There are several takeaways from Figure 5-1. First, there is dramatic nominal growth in the 46-65 and 66+ age groups. The growth in the upper age groups coincides with the baby boomer generation entering the latter years of life. Second, not only have these age groups grown relative to their historical values, but they are also representing a larger share of the total population. This second point is of particular importance in trying to explain how age distribution might be influencing VMT generation. Lastly, while there is nominal growth in the 16 to 25 population the share of total population is far outpaced by that of the older age cohorts. As a note, the 2001 population estimate for the age groups "less than 16" and 46 to 65 are outliers. While the values may not perfectly represent the actual population of the age group, it is likely they still represent the general trend in age distribution shift over time, just at a slightly exaggerated level for 2001.

5.2 Trip Rate

One of the major reasons for examining age distribution is the discrepancy in trip rates between population age groups. Figure 5-2 shows the daily person trip rate by age group.

Figure 5-2 Person trip rate per day by age

Almost universally, person trip rates by age group are dropping with exception of retirement age individuals who are taking more trips per day in 2017 than in 2009. There is a trip rate “bulge” that has shifted out from middle age persons in 2001 to the older age persons in 2017. Figure 5-3 show vehicle trip rate by age group, and it mirrors person trip rate. There is substantial decline in vehicle trip rate across all age groups except for the 66+ group which remained at about 2.0 vehicle trips per day.

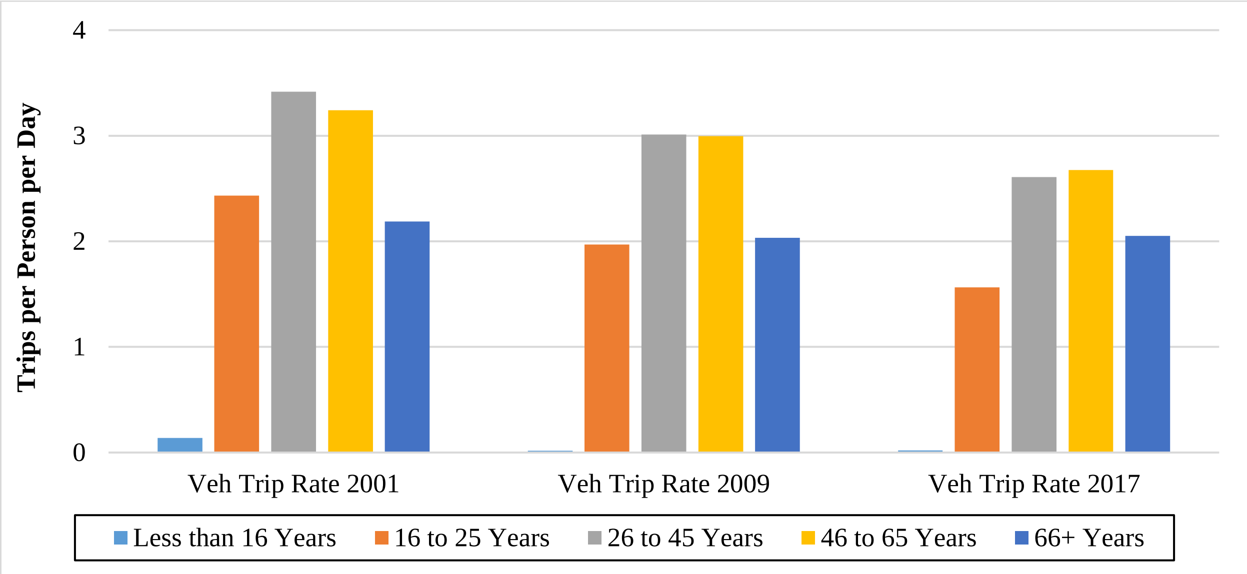

Figure 5-3 Vehicle trip rate per day by age

Vehicle trip rate for the age group less than 16 is nearly zero; this is because the vast majority of individuals at this age are unlicensed. In 2001 their vehicle trip rate was measured to be a little greater than 0.1 trips per day, but the impact on VMT was relatively small when compared to the other age groups. While it may seem prudent to omit the less than 16 years old age group from the analysis, the NHTS derived VMT already includes those values, so for the sake of continuity within the data the values are retained.

5.3 Trip Length

Unlike vehicle trip rate, vehicle trip length is relatively uniform across age groups. The middle age ranges tend to make slightly longer trips on average than the youngest and oldest age groups. Figure 5-4 shows the trips length distribution across age groups for each NHTS year.

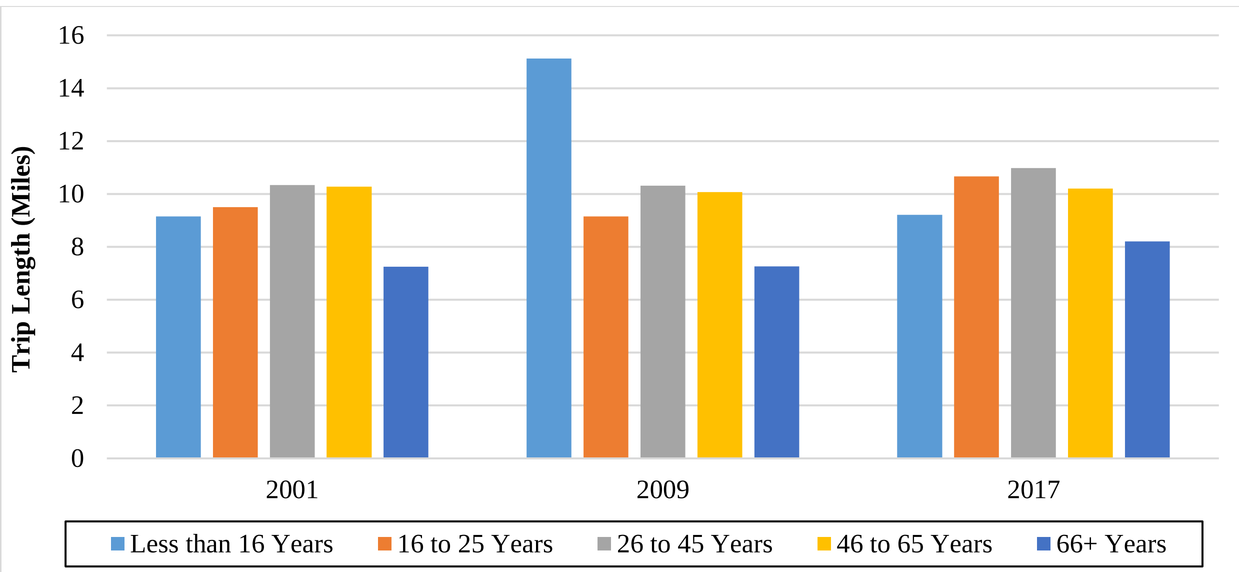

Figure 5-4 Average vehicle trip length by age

The notable trend with trip length is the increase for every age group for every NTHS year (not including 2009 less than 16 years length, which is clearly a sampling error). This means that people as a whole are taking fewer short and/or more long trips. This trend is in direct opposition of the vehicle trip rate trend and in fact, they play against each other to stymie meaningful growth or shrinkage in VMT.

5.4 Analysis

Using the population profile from each of the 3 years and projecting them onto the 2017 vehicle trip rate and average trip length it is possible to understand how historically younger populations would impact total household VMT in 2017. Population in the U.S. has naturally increased since 2001 and 2009 so the analysis multiplies the share of persons in an age group by the total population in 2017 to get an adjusted population profile. The equation is as follows:

$$2017\ Adjusted\ Population_{x,y} = \frac{Population_{x,y}}{Total\ Population_{y}} * 2017\ Total\ Population \qquad (5.1)$$

where x is the age group in question and y is the year. Table 5-1 represents the calculated adjustments to 2001 and 2009 population.

Table 5-1 2001 and 2009 population adjusted to 2017

Age	**2001 Population Distribution**	**2009 Population Distribution**	**2017 Population Profile Using 2001 Distribution**	**2017 Population Profile Using 2009 Distribution**	**2017 Population Profile**
Less than 16 Years	25.3%	16.1%	74,323,522	47,360,374	46,030,040
16 to 25 Years	12.8%	14.6%	37,499,957	42,811,183	43,276,098
26 to 45 Years	31.0%	30.3%	91,104,663	89,173,064	84,852,659
46 to 65 Years	20.4%	26.9%	60,058,592	79,231,386	79,860,661
66+ Years	10.6%	12.1%	31,091,183	35,501,909	40,058,459

The next portion of the analysis involves solving for VMT using the 2017 vehicle trip rate and average vehicle trip length. Since vehicle trip rate is presented as a per day variable there is an additional 365-day factor multiplied on to convert to years. VMT is solved as follows:

$$Theoretical\ VMT_x = \begin{matrix} 2017\ Adjusted \\ Population \end{matrix}_{x} * \begin{matrix} 2017\ Vehicle \\ Trip\ Rate \end{matrix}_{x} * \begin{matrix} 2017\ Average \\ Trip\ Length \end{matrix}_{x} * \frac{365\ days}{year} \qquad (5.2)$$

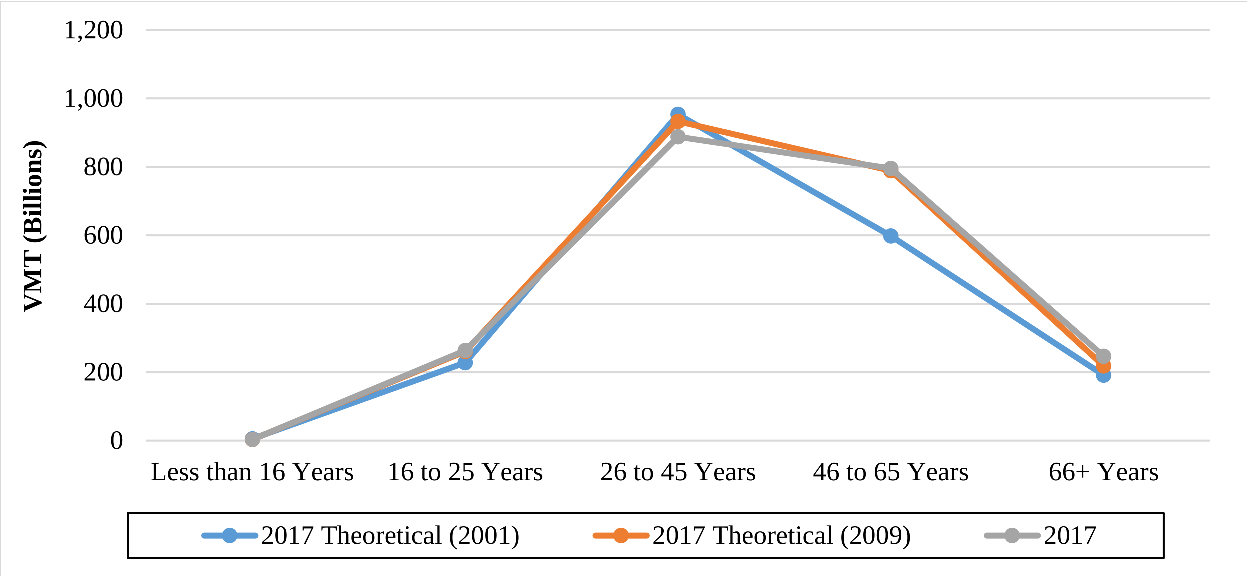

Figure 5-5 VMT by age group and scenario

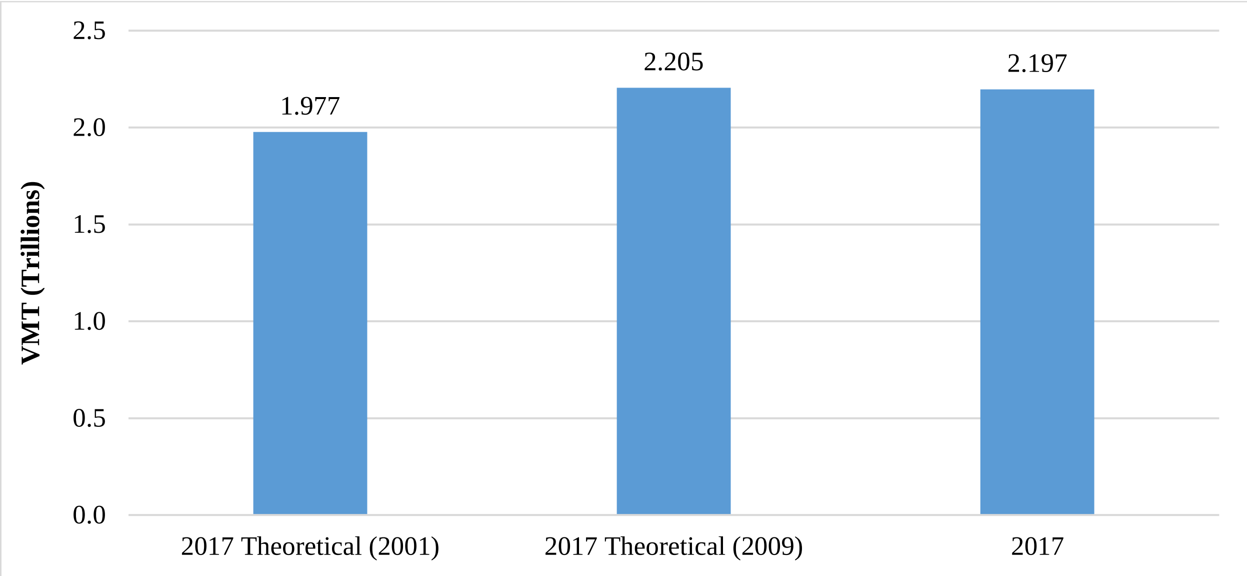

Figure 5-6 Total VMT by scenario year

5.5 Implications

Figure 5-5 and Figure 5-6 present the findings of the theoretical 2017 household VMT given the 2001 and 2009 age distributions compared to the actual 2017 VMT. Interestingly, VMT peaks at the 2017 theoretical VMT derived from 2009 population distribution. This means that as population aged to a point where middle and older age persons represented the largest share of total population the VMT potential from age distribution hit a maximum. The middle and older age individuals are now aging out of the maximum potential VMT and are inducing a negative change in total VMT. Therefore, the population distribution theory represents an 8 billion mile downward pressure on VMT, or 50% of the 2009 to 2017 change in VMT. Additionally, the nominal change in household VMT from 2001 to 2009 was 30 billion miles, which is a modest decline relative to over 2 trillion total miles, but 2009 represented the maximum potential for age distribution to affect VMT. Had it not been for the age distribution peaking in 2009 the decline in household VMT may have been much sharper.

The aging of the population out of prime VMT inducing years means that in the coming years household VMT could continue to see very modest growth assuming travel behavior for age groups doesn't change much. The aging effect implies that the household share of total U.S. VMT (including freight and services) will continue to decline.

CHAPTER 6: TNC USE

6.1 Introduction

Transportation Network Companies (TNCs) have been a portion of the transportation market since the late 2000's and have quickly dominated the ride-hailing industry. Their impact to VMT, while relatively small compared to personal vehicle travel, has been a point of focus as service has continued to explode. Figure 6-1 shows the number of person trips for what NHTS categorizes as "Taxi" and includes traditional taxi services, limousines and the addition of TNCs as of the 2017 NHTS. Taxi services grew only slightly during the period between 2001 and 2009, but as expected, it more than doubled between 2009 and 2017. The rate of change of taxi trips is of interest because such accelerated growth is difficult to predict both short term and long term.

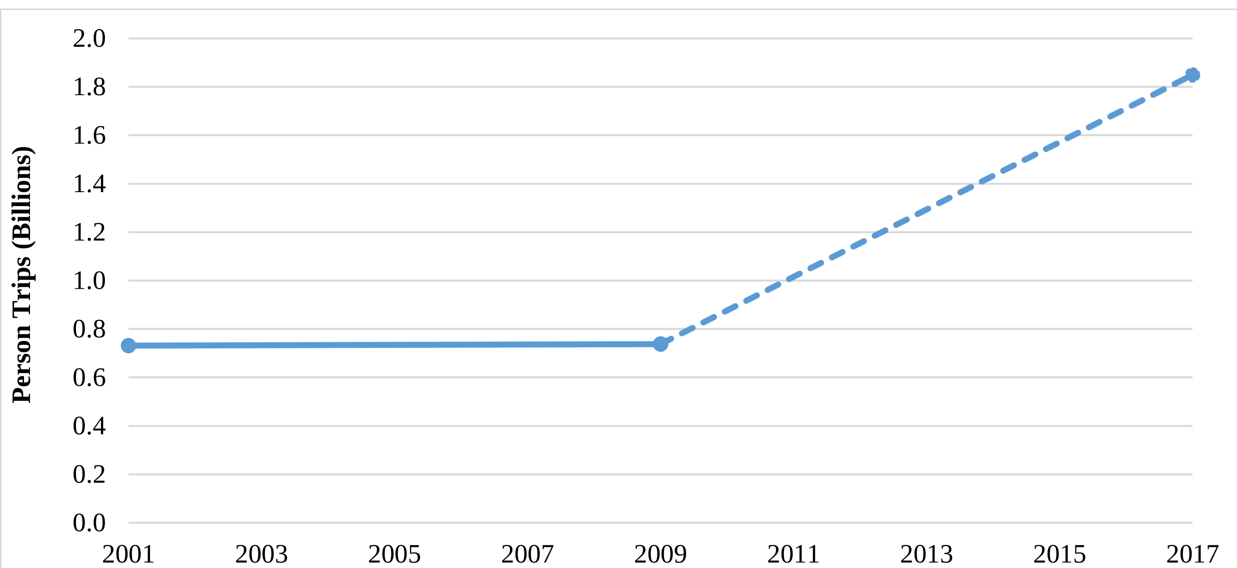

Figure 6-1 Person trips for NHTS defined taxi mode category
Note: Change in person trips between 2009 and 2017 is represented by a dashed line because growth is not linear

Inherent to any new trend arising in transportation there is a portion of time before extensive data can be collected where ambiguity exists in the interpretation of the existing information. For this reason, the paper presents a sensitivity analysis to show how TNCs may have had an influence on NHTS derived VMT. The analysis looks at taxi versus TNC market share and alternative mode choices for trips involving TNC use.

VMT as calculated by NHTS includes only personally driven vehicles like cars, pick-up trucks and motorcycles, so taxi trips are not included in the VMT value. Taxis and TNCs are legitimate generators of VMT, however, they only make up a small portion of total person trips. By calculating the additional VMT added by TNC's, it is possible to then determine how TNCs have impacted the personal vehicle travel market and what TNC mileage would do to VMT if it were allocated to household travel.

6.2 Background

This analysis will test three sensitivities under particular conditions. The first assumption is that all TNC users would have driven in a personal vehicle to make their trips. Second, it is assumed that all TNC users would have taken some other form of transportation not influencing household VMT (including transit, walk, bike, or not taking the trip at all) to make their trips. The third condition uses survey results presented by Clewlow and Mishra that asked respondents what mode they would have taken had they not taken TNC, and gives estimates on alternative mode share that can be applied to determine a more precise number of trips that would have otherwise been taken by a different mode of transportation.

All three analyses rely on TNC specific miles of travel, however NHTS does not give TNC specific trip data but rather groups TNCs and taxis into one mode. It is important to define the TNC market share of NHTS defined taxi trips to determine the number of trips that are attributable to TNCs specifically. Schaller presents an estimate of 78.8% TNC market share of the taxi industry in 2017, meaning only 21.2% of trips are taken using traditional taxis [19]. The 78.8% assumption will be applied to the number of trips being taken to sort between TNCs and traditional taxis in the NHTS data.

The Clewlow and Mishra paper seeks to explore the ride-hailing industry and the potential impacts on user travel behavior and usage rates. The scope of the paper focuses on the following seven metropolitan areas: Boston, Chicago, Los Angeles, New York, San Francisco/ Bay Area, Seattle, and Washington, D.C. The survey, directed at persons 18 years of age or older, was met with 4,094 responses. As part of the survey, the respondents were asked if they were not to take the trip using the TNC mode which mode would they have used. Figure 6-2 is a representation of the mode shift findings categorized for use in this paper [20].

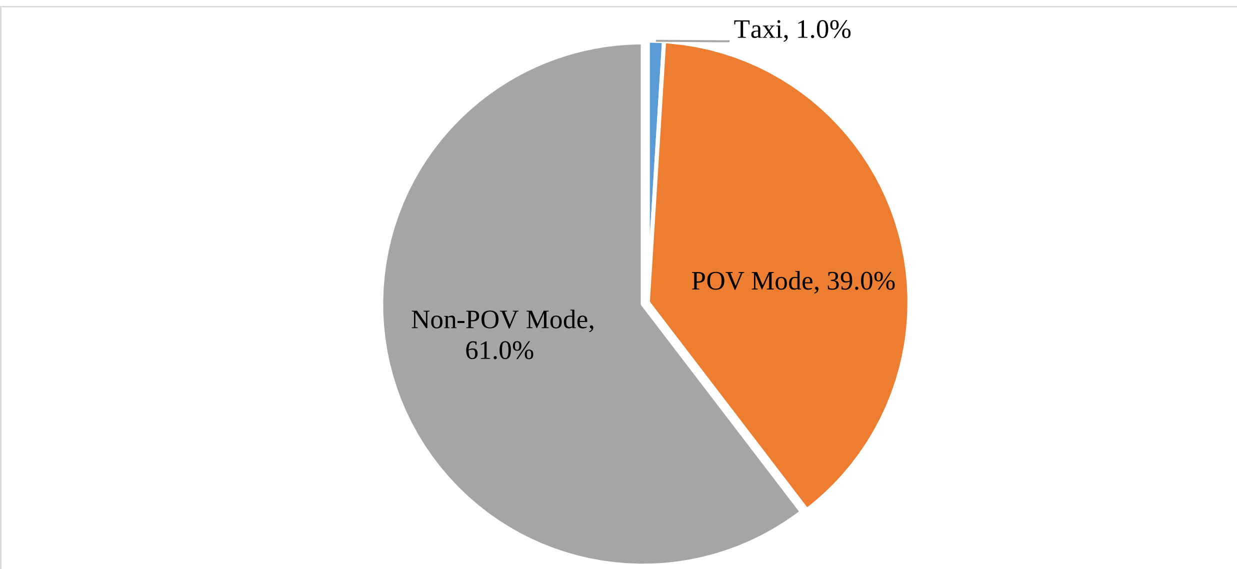

Figure 6-2 Mode alternative for TNC trips

The findings included other modes like transit and walking, but for the purposes of this analysis have been simplified to the three categories of relevance; Privately Operated Vehicle (POV), non-POV (i.e. transit, walk, bike, opt to not take trip, ect.) and taxi. This mode shift in conjunction with TNC market share will provide the framework for the sensitivity analysis.

6.3 NHTS Data

As mentioned, the NHTS does not include the taxi mode in its calculation for VMT as it is a service and does not represent a personal travel trip as the NHTS define it. In order to have a more comparable analysis taxi VMT must be added to the NHTS VMT to determine the total roadway demand. NHTS already publishes VMT for personally driven vehicles, but taxi vehicle miles needs to be derived using the following equation:

$$Taxi\ VMT\ (year\ x) = \frac{\left(taxi\ person\ trips\ (year\ x) * miles\ per\ taxi\ trip\ (year\ x)\right)}{average\ taxi\ occupancy\ (year\ x)} * 1.67 \qquad (6.1)$$

Taxi and TNC trips are unique because they involve a certain number of miles to access the persons requesting a ride called deadhead miles. Deadhead mile data is lacking in the TNC market, or at least proprietary, so the literature ranges from 20% to 65% of total trip miles. The California Public Utilities Commission published a report in April 2018 that estimates about 40% of the California TNC market's VMT comes from deadhead miles [21]. California can be used as an adequate stand-in for a national average deadhead VMT share for TNC trips. Since NHTS does not include deadhead miles in the trip length calculation the taxi mode VMT in the above equation is multiplied by 1.67 to account for these additional miles. The assumption then is that both traditional taxis and TNC operate at a 40% deadhead VMT share.

Figure 6-3 shows an adjusted axis of VMT from personal vehicle travel and the calculated VMT from taxis. Notably, taxi mode VMT is a small fraction of the total VMT between the two, only 0.19% and 0.26% for 2001 and 2009 respectively. From 2009 to 2017, however, the taxi share of VMT more than doubled to 0.55%. This percentage is still a small share of total VMT but the magnitude of trillions of miles still substantial. When taking into account the taxi mode, household VMT grew by 22.5 billion miles.

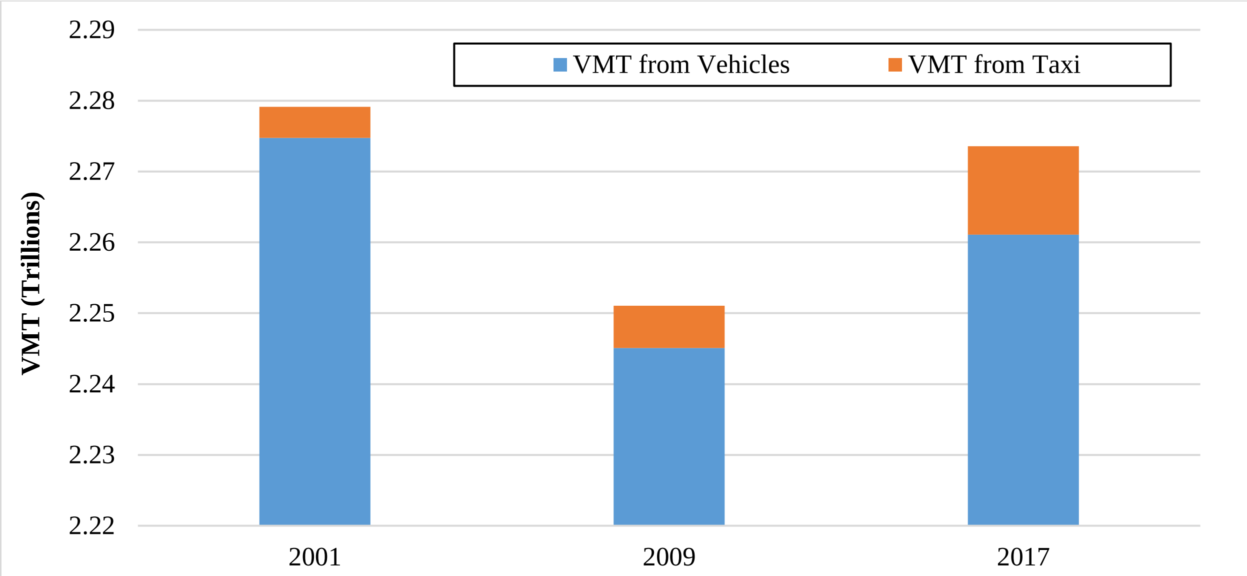

Figure 6-3 VMT from personal vehicle travel and taxis combined

6.4 Sensitivity Analysis

As stated, the sensitivity analysis focuses on three scenarios all stemming from the assumption that 78.8% of taxi trips are completed through TNCs:

- All TNC trips are actually taken by personal vehicles
- All TNC trips are actually taken by non-personal vehicles
- TNC trips are distributed at the Clewlow and Mishra mode substitution rate

Additionally, due to limitations in the data there are a number of assumptions that need to be made in order to curb for differences in trip characteristics between traditional taxis and TNCs. First, it is assumed that TNC trips that are loaded onto personal vehicle trips are done so at the same VMT per person trip rate of the personal vehicle mode. There are issues associated with occupancy and trip length since TNC trips are on average made for different purposes than personal vehicle trips, but since personal vehicles make up such a huge share of trips it is unlikely that the addition of TNC trips will drastically impact the status quo. Second, the VMT per person trip for taxi's was heavily impacted by the addition of TNCs in the 2017 NHTS. The 2017 traditional taxi trips are assumed to be made at the VMT per person trip rate in 2009 adjusted for deadhead miles. This assumption is more difficult to justify because the economic climate was different in 2009 than it was in 2017. It is impossible to say whether traditional taxi trips were the same length or occupancy in 2009 as they were in 2017, but 2009 NHTS taxi data did not include TNCs while the majority of the 2017 NHTS taxi data was TNC.

The following equations describe the steps taken for each of the three sensitivities to determine how much VMT changes under the various conditions:

$$\begin{matrix} Traditional \\ Taxi\ Person \\ Trips \end{matrix} = \begin{matrix} 2017\ NHTS \\ Taxi\ Person \\ Trips \end{matrix} * (1 - 0.788) + \begin{matrix} 2017\ NHTS \\ Taxi\ Person \\ Trips \end{matrix} * 0.788 * \begin{matrix} Taxi\ Share\ of \\ TNC\ Alternate \end{matrix} \tag{6.2}$$

where “Taxi Share of TNC Alternate” is 0.0 for the all TNC trips to vehicle assumption, 1.0 for all TNC trips to non-vehicle assumption, and 0.01 for the Clewlow TNC mode alternate.

$$\begin{matrix} Traditional\ Taxi \\ VMT \end{matrix} = \begin{matrix} Traditional\ Taxi \\ Person\ Trips \end{matrix} * \begin{matrix} 2009\ VMT\ per\ Person\ Trip \\ for\ NHTS\ Taxi\ Mode \end{matrix} * 1.67 \tag{6.3}$$

$$\begin{matrix} Vehicle/TNC \\ Person\ Trips \end{matrix} = \begin{matrix} 2017\ NHTS \\ Vehicle\ Person \\ Trips \end{matrix} + \begin{matrix} 2017\ NHTS \\ Taxi\ Person \\ Trips \end{matrix} * 0.788 * \begin{matrix} Vehicle\ Share\ of \\ TNC\ Alternate \end{matrix} \tag{6.4}$$

where “Vehicle Share of TNC Alternate” is 1.0 for the all TNC trips to vehicle assumption, 1.0 for all TNC trips to non-vehicle assumption, and 0.39 for the Clewlow TNC mode alternate.

$$\begin{matrix} Vehicle/TNC \\ VMT \end{matrix} = \begin{matrix} Vehicle/TNC \\ Person\ Trips \end{matrix} * \begin{matrix} 2017\ VMT\ per\ Person\ Trip \\ for\ NHTS\ Vehicle\ Mode \end{matrix} \tag{6.5}$$

$$Total\ VMT_X = \begin{pmatrix} Vehicle/TNC \\ VMT \end{pmatrix}_X + \begin{pmatrix} Traditional\ Taxi \\ Person\ Trips \end{pmatrix}_X \tag{6.6}$$

where X represents the given sensitivity analysis and the assumed modes shares that are applicable.

In the equations, traditional taxi refers to the 2009 NHTS interpretation of taxi which does not include TNCs, vehicle/TNC represents the sum of vehicles which as defined by the 2017 NHTS includes cars, motorcycles, pick-up trucks, RVs, rented vehicles, SUVs, and vans) and any TNC trips that would be included based on the sensitivity in question. The results of the calculations are presented in Table 6-1.

Table 6-1 Sensitivity analysis of VMT for vehicles, traditional taxi, and TNCs

Sensitivity	2017 Vehicle+TNC Person Trips (Billions)	2017 VMT (Billions)	VMT Change from Base (Billions)
All TNC to Vehicle	349.2	2,273.7	0.2
All TNC to Non-Vehicle	347.7	2,264.2	-9.3
Clewlow Mode Alternative	348.3	2,268.1	-5.5
No Alteration Base	349.2	2,273.6	-

Rather than representing a "worst-case" or "best-case" scenario, this sensitivity analysis show the range of possible values VMT could have taken given that TNCs did not exist at all. In Table 6-1 a positive VMT change from base means TNCs in operation are having a drag effect on VMT. TNCs are hindering VMT growth. The only operation where TNCs represent a drag effect is if all TNCs were converted to personal vehicle use. There was substantial growth of 22.5 billion VMT from 2009 to 2017 when taxi mode was included. This shows that 0.2 billion mile drag represents less than 1.0% of the 2009 to 2017 VMT change. This change is mostly negligible but shows that TNCs are possibly better than POVs. If all of the TNC trips were taken via transit or some other non-vehicle mode, the result is 9.3 billion fewer miles on the road, or about 41% of the 2009 to 2017 VMT change. The most relevant sensitivity analysis is the Clewlow and Mishra mode split that most accurately represents the modes people would have otherwise taken. The negative 5.5 billion mile change from base indicates that TNCs have actually added 5.5 billion miles to the road by capturing people from non-vehicle modes such as walking, biking, transit, and even those who would have otherwise not taken the trip. This increasing effect on VMT represents 25% of 2009 to 2017 VMT change.

6.5 Implications

Finding that TNCs are adding to VMT is not necessarily an unexpected result. The nature of ride-hailing services is to be readily available for customers, which means they must constantly be moving between drop-offs and pick-ups. The real impact of TNCs on roadways may be a bit higher than what is presented in the Table 6-1. This is a result of the assumptions that needed to be made. There is a case to be made for conflicting interests in cities where VMT reduction and transit-TNC partnerships are high priorities. If a city wants to pursue a lower VMT footprint with a struggling transit system, it may be counter intuitive to partner with TNCs. It seems people have taken to substituting a high enough share of transit and non-POV modes that VMT growth will only be exacerbated by incentivizing using TNCs, even if the incentive has the intention of getting people to use transit more. On the other hand, if mobility is the only factor of importance regardless of mode of travel VMT growth may not be an issue, in which case people may continue to substitute traditional mass transit out of existence in some areas. While "out of existence" is a hyperbolic phraseology, the findings here suggest that if cities over incentivize TNCs in an attempt to get people to ride transit more there may be negative implications in long-term transit ridership and congestion.

CHAPTER 7: LONG DISTANCE TRIPS

Long distance trips have always been a point of interest when examining VMT changes. Urban sprawl has played an important role in increasing work trip lengths, and modern fuel economy does little to discourage making long trips. As the automobile has expanded its position as the mode of choice for most Americans, it is apparent that trips of certain lengths have implications for future travel demand and VMT changes. An analysis on long trips also has value when considering the automation of driving, possibly in the near future.

7.1 Background

Classifying "long distance" trips is subjective, so for the sake of maintaining continuity "long-distance" is defined in this paper as any trip longer than 75 miles. The 75 miles mark serves to capture those trips that are being made on a less frequent basis, like vacations and recreation, while still capturing enough of a sample of commuting and work related trips.

Long distance trips are an interesting facet of transportation demand because they hold a lot of relevance in personal travel. As innovation seeks to improve how people get around there might be an expected decline in the vehicle share of person trips. This does seem to be the case, at least since 2001 when person trips via vehicle constituted 85.9% of all person trips (including those via plane, train, and other modes), but has since declined to 83.4% in 2009, and 82.6% in 2017.

In addition to the share of vehicle person trips shrinking, there is a net decline in nominal vehicle trips. Vehicle trips, that is trips in a personal vehicle without regard to occupancy, fell by 13.5 billion from 2009 to 2017. The decline in vehicle trips from 2009 to 2017 is concerning because across the same period VMT grew by 15.976 billion miles. This begs the question how are vehicle trips changing to still support VMT growth, albeit modest, from 2009 to 2017?

One such explanation comes from looking at the long trips, specifically trips over 75 miles, and how they are represented within total vehicle travel. Across every measure of trip making including vehicle trips, person trips via vehicle, and total person trips the nominal number is decreasing; but in the face of decreased travel demand, the nominal number of trips over 75 miles have grown from 2009 to 2017 for all three trip measures. Table 7-1 and Table 7-2 show the number of trips in billions for trips made over 75 miles in length and for all trips. While total trips have been declining anywhere from 5.3% to 6.3%, the trips over 75 miles in length have increase anywhere from 5.2% to 18.0%. The measure of particular importance is vehicle trip since those are responsible for VMT. Surprisingly, share of vehicle trips over 75 miles represent only 1.0% and 1.2% of total vehicle trips in 2009 and 2017 respectively.

Table 7-1 Number of trips for various trip measures and percent change, 2009 to 2017

Year	Person Trips >75 Miles (Billions)	Person Trips via Vehicle > 75 Miles (Billions)	Vehicle Trips >75 Miles (Billions)
2009	4.7	4.3	2.3
2017	5.5	4.5	2.6
Percent Change	18.0%	5.2%	12.3%

Table 7-2 Total trips for various trip measures and percent change, 2009 to 2017

Year	Total Person Trips (Billions)	Total Person Trips via Vehicle (Billions)	Total Vehicle Trips (Billions)
2009	392.0	327.1	233.9
2017	371.2	306.4	220.4
Percent Change	-5.3%	-6.3%	-5.8%

7.2 Trip Length and VMT

While vehicle trips over 75 miles had an increase in share of only 0.3% the implications for VMT are far more dramatic. Since long trips are classified as 75 miles or longer, they represent a remarkable portion of VMT. An additional 300 million trips at no fewer than 75 miles per trip results in an VMT increase of, at the bare minimum, 22.5 billion miles which is already well over the change in household VMT of 15.976 billion from 2009 to 2017. The actual growth in VMT from trips over 75 miles in length is over 68.7 billion miles which means each additional trip to the over 75 mile category averaged nearly 230 miles. The average trip length for vehicles trip greater than 75 miles in 2009 was about 178 miles. With the addition of the new, longer trips the average trip length increased to nearly 184 miles in 2017. This increase, in conjunction with fewer VMT from trips 75 miles in length or less, resulted in the share of VMT from trips greater than 75 miles to increase from 18.5% in 2009 to 21.4% in 2017. Representation of this magnitude is unrecorded since at least 2001, meaning this may be the first instance where over $1/5^{th}$ of household VMT is the result of trips that are longer than 75 miles, and at least the first instance since the start of this millennium.

Trip length explains the "why" to VMT increase, but trip purpose needs to be examined for the "what"' behind growth in trips longer than 75 miles. Table 7-3 and Table 7-4 present the VMT for each trip purpose and the share of total VMT that the greater than 75 mile trips represent. Notably, the trip purpose values changed slightly from 2009 to 2017. In 2017 the NHTS did not publish a "vacation" value or an "N/A" value. While there is no exact measure for which purposes had to compensate for missing values in 2017 it seems that "other", "other family/personal business", and maybe "shopping" and "school/church" added an inordinate amount of VMT so there is cause to believe they increased as a result of lacking other response alternatives.

Table 7-3 VMT by trip purpose, 2009

Purpose	Total VMT (Billions)	VMT from Trips >75mi (Billions)	>75mi Trip's Percent of Total Household VMT
Medical/Dental	57.5	7.0	0.3%
N/A	71.9	48.0	2.1%
Other	12.3	4.9	0.2%
Other Family/Personal Business	340.1	43.3	1.9%
Other Social/Recreational	294.1	53.9	2.4%
Refused	0.3	0.0	0.0%
School/Church	99.0	10.9	0.5%
Shopping	336.9	45.4	2.0%
To/From Work	623.5	34.5	1.5%
Vacation	49.0	31.0	1.4%
Visit Friends/Relatives	204.7	80.5	3.6%
Work-Related Business	156.1	56.8	2.5%
Grand Total	2,245.2	416.2	18.5%

Table 7-4 VMT by trip purpose, 2017

Purpose	Total VMT (Billions)	VMT from Trips >75mi (Billions)	>75mi Trip's Percent of Household VMT (Billions)
Medical/Dental	54.0	5.7	0.3%
Other	123.1	46.0	2.0%
Other Family/Personal Business	324.4	52.0	2.3%
Other Social/Recreational	351.4	94.5	4.2%
Refused / Don't Know	1.4	0.5	0.0%
School/Church	122.3	31.9	1.4%
Shopping	332.3	93.6	4.1%
To/From Work	682.5	58.6	2.6%
Visit Friends/Relatives	198.0	76.9	3.4%
Work-Related Business	71.6	25.3	1.1%
Grand Total	2,261.1	484.9	21.4%

In addition to the household VMT, Table 7-5 shows the VMT per vehicle trip generated by trip purpose for both trips greater than 75 miles and all trips. In comparing change in VMT per trip to change in VMT it is possible to understand the underlying increase in household VMT from the long distance trips.

Table 7-5 VMT per vehicle trip for trips greater than 75 miles and all trip, 2009-2017

Trip Purpose	Vehicle Trips Greater than 75 Miles		All Household Vehicle Trips	
	2009 VMT per Trip	2017 VMT per Trip	2009 VMT per Trip	2017 VMT per Trip
Medical/Dental	127.0	142.1	9.7	10.2
N/A	331.9	-	35.3	-
Other	169.8	162.0	18.7	16.3
Other Family/Personal Business	139.7	173.1	6.7	7.0
Other Social/Recreational	158.4	160.0	8.5	9.8
Refused	98.0	175.4	9.1	17.0
School/Church	238.7	364.4	8.6	10.6
Shopping	153.7	222.6	6.4	7.6
To/From Work	137.0	189.9	12.1	12.8
Vacation	206.4	-	30.9	-
Visit Friends/Relatives	190.9	172.0	15.4	15.7
Work-Related Business	189.3	166.6	17.1	16.3
Grand Total	177.6	184.2	9.6	10.3

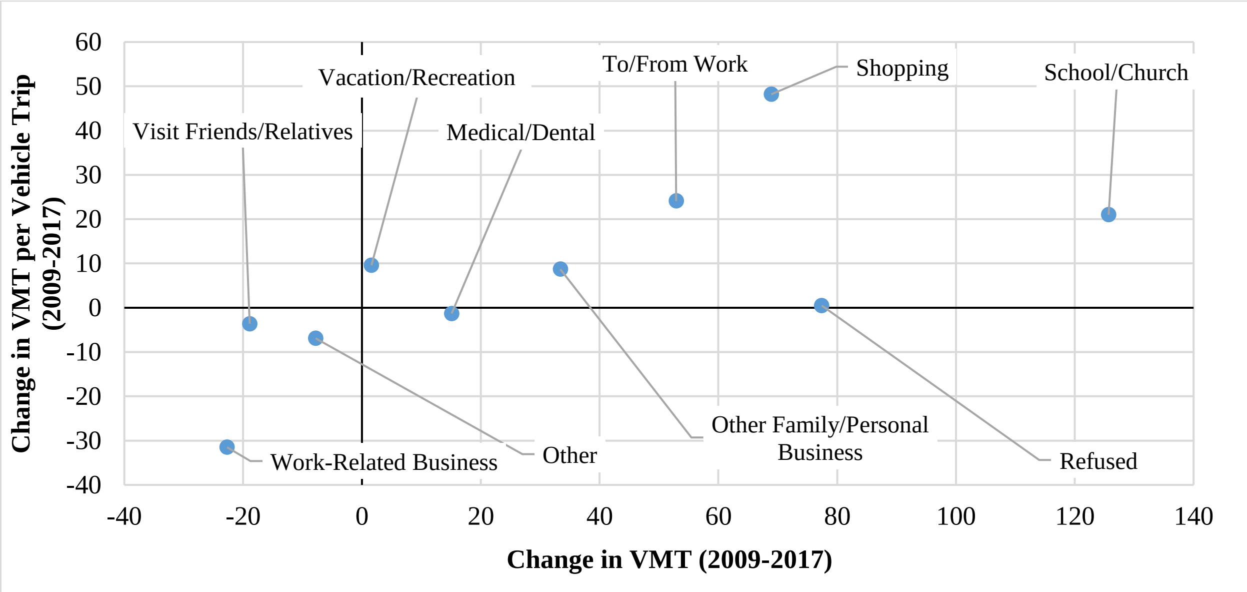

Figure 7-1 VMT and VMT per vehicle for trips longer the 75 miles, 2009-2017

There are only three trip purposes with declining VMT for trips greater than 75 miles (not including purposes that were not included in the 2017 NHTS), medical trips, work-related business trips and visiting friends.

Medical trip VMT for trips greater than 75 miles fell from 7.0 to 5.7 billion miles between 2009 and 2017. Over the same period medical VMT per trip grew from 127 miles per vehicle trip to 142 miles per trip. This suggests people on average are taking fewer of the close to home doctor trips thus increasing VMT per trip. It seems that people are foregoing what are likely check-ups and preventative care and coincides with millennials verging on surpassing the baby boomer population. As for the decrease in miles, it may be the result of a healthier and more active boomer generation entering into retirement years meaning fewer total people with the need to make what are likely very specialized long medical trips. There may also be an issue related to affordability of the medical care so they are foregone for financial reason. It is likely a combination of both.

Work-related business trip VMT for trips greater than 75 miles fell from 56.8 to 25.3 billion miles between 2009 and 2017. Unlike medical trips though, VMT per vehicle trip fell from 189 to 166 miles per trip. This means that longer work-related business trips are being forgone at a higher rate than shorter trips. The simplest reason, and most intuitive, is that people are replacing these long vehicle work-related trips with technology alternative like video conferencing. There may also be a modal shift for these long trips out of personal vehicle travel and into a non-household VMT mode like air travel.

Visiting friends and family also had a decline in VMT for trips longer than 75 miles from 80.5 to 76.9 billion miles from 2009 to 2017. What is unique about this purpose relative to the previous two is an increase in the number of person trips, but still a decrease in vehicle trips. VMT per vehicle trip also fell from 191 to 172 miles per trip, so the explanation is that people are still making these trips, but are doing so in a much more efficient miles per capita fashion by carpooling. This may be a shift in generational behavior as social structure changes with electronic media and communication capabilities improving.

While all other purposes had increasing VMT from trips greater than 75 miles, this section will only focus on commute and vacation/recreational with notes on church/school and shopping trips.

Commute trip VMT for trips greater than 75 miles grew from 34.5 to 58.6 billion miles between 2009 and 2017. Miles per vehicle trip for trips longer than 75 miles grew from 137 to 189 miles per trip. With commute trips, there is a distinct willingness to increase trip distance if there is a possibility to improve quality of life. In addition, commute trips are one of the most stable sources of VMT so long as the personal vehicles remain affordable. This trend seems to be in opposition with the idea that younger generations are living in urban areas closer to work. In any case, VMT is trending upward for commute trips thus presenting capacity concerns for major roadways designed to support mobility over accessibility.

Vacation/recreation trip VMT for trips greater than 75 miles increased from 84.9 to 94.5 billion miles between 2009 and 2017. The VMT per vehicle trip for trips greater than 75 miles, however, decreased from 173 to 160 miles per trip meaning the number of vehicle trips being taken for this purpose grew by 20% from 4.9 billion to 5.9 billion trips. People are enjoying more leisure trips closer to home. This trend likely has ties to economic vitality as the U.S. pulls out of the recession and people have more disposable income to increase the trip frequency of this purpose. An increase in disposable income could also coincide with people willing to make longer trips, maybe not as frequently as closer trips, but for multiple day to justify a longer drive.

Unfortunately, it is difficult to make any inferences on church/school and shopping vehicle trips longer than 75 miles because the data shows strong growth for both categories. For shopping trips, this would imply disposable income is supporting shopping for leisure rather than exclusively shopping for necessity. Leisure shopping might take place in a premier mall, which are usually sparse and would require a driving a longer distance for many. For church/school the VMT per vehicle trip for trips longer than 75 miles ranges from 240 to 360 miles which would suggest that these trips are for long periods of time, and possibly to a college, university, or mission. Students are more inclined than ever to pursue secondary education at a university or college and religious institutions are known to be philanthropic in nature.

7.3 Conclusion

This chapter's analysis is not as quantitative in nature, but rather seeks to determine what behavioral changes are being made based on trip length and trip purpose. The share of VMT coming from trips longer than 75 miles has increased substantially since 2009 and has potential to remain a dominating force in household VMT. There is no one reason people make long trips, but the trip purpose data shows a mix trips made out of desire and trips made out of necessity. The increases household VMT from trips longer than 75 miles was more than the change in household VMT from 2009 to 2017, so there is something to be said for the smaller short trip share of VMT, and certainly longer trips supporting growth in VMT.

CHAPTER 8: CONCLUSIONS

8.1 Conclusions and Policy

This thesis uses analyses of five factors to explore and quantify household VMT, but there are many factors worth examining with the given data sources. It is impossible to say any one factor has the absolute ability to define and predict household VMT, especially since many factors have overlapping and compounding effects on each other. Personal travel VMT is also uniquely vulnerable to behavioral shifts compared to service and freight related VMT, making it difficult to track and understand. This paper provides only a fraction of insight into household travel and VMT, but each factor plays an important role in developing an overall picture. Table 8-1 presents the chapters and the findings for how VMT is influenced by the analyzed factors.

Table 8-1 Summary of findings

Factor Affecting VMT	Effect Influence as a Percent of VMT Change for Time Frame	Time Frame of Effect
Household Density Distribution	-220%	2009-2017
Geographical Distribution	39%	2009-2017
Population Distribution	-50% 89%	2009-2017 2001-2017
TNC Use	25%	2009-2017
Long Distance Trips	-	2009-2017

The household distribution effect places household travel in the context of increasingly urban living and lifestyles. The findings of the analysis show that household VMT is on track to experience downward pressure in the future. From a policy standpoint, this is in line with much of the action taken regarding VMT as a whole. Vehicles are an increasingly burdensome means of transportation as density increases. The urban core is characterized by maximum efficiency when it comes to land use, and driving is a very demanding activity that requires not only sufficient space for operations, but also for short-term storage. Stagnant or decreasing VMT trends are beneficial for many dense communities that are battling congestion challenges. Additionally, vehicles are a substantial consumer of resources, in particular energy. The use of carbon based fuels generates emissions that some dense core MSAs are interested in mitigating for both environmental and health reasons. Every community, from large cities to small towns, have the propensity to experience densification. For this reason, it is important for everyone to consider the availability of alternative means of transportation, acknowledging that there is a real possibility for increased households per square mile. By ensuring the availability of transportation mode options, there is a possibility to capture people before they make their long-term transportation decision by purchasing a vehicle. An investment in a vehicle is a decision to use that form of transportation at least regularly for the foreseeable future. Consider refocusing funding from increasing roadway capacity to providing mass transportation or other non-POV right-of-way. Areas may experience increased congestion, but that disincentive along with the incentive of faster trip times on another mode will result in fewer people using POVs.

There are many cities across the U.S. that have a higher than average propensity to generate household VMT. Some of these cities are accompanied with high rates of population growth. It is extremely important to recognize that these high VMT generating locations exist, and may experience inordinate amounts of congestion in the future compared to other cities of similar size with different travel characteristics. Curbing the impact of VMT is integral in lessening congestion and improving roadway travel. One such policy method is to institute congestion pricing, peak hour pricing, toll lanes, and other disincentives for personal vehicle drivers. Vehicle fuel efficiency has hindered transportation funding to the point where users of the roadway are not absorbing the actual cost of driving [22]. The cost born by the users is primarily for the ownership and protection of a vehicle and not for actually using the very expensive roadways on which the vehicle operates. Low gas taxes burden all levels of government to redistribute funding from other sources, because the ability to transport people and goods is among the most important service the government provides. Making drivers pay for the actual cost of personal vehicle travel incentivizes decreased vehicle use, and thus reduces VMT.

As the population continues to age, there is expected to be a downward pressure on household VMT. This comes as the boomer generation enters retirement years when they experience lifecycle changes that include fewer or no dependents, part-time or no work, and fewer personal and social obligations. These changes lead to lower travel demand. As far as policy is concerned, there are two methods to consider promoting lower household generated VMT. First, policy aimed at getting older age cohorts out of POVs and into alternative modes of transportation. This method is challenging because mobility gets increasingly more difficult as people age, and personal vehicles are enticing because they provide a means of transportation that has absolute autonomy when it comes to selecting when and where a trip is made. However, older individuals do experience degradation in driving ability like reduced response time and difficulty seeing, that makes driving more hazardous than beneficial as a transportation option. Luring this market share to transit may prove effective in decreasing household VMT. The second method involves getting younger age cohorts to opt out of POVs and into alternative modes like transit, biking, and walking. This age group already seems more conducive to accepting alternative modes of travel, so the onus is on the local authorities to ensure the availability of other means of transportation. There is a livability movement gaining traction involved with making the area you live accessible, shared-use, safe, and a more all-inclusive live-work-play environment [23]. If livability improvements can excite younger generations, there might be continued downward pressure on household VMT.

The introduction of TNCs into the transportation market has more than doubled the number of users of ride-hailing services from 2009 to 2017. TNCs are generating an upward force on VMT and the trend seems to be increasing. What's concerning is the TNC capture of person trips from non-POV modes. TNCs have been absorbing trips from modes that would have otherwise not generated household VMT. Transit agencies that are looking to improve ridership may, in some instances, be considering public-private partnerships to tap into the TNC market. This should be done with caution, because transit agencies incentivizing TNC use may inadvertently induce more demand to TNCs as people get more comfortable using it. This may result in totally foregoing the transit aspect of the trip. Additionally, as a policy implication, reduced VMT per capita is still a national goal set by the Federal Surface Transportation Policy and Planning Act , and TNCs already generate a huge amount of deadhead miles and may increase this number driving people to and from transit stops.

Finally, over 20% of household VMT is generated by trips longer than 75 miles. Attempting to eliminate this source of VMT generation is difficult because these trips are not for any one specific reason. In fact, the opposite is true for long distance trips, which vary widely across several purposes. Rather than establishing new modes of transportation, it may be more beneficial to focus on improving vehicle occupancy to reduce VMT per capita. By using a mode whose cost is entirely borne by the user, a governing agency need only provide an incentive to carpool. Incentives to carpool can come in the form of reserved parking, high occupancy vehicle

(HOV) lanes, or any number of ways that improve travel time, make parking easier and more affordable, or otherwise reduce the cost to the user.

8.2 Future Work

The capabilities for the NHTS data set regarding household travel are endless. The survey provides a plethora of different variables for a multitude of geographic levels, and is open source for use by the public. There are several ways to increase the statistical technicality of the analyses presented in this paper using this and other data sources.

One of the more important notes to consider about these analyses is that they are on a national level, and therefore do not necessarily apply to every locality equally. Looking at regional, state, or in some cases MSA level data may provide better insight for researchers interested in exploring the travel needs of a specific area. The methods presented are applicable at any geographic level of analysis given robust enough data.

For the age distribution section, there is an opportunity to explore data sources beyond NHTS data. The analysis for age distribution used NHTS data for both travel characteristics and population estimates. While the NHTS is unique in providing specific trip characteristics and travel behaviors, there are more reliable sources for population data. For the U.S. as a whole, the U.S. Census Bureau publishes annual population and demographic data that can be filtered down to encompass very specific areas (MSAs, counties, and even certain cities). Additionally, the U.S. Census Bureau has a larger sample size that can improve accuracy in estimates. Intermingling data presents opportunities to explore and define new relationships between variables.

While the NHTS is only released every 5-8 years, there is still value in the re-evaluation of older analyses to determine if the trends predicted actually played out. The most recent NHTS is about a year old as of the completion of this thesis, so it still holds relevance in current behavioral research and should remain valuable for several years. In fact, there is still potential for the NHTS to release updates to the data making it immediately useable for already tested hypotheses.

One theory that is not teased out in this thesis, but could hold value for the future, is looking at how supplying roadways induces VMT generation. The make-up of VMT has changed dramatically in the last two decades, but roads are still built and expanded in the same, traditional way to support a now different travel demand profile. This begs the question, are we using resources to their fullest extent, and is there a better way to supply travel options? Roads are the backbone of transportation in America and, barring an absolutely revolutionary transportation mode, will remain extremely valuable infrastructure for years to come, but how we design them, and for whom matters. Are there supply options that might better leverage how and why VMT is generated to optimize travel?

There are major changes going on regarding the composition of VMT. Unfortunately, the data necessary to examine VMT generation as a function on non-household and non-freight modes is not necessarily available. The portion of VMT that is specifically lacking data is the vehicle services sector, which includes everything from plumbers to electricians to food delivery services to online ordering. When household and freight VMT both remained stagnant between 2009 and 2017, VMT still grew nationally, and it is mostly attributable to the vehicle services mileage. Again, the data is lacking for this segment of VMT, but by developing a better understanding of household and freight VMT, and urging data collection of this missing piece, there could be an opportunity in the future to develop a comprehensive VMT model.

Finally, this thesis was conducted in a univariate manner to try to gain an in-depth grasp of each factor in question. While univariate correlations were revealed, there is still a shortfall due to heterogeneity. Univariate analyses are difficult to pin down the exact contribution an independent variable has on a dependent variable. To fix the inherent heterogeneity, one might consider a multivariate analysis using modeling software. Multivariate analyses can be helpful in determining the actual impact of an individual variable, and how variables operate as a unit. Multivariate analyses are also conducive to the projection of trends.

Ideally, the information presented in this thesis exposed some of the underlying factors that contribute to household VMT, so future research can be conducted from the findings. Vehicle travel will continue to play an integral part of American transportation for the foreseeable future. Data analyses like the ones presented in this thesis are just the tip of the iceberg, and should be treated as a stepping-stone to continued research.

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