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16. ABSTRACT

The United States is going through an era of unprecedented transformation. Sociodemographic changes, major innovations in information technology, the reorganization of economic activities, and substantial shifts in the urban form of cities all contribute to changing the way Americans live, work, and travel. During the past ten years, transpot1ation demand in the United States has also gone through significant modifications. The use of private vehicles has gone through a period of apparent stagnation. Starting in the mid-2000s, the average per-capita vehicle miles traveled (VMT) have declined, at least temporarily (until 2013), after a long period of steady growth in the previous decades. In addition, an increased portion of Americans live without a car. While the total amount of trips in the country continues to rise, this has not translated into increased car use, and the use of alternative modes (including public transportation and active means of travel) is increasing, even if it still accounts for a rather low portion of mode share.

Passenger travel in the United States at the beginning of the 21st century is increasingly multimodal, and (slightly) less reliant on the use of private cars. Travelers are changing their behaviors in response to new alternatives available to them, changes in the characteristics of the old alternatives, and changes in the way they evaluate and value these characteristics. A complex combination of factors is behind the observed trends. The economic crisis from 2007-2009 ce11ainly contributed to reducing total VMT in the country. However, it is not the main cause of the observed changes in travel behavior, and other factors seem to play an impot1ant role. In particular, several studies have demonstrated how the observed reduction in car travel actually predates the economic crisis by at least a few years.

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WHAT AFFECTS U.S. PASSENGER TRAVEL? CURRENT TRENDS AND FUTURE PERSPECTIVES

February 2016

A White Paper from the National Center for Sustainable Transportation

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National Center for Sustainable Transportation

ITS UCDAVIS INSTITUTE OF TRANSPORTATION STUDIES

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Disclaimer

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What affects U.S. Passenger Travel? Current Trends and Future Perspectives

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List of Acronyms Used in the Document

ACS	American Community Survey
AEO	Annual Energy Outlook
AFV	Alternative Fuel Vehicle
AV	Autonomous Vehicle
CAFE	Corporate Average Fuel Economy (Standards)
C/AV	Connected/Autonomous Vehicle
Caltrans	California Department of Transportation
EIA	(United States) Energy Information Agency
EPA	(United States) Environmental Protection Agency
FHWA	Federal Highway Administration
GDP	Gross Domestic Product
Gen X	Generation X (Middle-aged adults, 35-50 years old in 2015)
Gen Y	Generation Y (Young adults, 18-34 years old in 2015)
Gen Z	Generation Z (Younger individuals of age below 18 in 2015)
GHG	Greenhouse Gas
HH	Household
ICT	Information and Communication Technology
ITS	Institute of Transportation Studies
LCV	Light Commercial Vehicle
LDT	Light Duty Truck
LDV	Light Duty Vehicle
NCST	National Center for Sustainable Transportation
NHTS	National Household Travel Survey
NHTSA	National Highway Traffic Safety Administration
NPTS	Nationwide Personal Transportation Survey
PAV	Personal Autonomous Vehicle
SAV	Shared Autonomous Vehicle
SB	Senate Bill
SCS	Sustainable Community Strategy
SUV	Sport Utility Vehicle
TDM	Transportation Demand Management
TNC	Transportation Network Company
TOD	Transit Oriented Development
TRB	Transportation Research Board
UC	University of California
UC Davis	University of California, Davis
US DOT	United States Department of Transportation
VMT	Vehicle Miles Traveled

Key Findings

Vehicle Miles Traveled (VMT) per capita declined in the United States between 2004 and 2013.

The economic recession appears to have reinforced the decline in car travel, without being its primary cause.

Sociodemographic trends in the U.S. include smaller household sizes, delayed childbearing, and increased presence of immigrants.

Baby boomers are starting to retire and make fewer commuting trips, while younger generations (e.g. *millennials*) tend to own fewer vehicles and are increasingly multimodal.

There is a resurgence of the central parts of cities, and increased availability of travel options also in non-central areas.

The impact of new transportation technologies, e.g. *shared mobility* services today, and *autonomous vehicles* in the future, on travel demand is uncertain.

What affects U.S. Passenger Travel? Current Trends and Future Perspectives

EXECUTIVE SUMMARY

The United States is going through an era of unprecedented transformation. Sociodemographic changes, major innovations in information technology, the reorganization of economic activities, and substantial shifts in the urban form of cities all contribute to changing the way Americans live, work, and travel. During the past ten years, transportation demand in the United States has also gone through significant modifications. The use of private vehicles has gone through a period of apparent stagnation. Starting in the mid-2000s, the average per-capita vehicle miles traveled (VMT) have declined, at least temporarily (until 2013), after a long period of steady growth in the previous decades. In addition, an increased portion of Americans live without a car. While the total amount of trips in the country continues to rise, this has not translated into increased car use, and the use of alternative modes (including public transportation and active means of travel) is increasing, even if it still accounts for a rather low portion of mode share.

Passenger travel in the United States at the beginning of the 21st century is increasingly multimodal, and (slightly) less reliant on the use of private cars. Travelers are changing their behaviors in response to new alternatives available to them, changes in the characteristics of the old alternatives, and changes in the way they evaluate and value these characteristics. A complex combination of factors is behind the observed trends. The economic crisis from 2007-2009 certainly contributed to reducing total VMT in the country. However, it is not the main cause of the observed changes in travel behavior, and other factors seem to play an important role. In particular, several studies have demonstrated how the observed reduction in car travel actually predates the economic crisis by at least a few years.

This white paper discusses the forces affecting U.S. passenger travel, the permanence of which is often unclear. We explore travel demand's relationship with explanatory factors such as economic activity, gas prices, urban form, socio-demographic traits and generational effects, the expanding availability of travel options (including electronic alternatives to travel) and technological innovations in the transportation sector (including the advent of emerging transportation and *shared mobility* services). We discuss how these factors modify the alternatives available to travelers, the characteristics of each alternative, and the way travelers perceive and evaluate these characteristics.

Among the most notable factors affecting travel demand, there are:

- Trends in passenger travel no longer seem to closely track trends in economic activity. A number of reasons may affect this, including the complex changes happening in society and work organization, the adoption of technology, the differential growth of the various economic sectors, with stronger growth observed in the technological, financial and service industries, and the growing disparity in personal wealth. In addition, several past correlates of economic development, such as the increases in the employment of women and in auto ownership rates, have now reached maturity and are not contributing to boosting travel demand as they used to. These trends are expected to continue, and thus economic activity may no longer be as strong of a driver of car travel as it has been in the past.

- Changes in gas prices have had a role in affecting travel behavior, but their impact on VMT is rather weak. Changes in gas prices affect vehicle choice, though, which in turn affects the relationship of Americans with their cars (though not necessarily their amount of travel). The increased fuel efficiency of the modern vehicle fleets reduces the cost of traveling by car, and increases the convenience of using private vehicles, especially at a time of increased adoption of electric and other alternative fuel vehicles.
- The urban form of American cities is changing. Previous studies have demonstrated that individuals living in more compact, diverse neighborhoods tend to drive less than those living in suburban areas. Recent data show some evidence of a return to the central parts of cities, though on average suburban growth continues to dominate land use development. In addition, investments in public transportation and other policies promoting pedestrian and bicycle mobility provide better multimodal accessibility and more travel options to many travelers. In the short run, these investments can lead to less dependence on car travel, and they may allow lower levels of auto ownership over the longer term, among those individuals interested in such choices. They also encourage changes in the awareness and perception of travel alternatives, further contributing to changes in travel behavior, and eventually supporting the use of non-auto travel modes.
- Current sociodemographic trends of U.S. households include *lifecycle effects*, *period effects,* and *cohort (generational) effects*, and unveil potentially lasting effects on travel demand. The observed trends include smaller average household size, delayed marriage, delayed childbearing and other life events, and an increased prevalence of immigrants. Furthermore, baby boomers are starting to transition into retirement. This reduces the number of commute trips (and related VMT) and increases the time available/potential for discretionary travel. Among the *generational* effects, younger generations are found to have different travel patterns from older cohorts. Both members of Generation X and Generation Y (i.e. *millennials*) drive less than their older peers at the same stage of life and seem to exhibit increased preferences for living in urban areas. Millennials, in particular, tend to delay having children and often live in smaller housing units. Members of this generation were hit hard by the economic recession and still have a higher rate of unemployment than older cohorts. Millennials are also credited with having stronger preferences for urban lifestyles, although it is not clear whether this represents a long lasting trait, or a temporary preference associated with their current stage in life.
- Individuals belonging to all generations have become frequent users of modern technologies. More than half of Americans own a smartphone, which allows increased opportunities for micro-coordination of travel and for the adoption of travel alternatives that may decrease car use. How these transformations affect travel demand is still not clear, though. Technology is associated with a complex

pattern of effects which may eventually lead to *substitution of*, *complementarity with* or *neutrality with* car travel.

- A new generation of technology-enabled *shared mobility* services is quickly reshaping transportation by offering users new ways to get to their destination, accessing a wider set of travel options and enjoying increased flexibility (on where and when to travel) without the fixed costs of owning a private vehicle. The overall impact of shared mobility services on the use of other transportation modes is not clear yet, and it might depend on the specific characteristics of each service and of the local context.

It is unclear if per-capita VMT will decline further, or if it will resume growth after the temporary "peak" observed in the past few years (as it seems to be the case, according to the recent data from 2014-2015). Accordingly, *peak car* may be a temporary or lasting phenomenon, depending on whether the growth in car travel will resume after some of the causes (e.g. the recent economic crisis) are removed. Findings from the literature are mixed. Still, there are reasons to believe that some of the trends observed in previous years will extend into the future.

The underlying regime of growth in passenger travel which powered the previous decades, with the massive expansion of cities into the suburbs, a significant gender gap and lower drivers' licensing rates among older cohorts, has lost strength. With an auto ownership ratio of approximately one vehicle per licensed driver, and almost all adults of driving age who desire to obtain a license already having one, it is reasonable to expect that future growth in passenger travel in the 21st century will be driven by factors such as economic growth, urban form, and personal preferences of individuals.

It is unlikely that car travel volumes will grow as rapidly as in the past. Instead, the factors outlined above will likely lead to more moderate growth rates. The travel patterns observed at the regional level will depend on the factors, or combination of factors, whose effects will prevail in each region. Future trends in passenger travel will also depend on the specific policies implemented, especially at the urban level. Most Americans live in environments that necessitate cars for personal mobility; however, options for multimodal travel are expanding though both public sector and private sector initiative. Disrupting technologies, including shared mobility services, are already transforming the way Americans travel. Connected and autonomous vehicles are expected to further revolutionize transportation in the future. These technologies may cannibalize other means of travel, at least under some circumstances. The final impacts of these emerging technologies on future passenger travel will depend on the way they are deployed, and how they are integrated into the existing transportation system.

Introduction

The characteristics of passenger travel in the United States are changing. Most notably, during recent years, the use of private vehicles, commonly measured in vehicle miles traveled (VMT), has gone through a period of (at least temporary) stagnation. In particular, starting the mid-2000s and for almost an entire decade the average per-capita VMT has declined, after many decades of steady growth. A growing body of empirical research suggests that the United States, similar to several other developed countries, might have passed the peak of per-capita automobile use (Kuhnimhof, Zumkeller, and Chlond 2013; Sivak 2013; Sivak 2014a; Zmud et al. 2013).

The reasons for this apparent peak in the use of personal vehicles, and their relationships with the use of other travel modes, are not entirely clear. Several possible explanations have been proposed to explain this trend in passenger travel. They include the impact of the recent economic recession, changes in gas prices, demographic trends, changes in the urban form of American cities, and emerging changes in personal preferences and lifestyles (Puentes 2013; Goodwin 2012; Wachs 2013). Little evidence exists, to date, as to whether these trends will continue in future years, therefore representing a deeper and more structural change in travel demand, or if they are only temporary as would be the case if they were largely the result of temporary economic conditions. In other words, it is unclear if *peak car* is a temporary or lasting phenomenon, and if after removing some of the causes, such as fuel price increases or the recent economic crisis, the growth in private vehicles use will resume as before.

The observed changes in passenger travel have important implications for urban and transportation planning owing to the large financial investments and considerable time required to provide new transportation infrastructure and services. Accordingly, understanding the factors affecting current passenger travel, and their potential relevance in affecting future trends in the use of cars relative to the other means of travel, is of outmost importance to planning processes.

This white paper aims to support transportation planners and policy makers in providing a better understanding of the current trends in passenger travel in the U.S., the factors behind these trends, and the future implications that these factors will have on travel demand in future years. We review the findings from scientific studies and recent technical reports, and discuss the contribution of each factor to the use of private vehicles rather than other means of travel, the direction and magnitude of the dominant effects of each factor, their potential future effects, and the degree of certainty with which these factors may affect travel demand in future years.

General Trends in Passenger Travel

The use of motor vehicles, including all light-duty vehicles such as passenger vehicles, pickup trucks, sport-utility vehicles (SUVs), and vans, grew steadily in the United States in the second half of the 20th and the first few years of the 21st Century. This trend mirrored the positive trends in economic growth and the expansion of cities towards a model of lower-density residential development with separated land uses observed in the same years.

Figure 1 summarizes the observed trends in *total VMT* and *VMT per capita* in the United States between 1970 and 2015, using data from the Federal Highway Administration (FHWA). The figure highlights the apparent *VMT peak* that was recorded in the first years of the 21st century. FHWA data from 2015, however, suggest a resurgence of VMT growth at the national level, with total VMT reaching a record-high value at the end of the year (according to the monthly-adjusted annual VMT estimates from FHWA), and an upswing in per-capita VMT as well (although the latter still remained below its 2005 peak).

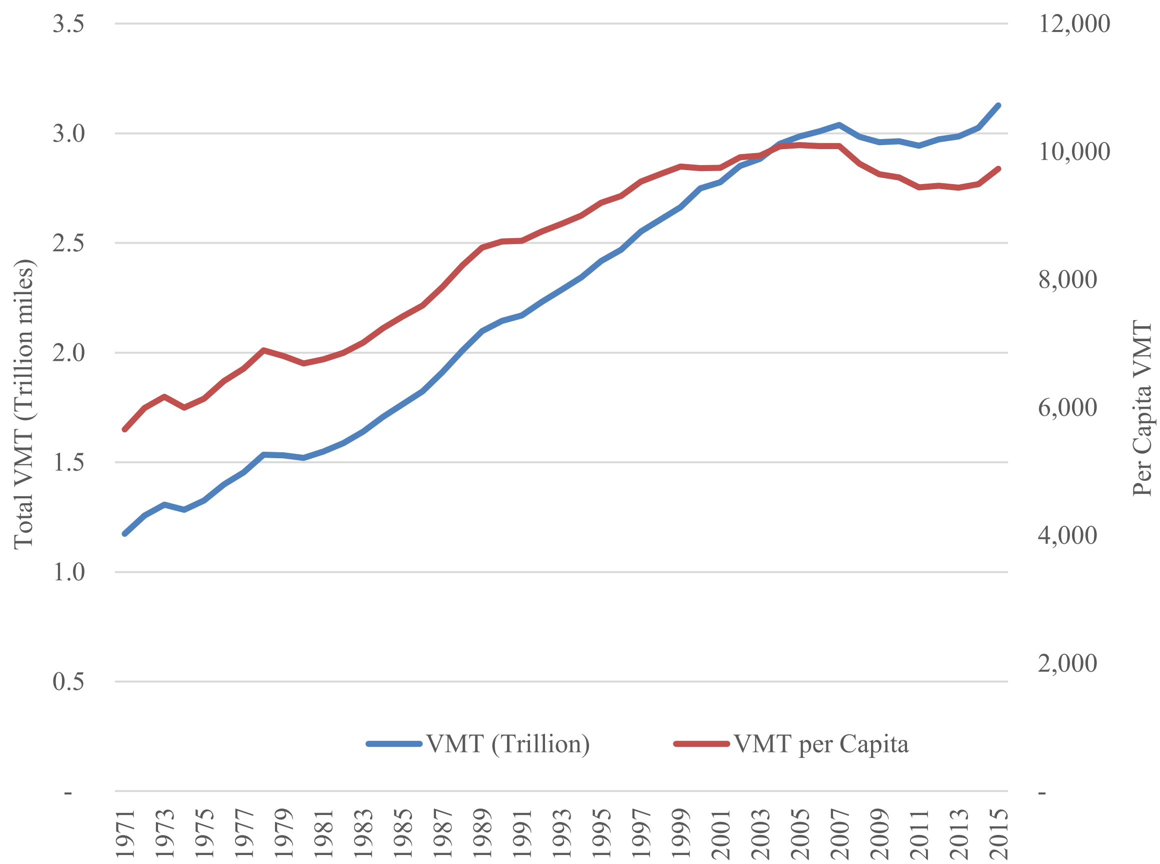

Figure 1: Trends in total and per-capita VMT 1970-2015 (Source: Created by the authors using FHWA and Census data for 1970-2015; forecast data for 2015 were added using information obtained from the moving annual-average VMT data from FHWA, last updated in October 2015).

Similarly, the total number of privately owned and commercial light duty vehicles[1] within the United States reached a (at least temporary) maximum of 243 million in 2008. It decreased nearly four million by 2011, but has rebounded to 241 million by 2013 (FHWA, 2015a). In addition, an increasingly large number of households are found to own fewer or no cars in many U.S. metropolitan areas (Sivak 2014b). Nationwide, 9.2% of U.S. households were found not to own a car in 2012, compared to only 8.7% in 2007 (Sivak 2014b). Similarly, during recent years a larger proportion of Americans, across all age groups, are found to choose to forgo a driver's license (Sivak and Schoettle 2016).

Car travel has probably reached a "saturation" level (Metz 2012; Van Dender and Clever 2013; Metz 2013). The underlying regime of growth in travel demand that powered the previous decades has lost strength, with the effects of factors like the *gender gap* (both in drivers' licensing and in employment) and the role of *age* on drivers' licensing (with the members of older generations being less likely to have a license or be active drivers than the members of the following generations by whom they are replaced) almost vanishing, after they had been important reasons for growth in travel demand in previous years (Metz 2013). The gender gap (in terms of total amount of miles driven), for example, was drastically reduced in the U.S. during the past 40 years: according to NPTS/NHTS data, women drove only 5,400 miles per year, on average, in 1969, which was equivalent to 48% of the average miles driven by men in the same year (11,352). By 2009, this ratio had increased to 67% (10,244 miles driven per year for women, vs. 15,139 for men) (Sivak 2015). With an auto ownership ratio of approximately one vehicle per licensed driver, and almost all adults of driving age that desire to obtain a license already having one, growth in passenger travel demand in the 21st century is now left to other factors, such urban form, and personal preferences of individuals.

Several possible explanations have been proposed for the recent changes in driving patterns and the apparent peak car usage (Puentes 2013). Possible factors affecting passenger travel include the changes in fuel prices observed during the past few years, the high levels of traffic congestion in large metropolitan areas, changes in household composition and demographics, eventual shifts in personal preferences and lifestyles of the U.S. population, and the impacts of emerging transportation services and new technological solutions – e.g. the eventual substitution of physical trips with electronic alternatives to travel (Newman and Kenworthy 2011; Wachs 2013). The 2008 economic recession has been offered as a possible, even if only partial, explanation for these trends. However, it has been noted that the VMT per capita, as well as the rates of vehicle ownership, including the number of vehicles per person, vehicles per licensed driver, and vehicles per household, reached their respective peaks between 2004 and 2006, approximately two years before the economic recession (Van Dender and Clever 2013; Sivak 2015). This lends supporting evidence to the importance of non-economic factors contributing to a decline in VMT per capita. The economic recession seems to have reinforced a pre-existing trend, and increased its magnitude, without being its primary cause.

[1] This measure includes the number of privately owned and commercial cars, motorcycles, pickups, vans, sport utility vehicles (SUVs), and other light trucks. It does not include buses, heavy trucks and government-owned vehicles.

The observed decreases in total and per-capita VMT have been accompanied by other changes in U.S. travel patterns. Analysis of National Household Travel Survey (NHTS) data shows that the total number of person-trips continued to increase between 1995 and 2009. However, the mode distribution shifted. In particular, the percentage of person-trips made by car fell from 87.8% in 1990 to 83.4% in 2009 (after reaching a maximum of 89.3% in 1995), while the percent of person-trips made by transit rose from 1.8% to 1.9% and walking rose from 7.2% to 10.4% over the same period[2] (Santos et al. 2011). During that same time period, Buehler and Hamre (2014) found that Americans have become increasingly multimodal: one in four uses a car and makes seven or more weekly trips by other modes. In addition, commuting data from the American Community Survey show that the number of commuters who traveled to work by bicycle increased from nearly 488,000 in 2000 to around 786,000 in 2008–2012, with an increase in commute mode share of 0.2 percentage points, from 0.4% to 0.6% (McKenzie 2014).

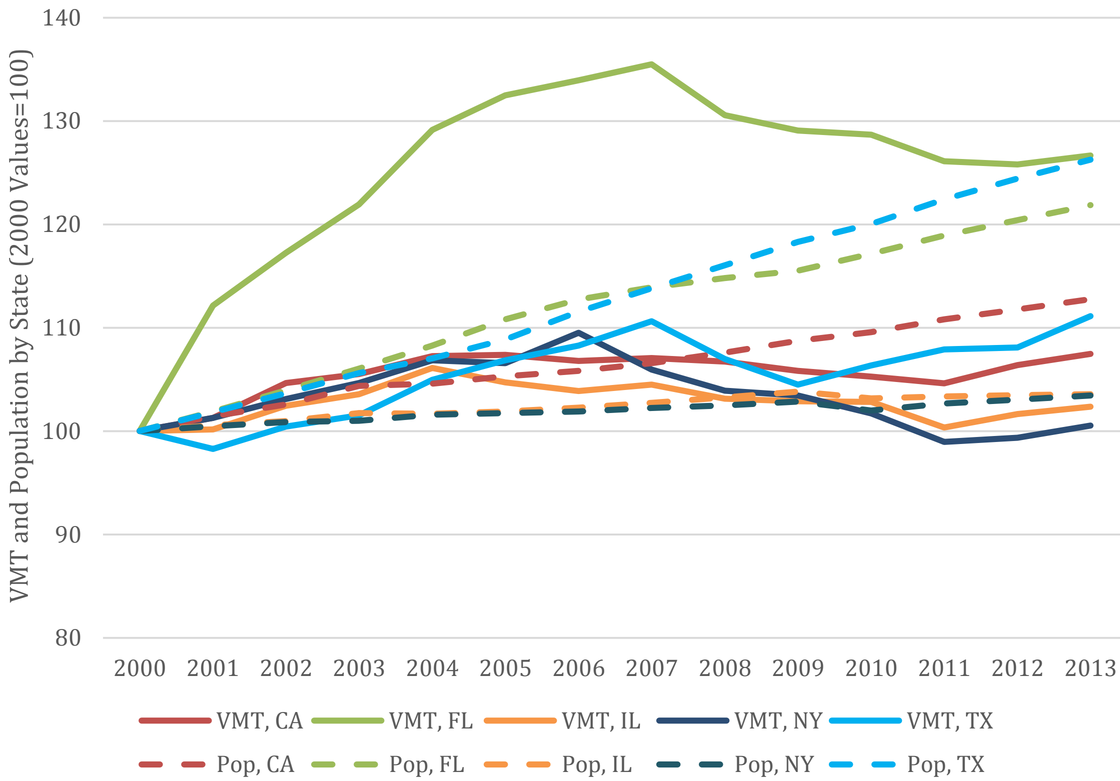

Figure 2. Annual VMT (solid lines) and total population (dashed lines) by state, indexed to 2000 values, for the five largest U.S. states by population: California (CA), Texas (TX), Florida (FL) New York (NY) and Illinois (IL) (Source: Created by the authors using FHWA and U.S. Census data)

[2] Caution should be used when comparing results from different NHTS datasets, as different methods in collecting the data were used. In particular, travel survey data were collected in the U.S. until 1995 with the Nationwide Personal Transportation Survey (NPTS), and with the National Household Travel Survey (NHTS) starting in 2001. Additional modifications were made in the language used to collect information for specific transportation modes, e.g. walking trips, which may explain part of the differences in mode share observed over time.

Figure 2 reports the trends in total annual VMT and population by state from 2000-2013 for the five most populous U.S. states: California, Texas, New York, Florida and Illinois (with total annual VMT and population in 2000 used as reference for each state). Appendix A includes a summary of total population, total VMT and per capita VMT for all U.S. States in 2003 and 2013 (i.e. the last year for which complete data for each U.S. state were available at the time of writing).

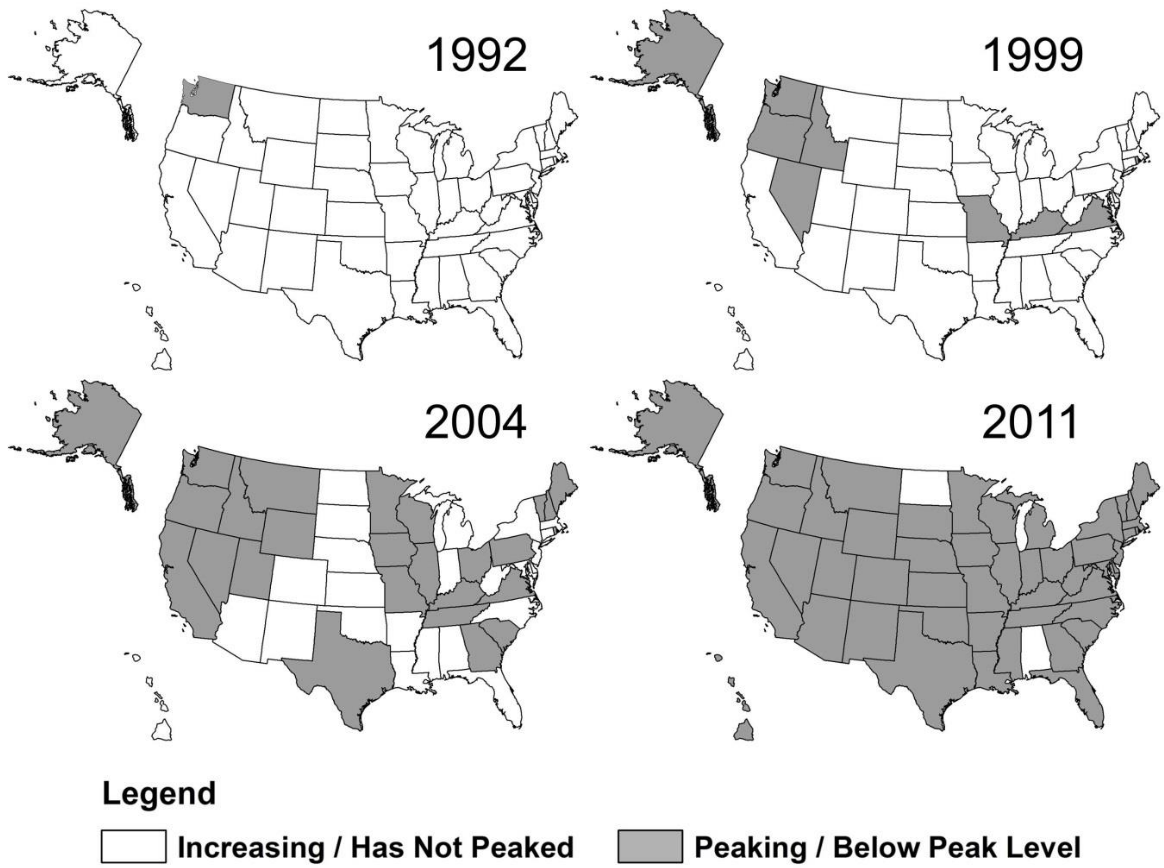

Figure 3. VMT peak by state, 1992-2011 (Source: Garceau et al. 2015[3])

Garceau et al. (2015) summarized the trends in VMT per capita for each state in the U.S. from 1980 to 2011. The results indicate that, in 1992, Washington was the first state to reach a peak in its per-capita use of cars. Six other states followed by 1999. By 2004, a total of 26 states had reached a peak in their VMT per capita, with a majority of those states continuing to decline since their respective peaks, during the remaining years that were studied. By the final year included in their analysis (2011), 48 out of 50 states had reached an apparent peak (Figure 3), with Alabama and North Dakota being the only exceptions. In 40 of the 48 states that reached

[3] From Garceau, T., C. Atkinson-Palombo, and N. Garrick. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2531, Figure 1, p. 39. Copyright, National Academy of Sciences, Washington, D.C., 2015. Reproduced with permission of the Transportation Research Board.

at least a temporary peak, per-capita-VMT continued to decline in the remaining years included in the study (Garceau et al. 2015)[4].

The observed U.S. trends in car use mirror the trends documented in other developed countries (Kuhnimhof, Zumkeller, and Chlond 2013; Marsden et al. 2016). For example, a decline in automobile usage has been observed in several European countries as far back as the early 1990s, thus preceding the apparent peak in car use in the U.S. by several years. Kuhnimhof et al. (2013) compared data from the national travel surveys from the United States, France, the United Kingdom, and Germany, and examined trends in travel behavior and mode choice over approximately 20 years (with the exact years included in the analysis varying by country). They found that during the first study period (1990 to 2000) every country experienced an increase in automobile travel per capita[5]. All four countries experienced an overall decrease in automobile travel per capita during the second study period, from approximately 2000 to 2010. The majority of study regions saw an increase in multi-modality and multi-modal behavior, especially within Germany (Kuhnimhof, Zumkeller, and Chlond 2013).

Estimating future trends in passenger travel over extended periods of time is not easy, due to the large number of uncertainties that are involved. For example, in May 2015, the Federal Highway Administration (FHWA) estimated that growth in total VMT by all vehicle types is anticipated to grow, on average, 1.04% annually between 2013 and 2033. Growth in total VMT is expected to slow to only about 0.2% annually during the ensuing decade (2033-2043), reducing the average annual growth rate over the entire 30-year forecast period (2013-2043) to 0.76%.[6] Such travel volumes would represent a significant slowdown from the growth in total VMT observed over the past 30 years, which averaged 2.08% annually (FHWA 2015b).

The large number of uncertainties associated with these trends make similar long-term estimates rather unreliable. For example, the impacts of technological developments that will be deployed over the next 30 years (some of which cannot even be conceived today) are very difficult to predict. Accordingly, in this document we do not attempt to provide future estimates for passenger (or car) travel. Instead, we focus on a systematic discussion of the (often counteracting) impacts that various factors have on passenger travel, based on a review of empirical findings available from the scientific literature. The future patterns of passenger travel will depend on which of these factors, or combination of factors, will prevail during future years.

[4] As national trends have shown an upswing in the amount of total VMT and per-capita VMT after 2011, it is possible that the state-level trends may have changed in that direction as well.

[5] The increase in automobile travel per capita was attributed to an overall increase in general travel in the United States and France, and mainly to an increase in automobile availability in the United Kingdom and Germany.

[6] The forecast was produced using economic data and gas prices, and uncertainty in those two factors causes the forecast of growth in total VMT to range from 0.58% to 0.86% per year over the 30 year horizon (FHWA, 2015b).

A Framework for Understanding Passenger Travel Demand

Overall patterns of passenger travel reflect countless decisions made by individuals and households. These decisions include daily decisions about where, when, how, and whether or not to make a trip from home. These short-term decisions are conditioned on longer term decisions such as whether or not to own a car or acquire a driver's license, as well as even longer-term decisions about where to live and work, and choices about lifestyles, such as getting married and having children (or, more simply, participating in specific recreational activities). Changes in these longer term choices can and often do drive changes in daily travel choices that, if widespread and tending towards one direction or another, can lead to changes in overall patterns of travel.

Understanding how individuals and households make choices is thus an important foundation for understanding how larger societal trends may affect overall patterns of travel. The underlying processes by which individuals and households make choices are the causal mechanisms by which societal trends lead to changes in travel patterns. Although many different theoretical frameworks have been used to explain the travel choice process, a commonly used framework, drawn from economics, suggests that choices depend on three elements:

1. The *set of choices* available to the individual or household: for example, the set of possible travel modes, such as driving, taking the bus, or walking, or the set of possible neighborhoods where one might choose to live.
2. The *qualities of the choices* available: for example, for travel modes, their respective cost, travel time, convenience, comfort, safety, and enjoyment.
3. The *relative importance* one puts on each quality: for example, one individual may consider safety more important than cost, while another prioritizes travel time over all other qualities.

The effects of the first two elements are filtered by individual knowledge and perceptions. Taking the bus might be a realistic option for an individual, but if he does not know that the option exists, he will not consider it as an available choice. The bus might be just as fast as driving, but if an individual perceives the bus to be slower, she will give less consideration to this option.

In addition, it is important to note that the choice process takes place within the context of the *needs and constraints* of individuals and households. The need to be in a particular place (e.g. the office) at a particular time (e.g. by 9 am) may limit the choices available and influence the importance of different qualities of the choices. Income significantly limits longer term choices such as where to live and whether to own a car, which then determine what choices are available for daily travel. On a more daily basis, income limits the choices that are available to an individual (e.g. using a taxi, or driving to and parking in the central part of the city, might be too expensive) and it influences the relative importance of the qualities of the available choices. This framework suggests a vast array of factors that could lead to changes in travel choices and thus explain aggregate trends in travel patterns (see examples in Table 1).

Table 1: Examples of Factors Potentially Influencing Travel Choices, by Time Frame of Choice and Element of the Choice Process

	Choices available	**Qualities of choices available**	**Importance of qualities**
Short-term choices e.g. mode choice	Ride-sharing services	Improved transit service	Personal preferences
Medium-term choices e.g. auto ownership	Car-sharing services	Tax incentives for electric vehicles	Job security
Long-term choices e.g. residential location	Mixed-use developments	Streetscape projects	Having children

In the remainder of this report, we use this framework to consider key societal trends that may be influencing overall travel patterns. These factors may influence individual travel choices by influencing one or more of the cells in this matrix, by influencing knowledge and perceptions of the choices available and their qualities, or by changing the context of needs and constraints within which these choices are made. We review the evidence for the following trends, which are acknowledged as the most important in affecting passenger travel in the scientific literature:

- Economic growth
- Gas price
- Urban form
- Socio-demographic patterns
- Information communication technology
- Shared mobility services
- Connected and autonomous vehicles

America is changing. The decline in the growth rate of car travel in the U.S. observed during the past few years, apart from some temporary effects associated with economic cycles and other short-term factors, certainly mirrors several recent modifications happening in society. Each group of factors discussed in this white paper might be responsible, in part, for these changes, with a complex combination of partial effects and covariates associated with the concurrent influence of multiple factors (which makes the estimation of the impact of each factor, in isolation, difficult in many studies).

A number of factors contribute, in the short-term as well as in the long-term, to affecting several components of the individual's travel decision processes. The resurgence of downtowns and more central areas of cities, and the increased mix of land uses in many neighborhoods, for example, increase the availability of choices for travelers, including the use of travel modes other than cars, e.g. walking and biking, for short-distance trips. In the medium-term, they may impact the decisions on whether to own a car/vary the level of vehicle ownership in a household. In addition, changes in personal lifestyles, trends in household formation and composition, and potential substitution of physical trips with electronic substitutes may also affect travel demand: in particular, the way individuals evaluate travel options is affected by their personal attitudes and preferences. Recent trends reportedly show an increased preference towards urban lifestyles at least among specific segments of the population (e.g. urban populations of young adults, or "millennials"). This can be responsible for part of the observed changes in travel choices. Similarly, electronic alternatives expand the ability of individuals to interact, work and shop also remotely, and potentially substitute physical trips with non-travel alternatives (such as *telecommuting*, *teleconferencing* and *e-shopping*). This effect, while increasing the set of available choices for an individual, frees additional time (and resources), which in turn can be reinvested in other activities (which might also include more travel, e.g. causing an increased in discretionary travel). The availability of new *shared mobility* options, such as car-sharing, bike-sharing and on-demand ride services provided by transportation network companies (TNCs) such as Uber or Lyft also has a large potential impact on the use of cars or other modes, by expanding the set of available choices, or modifying the qualities of existing alternatives (e.g. eventually making the use of public transit more attractive, by providing convenient access to/from transit stations). However, new mobility options are a recent phenomenon, and most of their impacts on travel demand and mode choice will manifest in future years.

The following sections discuss the role of the major groups of factors that, according to the literature, are found to affect passenger travel. For each group of factors, we discuss the main drivers of the expected impact on travel demand, as well as the way these factors are affecting individuals' choices related to passenger travel.

Economic Growth

- **Drivers:** income growth only for higher income groups; economic growth in the financial and service sectors; reduced impact of several covariates of economic development
- **Impact on travel demand:** non-linear relationship with income; if current trends in income growth continue, a rather slow growth in per-capita travel is expected

Economic activity and personal income have been recognized as important drivers of passenger travel, and VMT in particular, for many years: they are closely linked to major needs and constraints affecting travel choices. Simply put, as the economy improves, more jobs become available, hence the need for increased travel. The available income also represents a major constraint to travel choices, by limiting the number of choices that are available (and/or affordable) to an individual. Income also modifies the relative importance of the qualities of travel alternatives (e.g. through its impact on travelers' willingness to pay for faster or more comfortable services).

In general, as per-capita income increases, people tend to travel more by private vehicle (Greene, Chin, and Gibson 1995; Brownstone and Golob 2009; Litman 2015; Rentziou, Gkritza, and Souleyrette 2012). The direct effect of per-capita income on per-capita VMT has been found to be positive and statistically significant over several decades (Ewing et al. 2014).

Income has an indirect effect on VMT as well, through its effect on auto ownership (i.e. increasing auto availability, and reducing the competition for the use of vehicles in a household), on the purchase of new homes (often located further away from the urban core), and through the availability of larger amounts of discretionary funds for leisure trips. According to some studies, income may also have a positive effect on the use of some types of public transportation in urban areas (such as rail), and in those circumstances have a negative effect on VMT (Ewing et al. 2014).

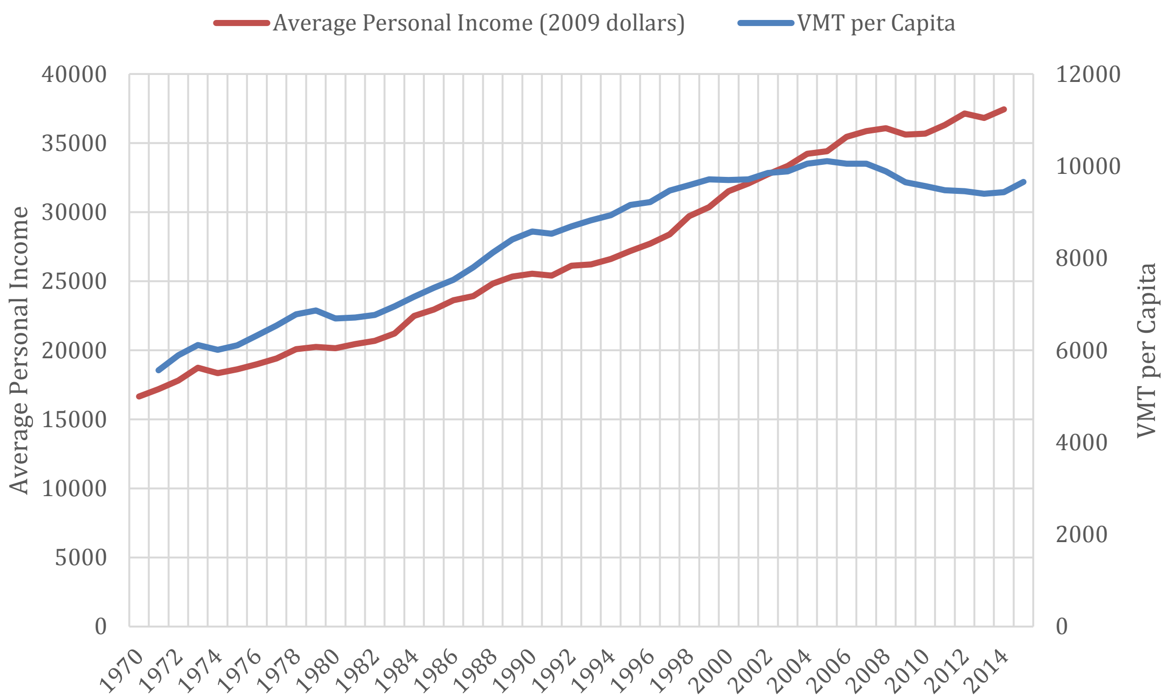

Figure 4. VMT per capita and average personal income in the U.S., 1970-2014 (Source: Created by the authors using data from the U.S. Bureau of Economic Analysis and FHWA).

Not surprisingly, VMT and economic growth appear in the aggregate to be positively correlated. The two measures have grown largely in parallel (e.g. proportionally): except during World War II, when many national resources were devoted to the war effort, the two indicators have largely followed the same path until the mid-1990s (Figure 4), when they started to diverge. Even the recent travel trends seem to show an uptick as the economy improves, after the plateau in passenger travel in the years 2005-2012.

Beginning around 1996, the two trajectories began diverging, with total VMT growing at a much lower rate than the U.S. gross domestic product (GDP). Travel demand seems to have largely *decoupled* from economic growth (Garceau et al. 2014). In the first two decades of the 21st Century, a robust increase in economic activities is not necessarily associated with an increase in passenger travel of a similar size: the growth in VMT appears to be more limited.

Several factors might be behind this trend, including the recent modifications in work organization, and the increased adoption of technological innovations, whose effects are not easy to separate. Two additional factors affecting passenger travel are worth it a mention: one relates to the *income distribution*, i.e. the tendency with which some social groups - usually, the higher income groups - benefit from the economic recovery more than others; the other one relates to the differential growth in various sectors of the economy, and their eventual different effects in terms of generated travel.

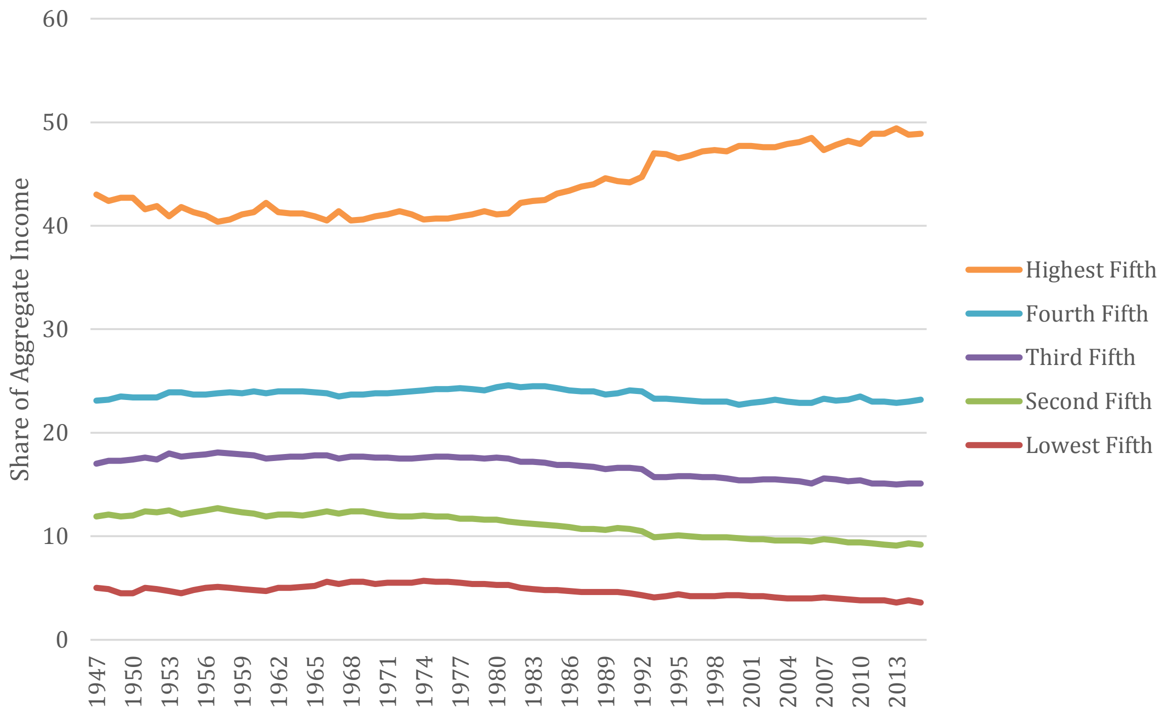

Figure 5. Percent share of aggregate U.S. income by quintile (1947-2014) (Source: Created by the authors using U.S. Census data)

Several authors have suggested that the relationship between income and VMT is not linear: VMT rises quickly at low income levels before tapering off (or even declining) at higher income levels (Holtzclaw et al. 2002; Salon et al. 2012; Bento et al. 2005; Boarnet et al. 2011). Salon et al. (2012) suggested that a quadratic relationship might explain the effect of income more appropriately. VMT rises with income only up to some level (with a threshold level identified at $170,000 to $179,000 in that study). Non-linear patterns were also identified by Boarnet et al. (2011), who found that VMT rises in lower income brackets (until households earn $50,000 a year, roughly the median income of their study area), then stagnates until households earn more than $150,000, at which point it rises again.

These findings suggest that at lower income levels, VMT increases as incomes rise, but once households have reached the area’s median income, VMT tends to level out. At the disaggregate level, this is probably due in part to the substitution of air travel for car travel. At the aggregate level, the apparent decoupling may partly reflect the same principle (marginal increases in income may generate more air travel and less car travel), as well as the broader economic climate (both air and car travel tend to decrease during an economic recession). This effect may partially explain the apparent decoupling of income and VMT during recent years, due to the increasing wage gap observed in the U.S. economy. While the economy has been recently increasing, according to US Census data, the income share for the top quintile has reached approximately 50% of the total income in the U.S. (see Figure 5). The real income growth for the bottom three quintiles has remained relatively stagnant (with an average annual growth rate of 0.09% for the bottom quintile since 1980), while the income of the top quintile has grown robustly during the same years. Median income declined 7% from 2000 to 2010 in the US, after adjusting for inflation (DeNavas-Walt and Proctor 2014). In addition, income distribution has impacted certain segments of the population in a different way. For example, the recent economic slowdown has impacted younger generations (e.g. *millennials*) disproportionately more than older cohorts, through higher unemployment rates and stronger reductions in available income. The effects of such impacts are expected to have longer-term consequences, as members of this generation are often found to continue to have weaker economic conditions, even after they (re)-gain employment.

The decoupling of economic growth and transportation demand may also be influenced by the differential growth experienced in various economic sectors of the U.S. economy: during the past 50 years, the share of total U.S. GDP associated with the goods-producing industries has fallen by roughly half. During the same years, advances in information and communication technology (ICT) and increased globalization of economic processes have accelerated the shift within the U.S. economy towards the service industries. These shifts might have contributed to dampening passenger travel and VMT, as well as to modifying freight transportation patterns. The relationships between the growth of the economy by various industry sectors and travel patterns may be rather difficult to fully disentangle, though, as they are the product of multiple effects often working in counteracting directions. For example, the overall effect of technological innovation has been generally cited as one of the factors contributing to a growth in overall travel. At the same time, the impacts of economic growth on total employment vary by sector, and so does the spatial distribution of workers in different industry sectors.[7] These effects may partially explain the decreased elasticity of VMT with respect to U.S. economic activity (and GDP) during recent years.

The changes in economic activity and the recent crisis are often cited as the cause of a large portion of the decline in car travel registered in several countries (Bastian and Börjesson 2015). As the economy continues to improve, there are reasons to believe that future trends in car travel will not follow trends in economic activity, at least not to the same degree that has contributed to pushing car travel growth in the past. In the U.S. as well as in other developed countries, this might be due to a number of factors, including the saturation of the driving forces behind past travel growth, the cooling off of some concurrent effects, and some shifts to non-car modes of transportation (Metz 2012; Millard-Ball and Schipper 2011).

[7] White collar workers (and, more generally, the workers of the service industry) often live farther away from work, and commute longer distances, than blue collars. However, they can also rely more easily on solutions for telecommuting, which are generally less available to workers employed in goods-production and manufacturing.

Put in other words, economic factors will probably continue to play a role in the generation of travel, but this effect will be downsized by the current modifications in certain conditions. Overall, when economic factors operate in the same direction as the impacts of demographics and other trends on travel, as it has been the case for most of the 20th Century in the United States, the effects of economic activity on travel are amplified. Now, with a recovering economy, the economic effects may be operating somewhat *against* the impact of the dominant demographic trends, with the effects of these factors on VMT largely canceling out. For example, on a state level, several states even exhibited a negative correlation between GDP per capita and VMT per capita, especially those that were the first states to reach peak VMT per capita (Garceau, Atkinson-Palombo, and Garrick 2014). Rather than a relation of causality among these variables, the apparent decoupling of VMT per capita from GDP per capita in these states may be a sign of the prevalence of non-economic factors, e.g. changes in sociodemographics and urban form, over economic factors, with the first group of factors causing a reduction in VMT per capita *also* at times in which the economy grew.[8]

Forecasting the future relationships between economic activity and travel demand is not easy, and it depends on a number of additional covariates. According to most forecasts, economic activity in the United States is expected to continue to grow as the economy continues to recover after the recent recession. This will contribute to an increase in passenger travel but with a slower pace than what was observed in previous decades. In addition, without major modifications in the composition of the economy and in the political agenda, the median income will probably remain stagnant over the next few years: especially if the income gap continues to widen, it is reasonable to expect that future VMT will grow at a much lower rate than economic growth.

Gas Price

- **Drivers:** historically travel demand considered inelastic with respect to gas price; larger impacts in times of larger fluctuations in prices
- **Impact on travel demand:** modest effect on VMT and mode choice (in the short term); impact on vehicle ownership and vehicle choice (in the medium term)

Gas price is a well-established driver of VMT, and its relationship with travel demand has been studied extensively in previous years. Most studies that investigate the impact of gas prices on travel behavior report the elasticity of VMT (and/or gasoline consumption) with respect to gas price as the ratio of the observed percentage change in VMT (and/or gasoline consumption) to the corresponding percentage change observed in gas price. For many years, the elasticity of VMT with respect to gas price has been considered rather low, or inelastic, and an increase in the fuel cost was not believed to determine a sizable change in the amount of travel (Noland 2000). Recent literature has found that the reality is more complex, and the magnitude of the

[8] VMT (and more generally total car travel) has been also suggested as a driver of GDP, though the underlying relationships are complex, non-linear, and may differ over time (Ecola & Wachs 2012).

impact of gasoline price on VMT varies with the timeframe that is considered. In fact, changes (increases, in particular) in gas prices can affect VMT in several ways. In the short run, travelers can adapt their driving style to improve fuel efficiency (e.g. eco-driving), reduce their VMT by making fewer trips or switching to other modes, or rely more heavily on a more efficient vehicle if the household has more than one. In the medium and long run, travelers have more options: they can buy a more efficient car, switch to an alternative fuel, or even change household location to optimize housing vs. travel expenditures.

Short-run fluctuations in gas prices may lead to temporary changes in driving behavior, whereas long-run changes in gas prices have lasting effects on VMT (and even larger effects on gasoline consumption, due to the additional impact of vehicle fuel efficiency). Furthermore, recent research shows that higher effects might be observed when gas prices exceed certain thresholds (Knittel 2012). Various studies have estimated the short-term elasticity of VMT with respect to gas prices, which is usually find to have modest values, in the range from -0.02 (Small and Van Dender 2007; Lin and Prince 2013) to -0.17 (Brand 2009). Hughes et al. (2008) found that the one-month elasticity in the 1970s was roughly -0.3, while it was -0.07 in the 2000s. However, others indicate that the elasticity has increased in recent years. Brand (2009) estimates a short run elasticity of -0.12 to -0.17 in the U.S. from 2007-2008, compared to -0.05 from 1966-2001 (Small and Van Dender 2007) or -0.03 from 1966-2004 (Hymel, Small, and Van Dender 2010).

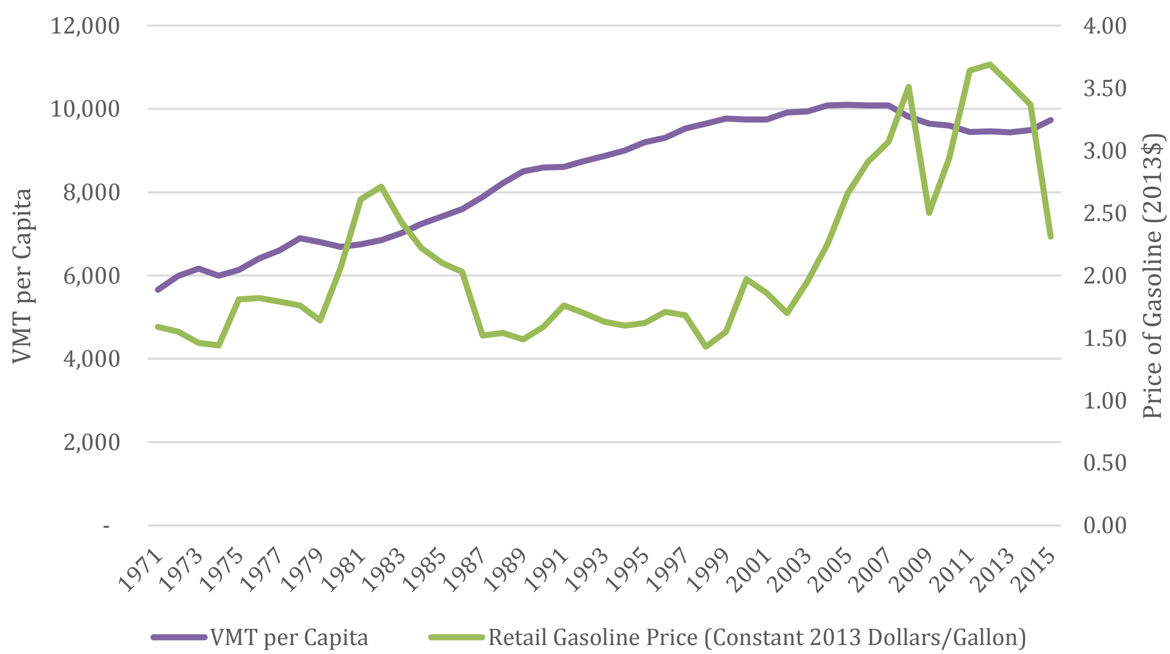

Figure 6: Real price of gas (in 2013 $) and VMT per capita (Source: Created by the authors using data from the EIA Annual Energy Outlook 2015)

Long-term elasticity is more difficult to quantify, though it is typically higher than in the short term, due to the increased ability of individuals to adjust their behavior in response to changes in gas price. Small and Van Dender (2007) estimate a long-term elasticity of vehicle miles travelled with respect to gas price of -0.11 from 1997 to 2001 and -0.22 across their entire sample from 1966 to 2001. Lin and Prince (2013) estimate -0.26 to -0.29 from 2001-2006 and Brand (2009) estimates -0.21 to -0.3 from 2007-2008. Price volatility plays a role in elasticity: demand is usually less elastic when price volatility is high (Lin and Prince 2013).

Though it may not reduce VMT and the use of cars to a great extent, fuel price has a potential effect on consumer vehicle choice (Gallagher and Muehlegger 2011; van Bree, Verbong, and Kramer 2010). For example, more fuel efficient vehicles were sold during the years of high gas prices, while during 2014 and 2015, when gas prices were again relatively low, the ratio of trucks/cars sold in the United States has increased again. According to the 2015 Energy Information Agency's (EIA) Annual Energy Outlook (AEO), gasoline prices are expected to increase only at an estimated average rate of 0.4% per year in real dollars (adjusted for inflation) from 2013 – 2040. The slower growth in the demand for oil, paired with the increased U.S. domestic production and increased availability of alternative energy sources, gives reason to believe that new peaks in gasoline prices are not expected in the short or medium term. This relatively flat (compared to the average annual increase of 2.1% during 1984-2011) increase in gas prices could mean rather negligible effects on VMT. Further, the increased fuel efficiency of modern vehicles, and the Corporate Average Fuel Economy (CAFE) standards, which are quickly reshaping the characteristics of the U.S. vehicle fleet drastically reducing fuel consumption of passenger vehicles, are expected to further weaken the relationship between gas price and VMT (Anas and Hiramatsu 2012). Still, foreign politics, unexpected internationally crises, and/or other factors may impact gas prices in unknown ways.

Urban Form

- **Drivers:** increase in population in denser areas; access to alternative travel modes; mixed land use and transit oriented development; policies for smart growth (e.g. Sustainable Community Strategies in California); self-selection of residents
- **Impact on travel demand:** urban residents travel less by car; increased availability of public transportation and walk/cycle options (*short term*); lower auto ownership rates (*medium term*); current trends point to a (moderate) decrease in per-capita travel

Various studies have attempted to quantify the effect of land use on transportation, particularly with respect to the effect of *density* and mixed land use on VMT. Most studies agree that higher urban density and mixed land use are associated with lower regional VMT, because of the reduced average trip distances and the higher proportion of trips made by travel means alternative to the use of cars, in particular walking or bicycling. Specifically, high accessibility, and by extension balanced, mixed-use growth, reduces total travel time and distance (Cervero and Duncan 2006), while housing-job proximity decreases commute time and regional VMT (Sarzynski et al. 2006). The impact of several different land use characteristics has been investigated in the literature, including density, diversity, design, destination accessibility and distance to transit (Ewing and Cervero 2010; Cervero and Kockelman 1997). Readers can refer to review studies as the one from Ewing and Cervero (2010) for a detailed discussion of the scientific findings on the relationships between travel and the built environment. The impact of the various characteristics of land use on travel behavior has often been studied independently. However, many authors have also highlighted how many of these characteristics are often correlated, e.g. higher density neighborhoods usually are also more diverse, have a better job-housing mix, and are served by better transit service, and particular combinations of land use characteristics may generate much larger *synergistic* effects on travel pattern than what would be explained by each factor alone (Ewing and Cervero 2010; Bento et al. 2005; Blumenberg et al. 2015). Further, changes in land use may generate large or small changes in travel behavior depending on the specific context, and the eventual *threshold* effects: for example, increases in density have been found to be associated with larger reductions in VMT through not linear relationship, with much larger VMT reductions observed only in very dense areas (Boarnet, 2010, Blumenberg et al., 2015).

The development of land use and transportation policies that aim to reduce the dependence on car travel and increase environmental sustainability is central to a variety of efforts to promote mixed land use development and support the use of public transportation. This is the case of policies inspired by the principles of *smart growth*, *new urbanism*, and *transit-oriented development* (Duany et al 2009; Dunphy et al. 2004; Dunphy & Porter 2006). In many regions, progressive regulations and planning policies promote changes in travel patterns as a strategy to achieve reduced GHG emissions from transportation: this is the case of the Sustainable Community Strategies (SCSs) mandated in California by the Senate Bill (SB) 375 (2008). SB 375 and the following legislation require metropolitan planning organizations in California to identify strategies that meet the transportation and housing needs of a region while ensuring an appropriate reduction in the environmental impact from transportation, and an increase in the livability of California's communities, identifying, among other things, the location of land uses, densities, areas to house future population, and the transportation network investments needed to serve these areas.

Similar policy approaches have been introduced in other regions of the country and abroad, with the stated goal of reducing the dependence on car travel and the environmental disruptions from transportation, and of improving health effects of transportation. Transit oriented developments (TODs) and other concerted efforts to provide housing near transit are becoming increasingly popular in many U.S. cities. Experimental findings indicate that TOD residents drive about 20% fewer miles annually than non-TOD residents, and rely more on walking, cycling, and public transport (Jeihani et al. 2013). Similar conclusions are found in the analysis of other measures of the land use and transportation connection: for example, a 5% increase in neighborhood walkability is associated with 6.5% fewer vehicle miles traveled (VMT) per capita (Frank et al. 2006), and a 10% reduction in average distance between homes and rail transit stations is credited, on average, to reduce VMT about 1% (Bento et al. 2003). The characteristics of the built environment also influence transportation mode choices: Salon (2006) concluded that the built environment accounted for one half to two thirds of the difference in walking levels among different neighborhoods. Differences in neighborhood type are found to affect the frequency of both utilitarian and recreational walking.

Analysis of NHTS data shows that the likelihood of a household not to own a car increases with the density of the neighborhood where the household lives: almost 29% of households living in areas with population density higher than 10,000 persons per square mile do not own a car. However, a very small percentage of the U.S. population lives in these high density areas (Santos et al. 2011), while the vast majority of the U.S. population lives in neighborhoods where the use of cars dominates, and the availability and attractiveness of other travel modes is limited.[9]

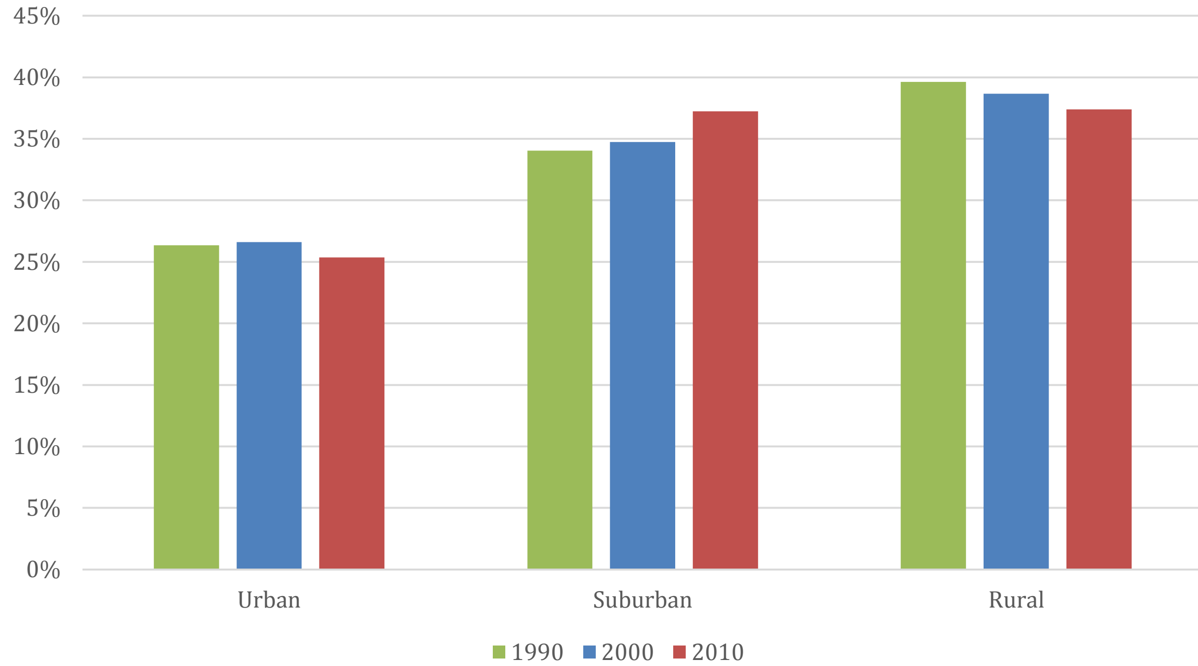

Figure 7. Distribution of U.S. population by urban, suburban and rural land use types (according to the definition of urban areas defined by the U.S. Census as the tracts with population density higher than 5,000 people per square mile; Source: Created by the authors using data from the U.S. Decennial Census)

Figure 7 shows the distribution of U.S. population by neighborhood type (aggregated by urban, suburban and rural areas) in 1900, 2000 and 2010, according to the U.S. Decennial Census data. The figure shows that despite a reduction in the amount of population living in rural areas, most of the actual growth in the U.S. population during the last few decades happened in suburban areas. This pattern of development is consistent with the results from Blumenberg et al. (2015), who estimated that in 2010 approximately 22% of the U.S. population lived in urban neighborhoods (according to the land use typologies defined in that study). Analyzing the distribution of the U.S. population at a higher level of spatial detail helps better identify differences in travel behavior.

[9] The availability of new modes, e.g. shared mobility services, might be changing these patterns: if, on one side, services such as those provided by transportation network companies (TNCs) such as Uber or Lyft may increase the convenience of using a car (even if driven by others) for many trips, new mobility services including bike-sharing or on-demand ride services might also increase the convenience and the access to public transit, e.g. providing the *last mile* access to/from public transit stations or stops (see discussion in the *shared mobility* section of this document).

Blumenberg et al. (2015) analyzed data from the last National Household Travel Survey and the most recent U.S. Decennial Census, integrated with the U.S. Environmental Protection Agency's Smart Location Database, and classified all U.S. census tracts in seven neighborhood types: *mixed use*, *old urban*, *urban residential*, *established suburb*, *patchwork suburb*, *new development*, and *rural*. They analyzed differences in travel patterns and average VMT by neighborhood type, finding (as expected) that individuals in rural areas have the highest average VMT. Most interestingly, travel patterns are relatively stable across the continuum rural-suburban-urban, with the use of cars dominating passenger travel in most neighborhood types, with the only notable exception of old urban neighborhoods. Individuals living in these dense historic urban neighborhoods have by far the lowest average VMT and the highest usage of public transportation across all land use typologies. However, according to the data from the last decennial census, these districts account for a very limited portion of the U.S. population (approximately 4%), and are clustered in very specific areas of the country, i.e. they mainly include the old districts of few U.S. major cities (Voulgaris et al. 2015; Blumenberg et al. 2015). Only in these very dense districts, which are very well served by public transportation, passenger travel seems to be heavily affected by the characteristics of the urban form. In these areas public transit and active mode use is greater than mode share for cars. In all other neighborhood types investigated, private vehicles dominate mode share, and any variation in urban density is associated with much smaller differences in VMT than in the old urban districts (Blumenberg et al. 2015).

Differences in travel patterns among residents that live in different neighborhood types may not be entirely attributable to the impact of land use and urban form. In fact, the effects of land use features on passenger travel are not homogenous across individuals, and some segments of the population (e.g. young cohort, and immigrants) seem to show larger impacts on their amount of car travel: Wang (2015) demonstrated that the elasticity of personal VMT with respect to residential density of the native-born U.S. individuals born in the 1950s is around 20% lower than for individuals born in the 1980s, and it is approximately 60% lower than foreign born respondents who have lived in the US for less than 10 years. These results highlight some important findings when analyzing impacts on passenger travel: the role of eventual *interaction effects* among variables (e.g. impact of urban form and personal background of the individual, in the findings above), which might eventually increase the impacts on travel demand when several factors act synergistically, or reduce their overall impact if one factor tends to mitigate (or cancel out) the effect of the other.

The fact that individuals that live in more compact, higher density neighborhoods travel less by car and use alternative means of transportation more often does not necessarily imply a direct relationships of causality between urban form and travel behavior. Individuals may choose to live in high density settings with varied land uses because they seek to drive less and enjoy an increased variety of travel options for their trips. If this is true, they do not adopt these travel patterns as a direct effect of the built environment, but as a consequence of their personal attitudes and preferences. The *residential self-selection* effect may significantly reduce the effects of policies designed to reduce the use of private vehicles and incentivize alternative transportation modes: if residential self-selection is in place, these policies would reduce VMT by providing living places for persons who already seek to drive less. Accordingly, if there is a shortage of such places, building higher density neighborhoods would reduce VMT to the extent that it would modify the travel patterns of the persons choosing to live in these areas. If the residential self-selection effect is not accounted for, empirical findings may overestimate the impact of the characteristics of the built environment on mobility patterns: many studies have attempted to quantify the effects of residential self-selection, highlighting how it often accounts for a large portion of the impact that could be otherwise attributed to the built environment (Cao, Mokhtarian, and Handy 2009).

Urban development in the 20th century has been strongly characterized by urban sprawl (Barrington-Leigh and Millard-Ball 2015; Bruegmann 2006). The growth of population in low density tracts, though, fell from the 1970s to the 2000s, leading to higher urban density in most regions. Most of this growth was associated with the growth of suburban areas at the expense of rural areas. The overall population in dense census tracts in metropolitan America also increased over the same time. Still, despite the growth in dense urban areas, sprawl continued to increase and the population in low density developments continued to grow at a faster rate than higher density urban tracts (Figure 7). For most individual cities, sprawl patterns were basically set in place by 1970 (Lopez 2014): despite efforts to revitalize neighborhoods and provide better alternatives for transportation, neighborhoods that were built with a low-connectivity street network tend to stay that way, even as the network expands (Barrington-Leigh and Millard-Ball 2015). Recent years have seen a resurgence of more central areas with an increase of the urban population in all major urban areas of the U.S. Census, indicating that many city centers grew faster than their suburbs between 2010 and 2012 for the first time in decades (Cohen, Hatchard, and Wilson 2015). As of 2014, the highest growth rates were again found in suburban areas, though most new development is multi-unit (Kolko 2015).

Independently from the growth rates of various neighborhood types, the division between city and suburb is blurring (Zmud et al. 2014): both suburbs and urban areas are increasingly home to residences and businesses, and this is contributing to a reduction in the average trip distances among origins and destinations. In addition, it offers more opportunities for the adoption of non-motorized means of transportation, thus expanding the set of choices available to residents and modifying the attractiveness of such choices. Most recent trends in real estate development show that there is not necessarily a clear delineation between an urban center where people work and suburbs where people live. The type of suburbs also matters: inner-ring suburbs have experienced population changes more similar to those in center cities than outer-ring suburbs (Zmud et al. 2014). Data from the 2010 Census also show that many suburbs linked to a city with public transit or well-developed roadways are benefiting from strong city growth. While these changes marginally contribute to reshaping the landscape of mobility-related decisions, most neighborhoods remain heavily reliant on cars, making the transition toward reduced VMT and increased multimodality more difficult.

Much of the effect of city growth on future VMT will certainly depend on future transportation investments and the availability of choices: both road and transit infrastructure improvements have distinct short-term and long-term impacts on VMT. In the short run, increased highway capacity releases latent demand as some travelers switch modes, routes, and times of travel (Cervero 2010). Eventually, lessening traffic might make it more attractive to travelers to switch from transit to driving. Households are assumed to choose their VMT and mode of transit so as to maximize their utility and minimize total cost of travel (Parry and Small 2007). The majority of empirical evidence, to date, suggests that the effects of induced demand are substantial, and it may be key to the future changes in passenger travel. A widely cited study by Hansen and Huang (1997) found that every 10% increase in lane miles was associated with a 9% increase in vehicle miles traveled (VMT). Handy and Boarnet (2014) summarize elasticity estimates of the short-run effect of increased highway capacity in the range of 0.3 to 0.6, with long run elasticity values from 0.6 to 1.0. Other studies have concluded that investments in road capacity increase average economic growth while simultaneously inducing additional growth in VMT (Melo, Graham, and Canavan 2012).

A similar finding is true of transit infrastructure investments and transit use, resulting in lower VMT: improvements in public transit may induce modal shifts among those travelers that have sufficient access to it. Improving the public transit system by making it faster and more convenient has a small but significant impact on mode choice (Spiller et al. 2014), but the results depend on the characteristics of the specific context. Too often, in American cities, public transportation is not a competitive option for most travelers, and it mainly serves captive users, who (because of their constraints) do not have access to other choices. Under these conditions, improvements in public transit services provide benefits to current users, but are not always able to attract behavioral changes from additional potential users, as most travelers continue to find the use of cars more convenient. For example, one study found no evidence that public transit service affects VMT (Duranton and Turner 2011). But in larger cities, where public transportation is a viable option for many trips, investments in high-quality rail services can return sizable effects on VMT: a 10% increase in a city's rail transit service reduces 40 annual vehicle-miles per capita (70 VMT including New York City), compared with just a one mile reduction from a 10% increase in bus service (Bento et al. 2003). Similar considerations may be true for investments in other transportation modes, even if the impact of investments in bicycle infrastructure has been less studied and not explicitly tied to VMT. Investments in sidewalk length has been found to decrease VMT (Fan 2007; Salon et al. 2012).

Future effects on transportation will largely depend on the difficult equilibrium between market forces (e.g. demand for housing, and market supply) and policies developed at the federal, state and local level. It is difficult to forecast future transportation investments in transit and highway infrastructure. For example, the recent infrastructure investments included in the proposed Grow America Act may provide increased stimulus to highway infrastructure, possibly contributing to an increase of total travel by car. At the same time, large investments in public transit services are occurring in several U.S. regions and cities, which may contribute to rebalancing mode share, and may have an additional calming effect on car travel. Cities that were once associated with car dependence such as Los Angeles are currently undergoing massive efforts to expand local public transportation options, while at the same time promoting investments in improved pedestrian and bicycling infrastructures, also at the expenses of the reduction of the number of car lanes. In addition to their direct impacts on mode share and

VMT, these investments may also have indirect effects on promoting the awareness and the perceived utility of non-car travel alternatives, thus changing the way individuals evaluate the available alternatives. Quantifying the effects of such impacts is often not easy, also due to the time lag between the time in which the investments and policies are deployed, and the time in which changes in travel behavior are observed.

Sociodemographic Patterns

- **Drivers:** slow population growth; smaller household size and changes in family structure; aging baby boomers; impact of immigration on population growth; urban lifestyles popular among some population segments; women saturating workforce
- **Impact on travel demand:** households without children travel less by car; first generation immigrants travel differently from U.S. born individuals; current trends point to a decrease in per-capita VMT.

Sociodemographic trends will likely have dampening effects on U.S. VMT. In a recent report for the Transportation Research Board, Zmud et al. (2014) summarize several sociodemographic trends of the past and future that impact U.S. travel demand, including: (1) slow population growth, (2) increasing aging population (over 65), (3) structural changes in population distribution by race/ethnicity, (4) changing work force makeup, (5) slow household growth. The authors predict that all but one of these trends (structural changes in population distribution) will result in lower VMT per capita.

Sociodemographic trends affect travel demand through a combination of *lifecycle, period*, and *cohort* effects. Lifecycle effects are associated with the changes and events that happen during a person's life, and that cause changes in their lifestyles and travel behavior. Period effects are associated with changes observed as the result of specific events and modified conditions occurring in a specific period (e.g. changes in work organization and social habits that modify constraints and needs, and affect individuals of all ages and stages in life during a specific period, although effects may vary among different segments of the population). Finally, cohort effects are associated with specific trends affecting individuals belonging to a specific cohort (or *generation*). The total impacts of these effects may be amplified when multiple effects are present at the same time, and they tend to reinforce each other's impact on passenger travel. For example, some lifecycle effects such as the ageing of the members of an older generation (e.g. baby boomers) who transition into retirement and begin to travel less seem to be currently reinforced by period effects pointing in the same direction (e.g. all individuals among all age groups tend to drive less due to changes in the urban form and increased accessibility by alternative modes) and/or cohort effects, as in the case of younger generations such as millennials who tend to exhibit travel patterns that differ from those of the previous cohorts.

Age and household composition may affect transportation demand and VMT through both the number of people living in a household and their ages and relationships. In particular, households with children have higher VMT than households without children. According to the 2009 NHTS, households with children averaged 30,400 VMT per year, while households without children averaged only 14,400 VMT per year (Santos et al. 2011). Census data from 2010 indicate that the number of households with children under 18 years has grown at the slowest rate over the period from 1960 to 2010, and increased by only 0.5 percent between 2000 and 2010 (Brownstone and Golob 2009). Vehicle travel tends to increase as adolescents become adults, peaks at 30-60-years when employment and childrearing responsibilities are greatest, and then declines as individuals retire and age (Le Vine and Jones 2012).

As average *household size* decreased from 4.6 people per household in 1900 to 3.3 in 1960 to a low of 2.58 in 2010, the proportion of households raising young children - about 50% in 1950 - has decreased to about 30% now and is projected to decrease to as low as 25% by 2030 (Nelson 2006). This long trend in falling household size has five main drivers: lower fecundity, aging baby boomers, longer life spans, entrance of women in the labor force (though this is unlikely to further affect future household size due to saturation of this effect), and rising incomes (Zmud et al. 2014). Figure 8 summarizes the overall changes in household composition of U.S. households between 1940 and 2010, according to U.S. Census data.

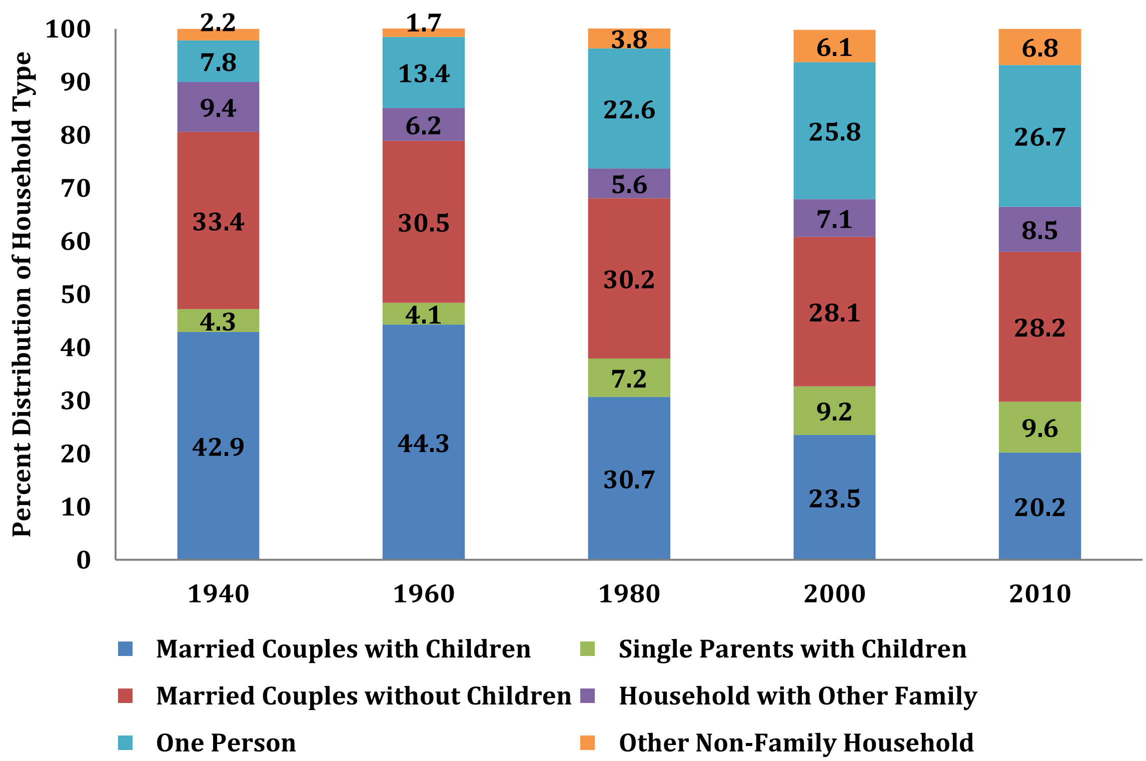

Figure 8. Distribution of U.S. households by type (1940-2010) (Source: Created by the authors using U.S. Decennial Census data)

The demographics of America is expected to change substantially in the future. According to the U.S. Census Bureau, the U.S. population is anticipated to increase to 438 million by 2050, which constitutes more than a 40% increase from the 2008 population of 304 million. A significant percentage of the projected increase is due to immigration, meaning that the population will be more ethnically diverse. New immigrants tend to have different travel patterns inherited from previous habits: individuals that recently immigrated often continue to have travel patterns similar to those they used to have in their country of origin. Immigrants tend to assimilate into the society over time, and the behavior of second-generation immigrants tend to differ from that of their parents, converging towards the general trends in the population.

U.S.-born Hispanics also tend to have more vehicles per household and own newer vehicles compared with foreign-born Hispanics (Liu and Painter 2012). Overall, as Hispanics become a larger portion of the total U.S. population and if current trends among Hispanic households continue, they are expected to contribute to increasing public transit use and aging of the vehicle fleet, at least until the groups of immigrants integrate more into the U.S. society.

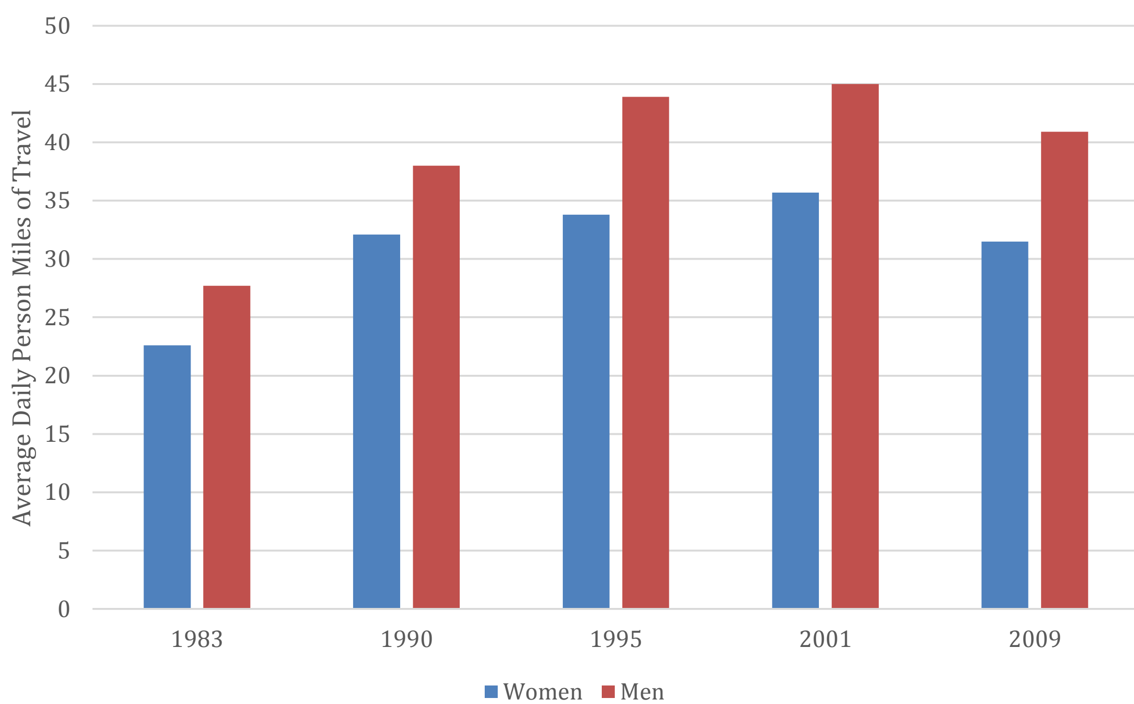

Figure 9 Average daily person miles of travel, by gender (Source: Created by the authors using NHTS data)

The *aging* (or *greying*) of the U.S. population is another important factor affecting passenger travel: according to current demographic patterns, the U.S. population will be significant older in 2050. About 20% of the population will be 65 years or older by 2050, compared to only 12.6% currently. Furthermore, only 25% of households will be raising young children by 2030, as opposed to roughly 30% in 2005 (Nelson 2006), contributing to reshaping future trip patterns, and reducing the impact of the presence of children in the household on trip generation and trip chaining: members of the households with children usually make more trips, and are more likely to use a car for these trips.

Additional effects relate to other sociodemographic features of the population, including *gender*. Historically, men and women have demonstrated different travel patterns. Women tended to make shorter work trips, make greater use of public transit, make more trips for the purpose of serving another person's travel needs (e.g. escorting children or other family members), and drive fewer miles per year than men (Gordon, Kumar, and Richardson 1989). However, women's increasing participation in the labor force in addition to familial obligations has resulted in an increase in their VMT (Sivak 2015). Transportation planners and policy-makers expect women's VMT to further increase in the future (Sloboda and Yao 2005), and the gender gap to gradually diminish, although women's VMT may have plateaued: Figures 9 and 10 represent the trends in the average number of daily trips and VMT by gender, with the reductions in 2009 that can be in part attributed to the impact of the economic recession. Overall, the difference in car use between men and women is declining (or, at least, it seems to have stabilized), and the gender gap is expected to have less of a role as an engine for future VMT growth.

Figure 10. Average daily person trips, by gender (Source: Created by the authors using NHTS data)

Generational changes are also observed in the lifestyles and dynamics associated with the travel behavior of different cohorts. Figure 11 summarizes the differences in average VMT among the members of different age groups in the last four decades. The following subsections specifically discuss the travel patterns of the four main generational groups: *baby boomers*, *Generation X*, *Generation Y* (also known as "*millennials*") and *Generation Z*.

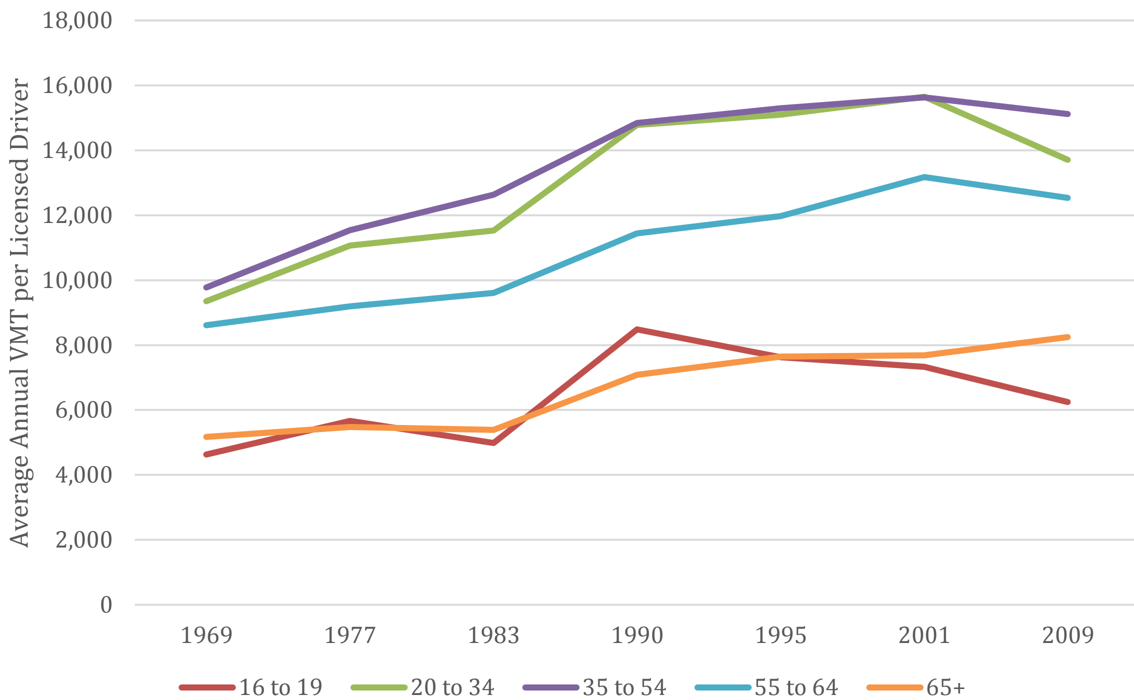

Figure 11. Average annual miles per licensed driver by age group (Source: Created by the authors using FHWA data)

Baby Boomers

- **Drivers:** baby boomers transitioning into retirement; higher income generation; increased discretionary funds for leisure trips; lower need for residential space
- **Impact on travel demand:** fewer commuting trips; potential replacements of short-distance trips with infrequent long-distance trips; unlikely to leave suburbs as they age

Baby boomers, individuals born between 1946 and 1964, represent a major wave of aging adults. In 2010, 13% of the population were aged 65 and over in the United States, but by 2030, all of the baby boomers will be aged over 65, pushing the United States' share of 65+ to 19% of the population (Vincent and Velkoff 2010). The baby boomer generation has driven many trends in travel over the past 40 years, both in the number of travelers and in the amount of travel per person. Still, nowadays, baby boomers are a very influential group in terms of car purchasing behavior, as an effect of both the total volumes of purchases and the relatively high price of the vehicles purchased by the members of this cohort. Those in the baby boomer age cohort have traditionally traveled more than their counterparts from other generations at the same stages in life. Baby boomer seniors tend to drive more than seniors of previous generations, and this is particularly true for women, given the large gender gap in driver licensing and car travel that characterized the previous *silent* generation. As part of their life cycle, baby boomers now drive less than during their peak driving years, when they were employed and raising children. They are also found to use public transit more often (Litman 2015).

As trends in society and the economy continuously change, also as an effect of the increased adoption of technology, a majority of baby boomers are expected to choose a "soft retirement" and continue to work part-time beyond retirement age. The past decade provided some evidence that baby boomers became more urban and less automobile dependent (across residential settings) and walked for a greater share of all trips in both suburban and urban settings (Lee et al. 2014). However, massive relocation of non-urban boomers to urban areas remains to be seen. An American Association of Retired Persons analysis of 2010 Census data showed that 9 of 10 older adults nationally were living in the same communities where they raised their children (Farber et al. 2011). Suburban baby boomers may express concerns regarding their current neighborhoods becoming unsuitable for them as they age, but they are unlikely to move away in large numbers from the privacy, amenity, and their existing social networks that suburbia provides (Lee et al. 2014). While reducing the need for commuting trips, the transition into retirement of the members of this generation, the relatively high available income and the increased life expectancy all concur to increase the potential for discretionary trips. This represents a growing market for the tourism industry and a topic that deserves attention in long-distance travel research (which is not discussed in details in this document).

Generation X

- **Drivers:** Active workers with children; higher adoption of telecommuting and e-commerce
- **Impact on travel demand:** increased multimodality; probable decrease in future VMT as an effect of lifecycle effects

Generation X includes those individuals that were born from 1965 to 1980 (35 to 50 years old as of 2015). This cohort is relatively small, being an "echo" of the Depression era generation. This group is less well studied than the following generation (millennials), as is often described as a generation of transition between the bolder characteristics of baby boomers and millennials. Research findings suggest that members of Generation X drive less than their parents at the same age (Kamga 2015). Part of the different behaviors observed among the members of the Generation X is associated with the drop in travel caused by the recent recession (McDonald 2015). In 2009, 31-42 year olds drove 33-35.6 daily auto miles per day, as opposed to 38.5-39.2 auto miles per day driven by the same age group in 1995. Generation Xers make fewer automobile trips than the same age group did in 1995, and make more biking and walking trips than the previous generation (McDonald 2015).

This reduction in driving is likely to be related to a number of factors, one of which may be the adoption of information and communication technologies (ICTs) by Generation X (Mans et al. 2012). Generation X is the first generation that has widely adopted telecommuting as potential trip replacement[10] (Mans et al. 2012). This generation is also more likely to shop online – the Pew Research Center found that 80% of Generation X Internet users engage in e-commerce compared to 71% of Millennial Internet users and 38% of online teens. These

[10] The overall impact of telecommuting on VMT is unclear, though, and most evidence seems to indicate that it does not lead to a *net* reduction in VMT. This topic is better discussed in the section on the *impact of technology*.

behaviors are generally found to decrease VMT (Mans et al. 2012; Choo, Mokhtarian, and Salomon 2005). In contrast to the members of Generation Y, as of 2009, Generation X has formed households and is in the mid phase of their careers; roughly 70-72 percent of Generation X were a parent (McDonald 2015). Typically, having children in the household contributes to increasing VMT (Le Vine and Jones 2012), but this effect tends to disappear as part of one's lifecycle leading to potential reduction in VMT per capita for the members of this generation in future years.

Generation Y

- **Drivers:** delay in childbearing and other life events; high adoption of technologies; preference for urban areas
- **Impact on travel demand:** reduced use of private cars; increased multimodality; unclear long-lasting trends of millennials travel

Generation Y (or "Millennials") includes individuals born from 1981 to 1997 (18-34 as of 2015). Millennials make up approximately 25% of the U.S. population and represent a very influential demographic group due to their stage in lifecycle, and their differences in lifestyles and in consumer and travel behavior from the previous generations. Among the observed trends, millennials tend to own fewer cars (and often do not own a car), drive less if they do own a car, and use alternative non-motorized means of transportation more often than the members of older generations (Blumenberg et al. 2012; Kuhnimhof et al. 2012; Frändberg and Vilhelmson 2011). Millennials are credited to drive less than previous cohorts at the same age for two possible reasons: their lifestyle-related demographic changes, including shifts in employment rates, delays in marriage and childbearing (Pew Research Center 2014), and shifts in attitudes and use of virtual mobility, which are believed to be more specific of their cohort (McDonald 2015). Additional period effects reinforce the differences observed between the behavior of the members of this generation and that of the members of previous generations at the same stage of life: thanks to technological development and the evolution of society, a number of additional travel (and non-travel) options have become available during recent years.

Millennials are less likely to be employed, to be married, and to have children than members of previous cohorts at similar ages (McDonald 2015). Blumenberg et al. (2012) suggest that there are very few, if any, differences between the factors that influence middle-aged adult travel and young adult travel. Economic factors seem to have a predominant influence on travel behavior for both groups (Blumenberg et al. 2012). Of note are the generational changes suggested by the quasi-cohort model: the youngest cohorts make about 4% fewer trips and they travel about 18% fewer miles than the previous generation at the same stage in their lives, though no clear motivations are identified.

Millennials more likely adopt virtual mobility options, such as online shopping, telecommuting, ride-sharing, and other real-time transportation services. The Millennial generation is characterized by, among other things, the widespread adoption of the internet, cell phones, and social networks, which have been hypothesized as "game-changers" in terms of young adult mobility (Blumenberg et al. 2012). Further, this group faces hurdles to obtain driving licenses (Raimond and Milthorpe 2010; Blumenberg et al. 2012).

Millennials are credited for being more likely than older Americans to prefer living in a big city, and they showed the strongest preference for communities with mixed uses and different types of housing (BRS 2013). 2010 Census data indicate that 20–34-year-olds who are delaying marriage form a disproportionate share of new city residents (Zmud et al. 2014). This may account for some of the decrease in VMT, as urban residents are more likely to use other modes. Younger age groups like millennials are also more likely to be multimodal than older individuals (Buehler and Hamre 2014).

Understanding the reasons behind millennials' behaviors is fundamental in order to predict future impacts of this cohort on travel demand. If the decrease in millennial driving can be explained by lifestyle-related changes, millennials may begin to drive more as they become employed, get married and have children (even if this happens at a later stage in life, compared to their parents) (Jorritsma and Berveling 2014). However, if an attitudinal shift is the cause of the decline, the decline in VMT may be more permanent. Some studies have attempted to quantify the relative prevalence of these factors: McDonald (2015) suggested that "millennials' specific factors such as changing attitudes and use of virtual mobility explain 35% to 50% of the drop in driving" of this generation. However, the NHTS data available for that study do not seem to support such results with certainty, as specific information about personal attitudes is not available, and the effect of these factors are largely inferred in an indirect way. Further, despite the trends observed among millennials who reside in large cities throughout the country, there is evidence that large masses of millennials continue to live in suburban settings, and exhibit more traditional behaviors. Accordingly, further research is needed to assess how millennials will travel in the future, and the relative permanence of their preferences if and when they form households and engage in more stable employment after the recent economic downturn (Circella et al. 2015).

Generation Z

- **Drivers:** young teenagers getting into driving age; delay in driver's licensing; high-use of technologies and social media
- **Impact on travel demand:** Generation Z has more options than previous generations; uncertain effects on travel demand

Generation Z (also *Post-Millennials* or *Pluralists*) are the cohort born after the millennial generation. This includes individuals born from either the late 1990s or early 2000s to today. There are approximately 60 million members of this generation as of 2015, outnumbering the millennials by about one million. Little is known about this generation, which was mainly born and raised in the new millennium. The oldest members of this generation are currently reaching driving age, and they will enter the workforce soon.

Generation Z is the first generation born after the invention of the internet (they are "digital natives"), and they are expected to be very open to, and used to, the adoption of a wide range of technologies. These represent the environment in which they have been raised and with which they familiarized in the early stages of life. There is reason to believe that several trends of the millennial generation will extend also among the members of the Generation Z, including many consolidated trends of society, including the modified household structures, and tendency to delay important life events (e.g. marriage, childbearing). Generation Z is more ethnically and culturally diverse than the previous generations, and its members reasonably have more diverse groups of friends.

It is currently too early to advance speculations about the potential travel behavior patterns of the members of this generation. However, it is not unreasonable to assume that the behavior of at least the older members of this cohort will largely resemble that of younger millennials. Other speculations suggest, instead, that the members of this generation, who were largely born and raised at a time of economic crisis, and international, cultural and social tensions, will more likely resemble the characteristics of another generation that was raised at a time of financial hardship and social crisis, the *silent* generation.

Adoption of Technology

- **Drivers:** increase in ICT usage; wider adoption of telecommuting and e-commerce; proliferation of smartphone apps and social media
- **Impact on travel demand:** unclear impact of many technologies; increased alternatives for mode choice; probable slight increase in per-capita VMT

For many years, information communication technology (ICT) has been seen as a trip replacement strategy and thus a solution for many societal problems, including urban congestion, dependence on non-renewable energy sources, air pollution, and greenhouse gas emissions, as well as rural underdevelopment, reduced economic opportunity for the mobility-limited, and the struggle to balance job and family responsibilities. Certainly, technological solutions such as telecommuting can function as a substitute for commute trips (Zhu 2012) and can replace *some* travel, but at the same time they can generate additional travel as well. Mokhtarian (2009) discusses a number of reasons for which ICTs can respectively have no relevant effect on travel (*neutrality*), generate new travel (*complementarity*), alter travel that would have occurred anyway (*modification*), or reduce travel (*substitution*) (Salomon and Mokhtarian 2008). The rapid increase in the use of technological solutions, and communication devices and services in particular, means that increased opportunity to work, study, access news and information, and communicate with others are nowadays accessible to a vast majority of the U.S. population. Figure 12 shows the increase in the availability of a variety of communication devices in U.S. households (with a notable drop in the use of landline phones, which were largely replaced by the use of mobile phones in many households).

Most findings, to date, show that high frequency of internet use and mobile phone use are both positively correlated with VMT, suggesting a complementary effect between e.g. mobile phone and internet usage and travel, rather than a substitution effect (Zhang, Clifton, and Shen 2007). At least early studies in this field show that the individuals that engage more often in ICT and online activities are also more likely to travel more by car, but more research is needed in this field to better understand the direct relationships between these variables (e.g. the eventual causality of ICT use on car travel) vs. the effect of other factors (e.g. indirect effects of socioeconomic status, lifestyles, or personal attitudes, which affect both ICT use and travel) (Circella & Mokhtarian, *forthcoming*). In the remainder of this section, we discuss the impacts on travel demand of three main groups of technological solutions associated respectively with the adoption of *telecommuting*, *e-commerce*, and *online social media*.

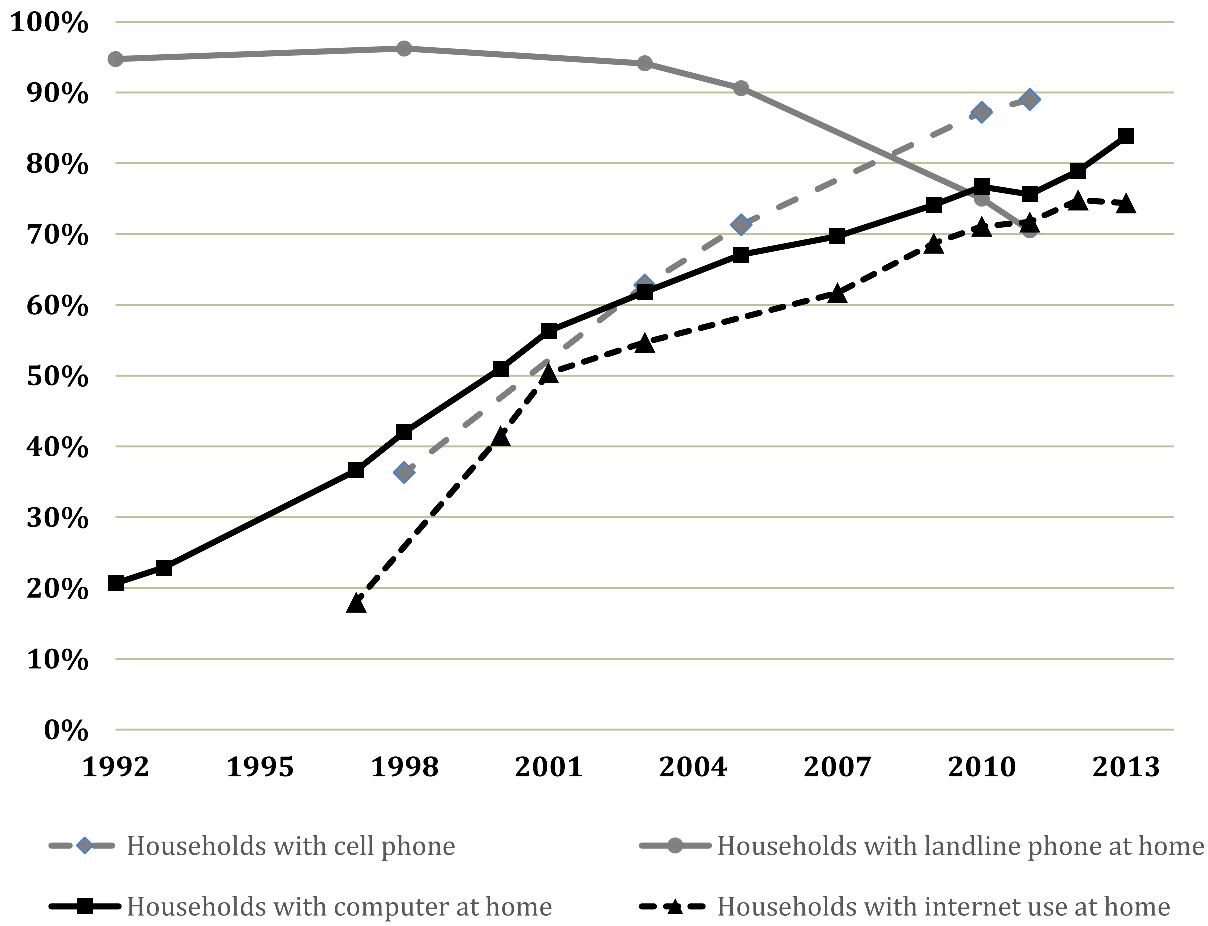

Figure 12. Percentage of U.S. households using various types of technologies at home: 1990 to 2013 (Source: Modified from Circella and Mokhtarian, *forthcoming*. Data from the U.S. Census Bureau)

Many early studies found a positive correlation between *telecommuting* and travel. However, more recent studies have found that telecommuting tends to either reduce or modify the nature of work-related travel (Mans et al. 2012). Choo et al. (2005) found that, from 1988 to 1998, all telecommuters in the United States reduced annual national VMT approximately 0.8%. Telecommuting may decrease individual VMT, but there are questions about the number of individuals that will opt in, the type of travel that is most affected by the adoption of telecommuting, and the eventual saturation point. The number of individuals working from home as the usual "means of transportation to work" has grown from 3.3% in 2000 to 4.3% in 2009-2013 in the U.S. according to the data from the U.S. Census and the American Community Survey. A 2009 study found that the number of Americans working at least 1 day a month from home or remotely increased by 74%, from about 9.9 million in 2005 to 17.2 million in 2008 (Dieringer Research Group 2009). The growth in telecommuting between 2006 and 2008 appears to have been driven mainly by the younger population, with the median age of telecommuters decreasing from 40 to 38 years old (Mans et al. 2012). The age of telecommuting workers is important in considering the permanence of the trend. About 80% of the roughly 80 million baby boomers will retire over the next decade. A poll of millennial workers found that 14% listed the ability to work from home as one of the top three actions an employer could take to retain them (Deloitte 2009). Similarly, a further increase in the adoption of telecommuting is expected in future years. Accordingly, more research is needed to better understand the impact of such trends on total travel demand and mode choice among the entire population, and among specific subgroups in particular. For example, a reduction in the number of commute trips might generate other kind of travel as the commuting trips that are eliminated by telecommuting free up time for making more non-commuting trips, which might be made more easily by car instead of transit, and therefore use more energy than the commuting trips they replace (Circella and Mokhtarian, *forthcoming*). Additional impacts relate to the trip distances and the time of the day when these trips are made.

Online shopping has also dramatically increased in the past ten years, but the impact of increased online shopping on travel behavior remains ambiguous. Similarly to what is said for ICT in general, e-shopping can also generate a number of partial impacts, including effects of substitution (replacing trips to a store with e-shopping), complementarity (generating additional trips to stores, e.g., to touch, try, and/or buy items seen online), modification (adjusting the patterns of pre-existing trips), and neutrality (no significant impact) (Mokhtarian 2004; Weltevreden 2007). Most studies on the topic have found mixed results: in some cases, making online purchases replaced a shopping trip, and in other cases, e-commerce resulted in new shopping trips, possibly due to product information obtained online (Wilson, Krizek, and Handy 2015). Certainly, the delivery of merchandise purchased online may increase the total travel associated with freight distribution.[11] The larger adoption of e-shopping may also have relevant effects on reshaping retail organization and thus impact the urban form, with the disappearance of some types of shops more directly affected by the competition of online shopping, and the transformation of other retail stores into entertainment center that are less subject to online competition (Circella and Mokhtarian, *forthcoming*). The future effects of e-shopping on passenger transportation demand will also depend on the online shopping behavior of specific groups, e.g. younger generations. Several studies have found that younger generations are more likely to shop online, as a result of their comfort with technology (Sulaiman, Ng, and Mohezar 2008). To date, the members of Generation X still dominate online shopping by volume of sales and frequency of use: 80% of Generation X Internet users engage in e-commerce, in comparison with 71% of millennial internet users and 38% of online teens

[11] We will not further discuss the impacts of modern ICT solutions on freight transportation, as goods movements are not part of the focus of this white paper.

(Jones and Fox 2009). The impact of the latter is expected to increase strongly during the next few years: understanding the relationships between adoption of e-shopping and travel (e.g. frequency of physical trips to stores) among the members of these segment of the population, and in different geographic areas, will be fundamental to understand future impacts on car travel.

Online social media are a relatively new phenomenon, and the effects of this expansion in social networking on transportation behavior and VMT are still unclear. It is possible that the increase in online social activities results in an increase in trips for social purposes. It is equally possible that in some cases social networking replaces some types of social trips. Overall, social networking has ambiguous effects on travel (Contrino and McGuckin 2006): in some cases, online interactions might replace social interactions. Alternatively, by widening an individual's social network and increasing the ease of connecting with others, social media usage may indicate increased travel. The analysis of the 2001 National Household Travel Survey provides some preliminary evidence that Internet users may be reducing their time traveling for social and recreational reasons (Contrino and McGuckin 2006). More robust evidence is needed in this area, in particular considering the continuously changing landscape of available online services, and the evolving effects that they might have on travel.

The use of ICT devices has largely expanded in the last few years among large segments of the population. These technological solutions have offered increased options for communications, as well as for the micro-coordination of trips and access to news and information, which can increase the opportunities to travel, as well as the efficiency of transportation services and the awareness about the options available for a trip, e.g. information about the available destinations for a trip, the travel time needed to reach a specific destination, and/or the modes available for (and related characteristics of) a trip. All of these topics require more research to better understand the impact that these evolving technologies will have on mobility-related choices and passenger travel.

Shared Mobility Services

- **Drivers:** emerging technologies in transportation and shared mobility services; separation of access to vehicles from ownership
- **Impact on travel demand:** increased alternatives for mode choice; reduced importance of auto ownership; potential substitution or complementarity with other travel modes

The massive adoption of ICT combined with the continuously increasing number of smartphone applications provides a great opportunity for users to access transportation services long imagined but never deployed on a large scale. Recent innovation in the sharing economy and growth in the availability of technology-enabled transportation services provide individuals with increased choice options and flexibility in organizing the way they live, work and socialize.

Shared mobility services range from *car-sharing* services, including *fleet-based* round-trip and one-way services such as Zipcar and Car2Go or *peer-to-peer* services such as Turo (formerly known as RelayRides), to *ridesharing* services, including dynamic carpooling such as Carma and *on-demand ride services* such as Uber and Lyft, and *bike-sharing* services. Although the share of total trips made with these new shared mobility services is still rather small, the foreseeable increase in the popularity of these services is expected to bring large effects on future passenger travel. According to the Special Report 319 from the Transportation Research Board (Taylor et al. 2015), numerous social and environmental effects may derive from the adoption of these services, depending on the regulations and policies that are enacted.

The range and availability of new shared mobility services is continuous evolving, and new services and related smartphone apps are introduced almost on a daily basis.[12] Hallock and Inglis (2015) found that 19 of 70 U.S. major cities already had access to nearly all new mobility options included in the study. In addition, 35 other cities have access to most emerging transportation options (but not all), leaving only 16 cities where few technology-enabled transportation options are available.

There is no doubt about the potential revolutionary effect that new shared mobility services can have on travel behavior. The new services expand the set of choices available to travelers, and can affect key travel-related decisions and the way individuals evaluate factors such as travel cost, convenience and security (Taylor et al. 2015). The effects of emerging transportation and shared mobility services may significantly vary based on the characteristics of each type of service, the local context in which the service is provided, the characteristics of the different groups of user, and the eventual behaviors observed among different subsets of the population. New shared mobility services may expand the set of choices available to users. They may provide a valid alternative to the use of private cars, and contribute to reducing car ownership and VMT, or stimulate additional demand for trips that would have not been made if these services were not available. Under some circumstances, they can boost transit ridership by better serving the first and last miles, improving the experience of riding transit services (Hallock and Inglis 2015; Shaheen et al. 2015a; Taylor et al. 2015), or providing the availability of a ride home outside the hours of operation of public transit or at a time in which traveling by transit and/or walking to/from the transit stops may be considered unsafe (Circella et al. 2015).

The adoption of new shared mobility services may vary significantly among members of different segments of the population. Not surprisingly, millennials are reported as the most frequent users of these emerging transportation options. For example, according to a 2013 study commissioned by Zipcar, millennials are more willing than older peers to use technology-enabled transportation options (Zipcar 2013). In a recent statewide study in California, Circella et al. (2015) found that millennials were consistently more likely to report higher awareness, adoption and frequency of use of all shared mobility services (including fleet-based car-sharing,

[12] In addition, some shared mobility companies also disappear rather quickly: at the end of 2015, Sidecar, one of the pioneers in ridesharing, announced that they would ceise their opertations, after only four years of activity in the highly competitive market they largely contributed to building but that was later dominated by larger competitors such as Uber and Lyft.

peer-to-peer car-sharing, bike-sharing, dynamic ridesharing, and on-demand ride services), if compared to the members of the older Generation X that live in the same regions. Similarly, in a survey of bikesharing users in Washington D.C., Buck et al. (2013) show that more than half of the annual members of the bikesharing program are in the age group between 25 and 34. This is also true for the users of on-demand ridesharing services: Rayle et al. (2014) showed that the majority of the users of on-demand ride services are young and highly educated people.

Millennials are found to be heavy users of these services, possibly due to the familiarity with technological solutions in general, or because of their residential location, and the availability of new mobility options. As discussed earlier, millennials seem to be more interested in living in central, urban areas and more open to alternative means of transportation. The two factors combined would mean that not only do millennials have higher accessibility to the new mobility options, but when exposed to them they are more inclined to adopt them. Overall, though, the user base of these services seems to be continuously growing among all age groups (ITS America 2015). The following sections discuss the four major categories of services which respectively provide *car-sharing*, *bike-sharing*, *dynamic ride-sharing* and *on-demand ride services.*

Car-sharing

- **Drivers:** various models of carsharing increasingly available; separation of access to vehicles from ownership; corporate programs and TDM strategies
- **Impact on travel demand:** reduced auto ownership among carsharing members; higher marginal cost for use of cars; unclear (probably positive) effect on use of public transit

Carsharing encompasses some of the most well-known technology-enabled transportation services. Carsharing services are provided through a variety of business and operational models. Carsharing programs are either fleet-based (e.g. Zipcar) or provided on a *peer-to-peer* basis (e.g. Turo, formerly known as RelayRides), in which a user can rent a vehicle, when needed, from another user. While fleet-based carsharing services have achieved rather large popularity in the denser areas of major US cities, peer-to-peer carsharing is emerging as an important alternative because of its capability to expand the benefits of carsharing to the suburbs and to rural areas. In these areas, the lack of critical mass associated with the lower urban densities, the high proportion of home-based trips, and the higher auto-ownership rates, makes fleet-based carsharing unprofitable. Regardless of the ownership model that is adopted, carsharing programs are offered in two general operational models: (1) round-trip carsharing; and (2) one-way carsharing (with the latter which can be further classified as free-floating or station-based carsharing). Zipcar is probably the best-known (and widely available) provider of round-trip carsharing services in the United States. The availability of one-way carsharing services, e.g. Car2go, is becoming increasingly common in large, dense U.S. cities.

Carsharing can potentially impact vehicle ownership and mode use, and influence travel behavior in a number of ways. It allows individuals to access a vehicle when needed without bearing the associated fixed costs (*e.g.* cost of insurance, maintenance, and long-term parking).

While this effect can contribute to increasing car use among those individuals that do not feel the need to (or cannot afford to) own a car (or travel far away from the place where their personal vehicle is located), it also contributes to reducing the importance of car ownership among other users, i.e. those that already own one or more vehicles. Thus, carsharing can contribute to reducing vehicle ownership, allowing at least a portion of their users to get rid of one (or all) of their vehicles. The reduced car ownership rate may translate in lower average VMT. Reduced vehicle ownership may create a positive feedback loop in which even larger VMT reductions are achieved if limit requirements for parking space are revised, which may allow construction of denser urban areas.

Round trip carsharing has been documented as a strategy to reduce car ownership and VMT in the urban areas: it is suggested as an efficient tool to achieve the reductions in VMT and greenhouse gas (GHG) emissions targeted in the State by 2040 (Caltrans 2015). The study forecasts that statewide VMT could be reduced by 1.1% with a 5% increase in the adoption of carsharing. In another study, Cervero and Tsai (2004) found that 30% of the members of car-sharing programs were willing to sell one or more of their vehicles, while other members postponed the purchase of an additional vehicle after using car-sharing services for about two years. More recently, Mishra et al (2015) found that vehicle holding among the members of urban carsharing programs is lower by about 10-14 percent, while the proportion of transit, biking and walking trips are all higher. However, early adopters of car-sharing services tend to be higher-income individuals, who often report car disposal or postponement or complete avoidance of a car purchase to fulfill their mobility needs. The behavior of such early adopters may not be typical of later entrants to the car-sharing market. In another study, Martin and Shaheen (2011) surveyed members of car-sharing programs in the United States and Canada, and concluded that adding another vehicle to the fleet of shared cars would replace 9 to 13 privately-owned vehicles among members of car-sharing services, which might contribute to a 27-43 percent reduction in VMT.

One-way carsharing has been studied from several perspective, including (1) optimum fleet size, location of the stations, the size and number of vehicles; (2) strategies to deal with changes in demand for the service; (3) vehicle relocation systems (Shaheen et al. 2015b). Despite numerous studies about one-way carsharing have been developed, the information available on the impact of this service on travel behavior is still limited. In a study of the Car2go service in Ulm (Germany), Firnkorn (2012) found that more than 25% of respondents would be willing to get rid of their personal vehicle. In a similar study among the subscribers to one-way carsharing in London, Le Vine et al. (2014) found that non-car-owning members reduced their frequency of grocery shopping as well as the time traveled for food shopping purposes.

Studies about how carsharing can affect the use of public transit are more limited: Chatterjee et al (2013) suggested that carsharing can enhance the access to the other modes and as a result enrich multimodality, but they did not discuss how and to what degree this might happen. Still, other studies have suggested that, by eliminating the fixed costs associated with accessing a vehicle but increasing the marginal costs for traveling by car for a trip, carsharing might reduce total VMT. It may complement the use of public transit, in particular increasing patronage for off-peak public transit services (Firnkorn and Müller 2011; Costain, Ardron, and Habib 2012). Other studies showed that carsharing can lead to opposite effects on the use of public transit, depending on the specific characteristics of each program. Le Vine et al. (2014) found that one-way carsharing is often used in place of public transportation, while round-trip carsharing is complementary to its use.

Carsharing providers have also targeted universities and businesses, and are increasingly becoming part of several transportation demand management (TDM) strategies. Clark et al. (2015) found that carsharing can change employer's habits of using private car for commuting to work. Similarly, as of October 2014, 175,000 members of Zipcar in North America are identified as corporate members. In a survey of 523 corporate members in North America, Shaheen and Stocker (2015) found that 2 in 5 corporate members sold or postponed a vehicle purchase due to joining Zipcar, which is equivalent to the removal of 33,000 vehicles across North America.

Bike-sharing

- **Drivers:** bikesharing increasingly available in many U.S. cities; last-mile access to public transportation; differences between casual users vs. annual members
- **Impact on travel demand:** valuable alternative for short-distance trips; increased adoption of bicycling; potential substitute or complement of public transportation

Bikesharing programs are becoming an increasingly popular presence in many American cities. Bikesharing provides users with on-demand access to bicycles for short-distance trips that seem too long for walking. Like carsharing, bikesharing is offered in various operational and business models. Bikesharing comes in a variety of forms, including dock-based bikesharing programs (by far the most common model of bikesharing services in large urban areas), dockless or GPS-based systems, and peer-to-peer bikesharing services. Bikesharing members can usually choose between daily/weekly passes and annual membership plans (Shaheen et al. 2014), with additional hourly rates that are charged based on pricing plans that discourage long bike rentals (in order to maximize the availability of shared bikes among members).

Bikesharing programs have been found to reduce driving and taxi use in almost every city in which they are available (Shaheen 2012). Shaheen et al. (2014) found that 50 percent of respondents reduced their automobile use due to bikesharing in a study of four different bikesharing programs in North America. In addition, while in small cities bikesharing tends to increase transit use through better serving the first and last mile access, in large cities bikesharing may reduce transit ridership through providing a faster and cheaper travel option for many trips (Shaheen et al. 2014; Shaheen 2012). Similarly, bikesharing programs may increase transit use for those living in the urban periphery, where access to public transportation by walk is limited, and decrease transit use for individuals in the urban core (Martin and Shaheen 2014). A similar pattern has been observed among the members of the Capital Bikeshare program in Washington D.C.: 35% of casual user and 45% of annual members reported that their bikesharing trip substituted a public transit trip (Buck et al. 2013).

Comparing users of the San Francisco Bay Area bikesharing program, Shaheen et al. (2015c) found that significant differences with respect to trip purpose, trip duration and home city are observed in the use of bikesharing of casual users vs. annual members.

Dynamic Ridesharing

- **Drivers:** evolution of traditional carpooling/ridesharing; ability to find peers to share a ride in real time; strategies to promote higher car occupancy and reductions in VMT
- **Impact on travel demand:** potential for reduction in VMT; limited success unless complemented by dedicated drivers

Sharing a trip can be an effective way to increase car occupancy and reduce overall VMT. Unlike other emerging transportation services, ridesharing/carpooling has always been a travel option available to travelers. Thus, the introduction of modern smartphone-based ridesharing apps has not introduced a new service or travel mode, but rather it has modified the qualities of an existing option. It changed the way travelers can match their travel needs, by helping them find other peers with whom to share a ride. The characteristics of ridesharing among travelers that are not members of the same household have evolved gradually over a time. Chan and Shaheen (2012) divided the ridesharing evolution into five main phases: (a) the World War II carpooling clubs, (b) the major response to the 1970s energy crisis, (c) the early organized ridesharing schemes, (d) reliable ridesharing systems, and (e) modern technology-enabled ridematching.

Technological advances have revolutionized traditional ridesharing/carpooling by easily matching riders with drivers in real-time (or on a very short notice). Compared to traditional ridesharing, dynamic ridesharing has higher flexibility, which can improve accountability and reliability of the ridesharing services and can expand its potential markets, even for occasional, non-work trips. Despite the rapidly growing market of dynamic ridesharing services, the impact of this service on travelers' behavior is relatively unexplored (Viti and Croman 2013). Most of the existing research in this area has analyzed the potential market of dynamic ridesharing regardless of its impact on individual's travel behavior. For example, Rodier et al. (2016) projected that with moderate dynamic ridesharing market penetration, 9% reduction in VMT would be achieved in the San Francisco Bay Area. Amey (2011) applied a similar approach to the analysis of the Massachusetts Institute of Technology commute data, finding that a VMT reduction in the range of 9-27% would be achieved if ridesharing was adopted by 50% to 77% of the commuters. In another study, Deakin et al. (2011) conducted a feasibility analysis of the potential of dynamic ridesharing, focusing on the UC Berkeley commuters, and found that 20% of commuters to the Berkeley campus would be interested in replacing their drive alone trip with dynamic ridesharing. Despite the large potential market for these types of services, many real-time ridesharing programs failed. Among numerous reasons, the lack of critical mass of users is often considered the main reason for the failure of dynamic ridesharing programs. Besides reaching and maintaining a critical mass of users, a sustainable ridesharing system requires employing dedicated drivers to serve riders who would otherwise remain unmatched. The existence of these dedicated drivers ensures that a certain service level is attained and maintained across both the peak and off-peak hours (Lee and Savelsbergh 2015). This creates another group of transportation services which are known as on-demand ride services.

On-Demand Ride Services

- **Drivers:** transportation network companies (TNCs) increasingly available in most regions of the country; higher adoption among younger, well-educated travelers
- **Impact on travel demand:** increased alternatives for mode choice; potential reduction in driving alone; probable increase in VMT; substitution of use of other modes

One of the most controversial and rapidly growing forms of shared mobility services include on-demand ride services, also known as ridesourcing or transportation network companies (TNCs), such as Uber and Lyft. On-demand ride services primarily resemble taxi services, in that they connect travelers requesting a ride with the pool of drivers through a smartphone application. On-demand ride services are different from dynamic ridesharing because drivers who participate in dynamic ridesharing programs only offer rides to other travelers on the route (including small deviations from it) on which the drivers intended to travel for their own needs.

The growth of TNCs has been rapid, but the information on the effect that these types of services have on the use of other modes is limited. According to an online national tracking poll from June 2015[13], respondents who live in urban areas reported that they used on-demand ride service apps more frequently than users in suburban and rural areas. Another study showed that frequent users of these services in the San Francisco Bay Area mainly included higher educated young adults (Rayle et al. 2014); however, as these services become increasingly more common in many parts of the country, future adoption rates and overall impact on the use of other modes will depend on a number of factors, including, for example, the perceived convenience of using these services, based on individuals' residential location and availability of other travel alternatives, and on whether current users will continue to use these services with the same frequency as they transition in their stages of life and move to other residential locations. It is currently difficult to ascertain how riders change their behaviors with regard to the use of other transportation modes as a result of the adoption of TNCs (Taylor et al. 2015). TNCs may substitute for single occupant driving trips, e.g. 40 percent of users in San Francisco reported that they have reduced their driving due to the adoption of on-demand ride services (Rayle et al. 2014). In a recent study about millennials mobility in California, a larger proportion of millennials reported that the overall effect of their last trip with an on-demand ride service company such as Uber or Lyft was to substitute for a trip they would have done by walking or biking, whereas a larger proportion of members of the previous Generation X reported that their Uber/Lyft trip replaced a trip that they would have otherwise made by car (Circella et al. 2015).

On-demand ride services may reduce the total amount of driving, but the TNC pick-up and drop-off mileage may result in more total VMT (Cooper, Mundy, and Nelson 2010).

[13] Available at http://morningconsult.com/wp-content/uploads/2015/06/150505_crosstabs_mc_v2_AD.pdf (Last accessed on February 3, 2016).

Depending on the specific circumstances and characteristics of the local context, on-demand ride services may act as a VMT-additive or VMT-subtractive force. The overall impact on total VMT may depend on the typologies and distribution of drivers (Anderson 2014). As discussed above, it is reasonable to expect that these new shared mobility services influence travel demand and mode choice, with the resulting effect varying based on the local context, the characteristics of the users, the land use features and the transportation alternatives that are available.[14] Newer services, such as those introduced with Uberpool and Lyft Line, are also becoming popular: they allow multiple users to share a ride in the same vehicle. If this type of service became dominant in the field of on-demand ride services, a reduction in VMT would result (Taylor et al. 2015).

Connected and Autonomous Vehicles

- **Drivers:** improved mobility conditions for those who cannot drive; change in value of travel time; increased road network capacity; ability to perform activities while traveling
- **Impact on travel demand:** latent demand for travel; increase in VMT if widely implemented; role of regulations may significantly affect results

In a not far future, passenger transportation will be potentially revolutionized by the advent of connected and (in particular) fully autonomous vehicles (AVs). The automobile industry has already made significant strides in automating driving: many current car models include features like cruise control, parking assist and other assistive technologies which are all components of what will be needed in the future for full automation of cars. The U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA) has defined five levels of vehicle automation, from Level 0 (i.e. no automation) to Level 4 (full self-driving automation) (NHTSA, 2013). Manufacturers have already produced prototypes of autonomous vehicles that can drive themselves on existing roads and navigate many types of roadways and environmental contexts with (almost) no direct human input. However, the mass deployment of Level 4 AVs on public roads will still require many years due to a combination of engineering, economic, legal and, in particular, regulatory factors. Assuming that these technologies will prove to be fully successful and become available to the mass market (subject to regulatory approval and/or any restrictions from federal, state and local agencies), AVs have the potential to dramatically change future travel demand. If widely adopted, autonomous vehicles may lead to, among other effects, safer roads, reduced congestion, increased network capacity, improved travel comfort and increased utility of traveling by personal vehicles, and reduced parking requirements.

Connected and autonomous vehicles (C/AVs) are expected to increase road network capacity (in particular for Level 4 automation, and under high adoption rate scenarios), increase road safety, improve comfort and lower fuel consumption. C/AVs may provide mobility for

[14] Available at http://ww2.kqed.org/news/2015/12/07/are-uber-and-lyft-really-disrupting-transportation (Last accessed on February 3, 2016).

those too young to drive, the elderly and the disabled. Further, among the effects of AVs on individual's travel behavior are the reduced fatigue associated with driving and the increased ability to perform activities while traveling. They are expected to increase the utility of using a car, as travelers can combine the scheduling flexibility of being a driver with the comfort of riding as a passenger. Thus, AVs are likely to lower the value of travel time for car users, and affect mode choice by favoring the adoption of private vehicles for a larger number of trips at the expenses of other travel modes (Malokin, Circella, and Mokhtarian 2015). The adoption of AVs will likely result in higher per-capita VMT due to latent demand, and the increased utility of using a car: explorative research suggests that with increased mobility among the elderly and others, as well as lowered travel effort and congestion delays, the U.S. will almost certainly experience large VMT increases, unless demand-management strategies are thoughtfully implemented (Fagnant and Kockelman 2015; Litman 2014). Brown et al. (2014) estimate that VMT could approximately double and overall energy use increase threefold. However, the overall effects of C/AVs on passenger travel will largely depend on the policies and regulations that are implemented, including, but not limited to, eventual restrictions in some portions of the road network (e.g. city centers and local roads), regulations for specific categories of users (e.g. unaccompanied minors), ownership models (e.g. personal autonomous vehicles, or PAVs, vs. shared autonomous vehicles, or SAVs), traffic regulations and parking requirements (e.g. whether empty vehicles will be allowed to travel back home vs. will need to be parked at the final destination of a trip). The use of AVs may also be integrated in other transportation services: for example, TNCs such as Uber and Lyft have already been evaluating the future integration of fully autonomous vehicles into their fleets, thus revolutionizing on-demand ride services through the use of driverless SAVs.

To date, it is still unclear when fully autonomous vehicles will become commercially available, and how quickly they will be adopted by consumers. Some studies predict that AVs will be an accepted technology by 2030 (or even earlier) and dominate personal transportation by 2050 (Greenblatt and Shaheen 2015). Overall, more research is needed in order to better understand the impacts of C/AVs on travel demand, the way various policies will affect C/AV use vs. the use of other travel modes, and fill the gap on the analysis tools and data required to conduct C/AV analyses as the associated technologies mature and are deployed (Campbell et al., 2015).

The impact of AVs on travel demand is the topic of another White Paper being developed by the National Center for Sustainable Transportation, and is not further discussed in this report.

Conclusions: Impact on Future Travel Demand and Knowledge Gaps

The large technological, social, economic and demographic forces that are changing modern society are modifying the way Americans live, work, and socialize, probably forever. These changes translate in similar modifications in travel behavior and in the use of transportation. The observed passenger travel patterns are the result of numerous, often counteracting and deeply interrelated factors, whose effects are often difficult to separate. Not surprisingly, several factors have been suggested in the literature to explain the recent changes in passenger travel, and in particular the reduction in per-capita VMT observed in the U.S. over the past ten years, with a recent uptick trend registered during 2014-2015. However, evidence on these effects is mixed. In this paper, we discuss the impacts of the factors that have been suggested as the most relevant in affecting passenger travel and that are grouped in the following groups: *economic activity*, *gas price*, *urban form*, *sociodemographic patterns* and *adoption of technology*. We also discussed how the introduction of innovative forms of *shared mobility services* (today) and connected and autonomous vehicles (in future) can revolutionize travel demand, and our relationship with transportation. All the presented effects are expected to partially influence travel demand, in a complex pattern of relationships and causality effects that concur to influence individuals' travel behavior choices.

Little evidence exists, to date, whether current observed trends will continue in future years, and therefore represent a deeper and more structural modification in travel demand, or if they are only temporary (e.g. the result of temporary economic conditions). As Goodwin and Van Dender (2013) say, "*The aggregate trends […] do not allow us to forecast with any certainty the car use that we can expect in the future"* (Goodwin and Van Dender 2013). In other words, it is unclear if the peak in the use of cars is a temporary or lasting phenomenon, i.e. if after removing some of the causes the growth in travel demand and the use of private vehicles will resume as before, or not. Accordingly, future trends in car use might differ significantly: car use might keep growing in the long term, with the temporary peak in per-capita VMT being mainly an interruption dominated by economic circumstances; it might no longer grow, having it reached a physiological saturation level (or "plateau") in which contrasting factors cancel out their effects on VMT. Finally, if the forces driving the modifications in travel demand (e.g. changes in urban form, multimodal accessibility and individuals' lifestyles) continue and become more dominant in the future, car use might further decline in the longer-term, despite the economic recovery and expansion of economic activities (Sivak 2014a).

Table 1 summarizes the main findings reported in the literature, to date. We report the impact of each specific factor on car use, as well as the other impacts the factor are likely to have on other components of travel behavior, and on the use of other means of travel. There are reasons to believe that the effects of some of the factors that shaped passenger travel in previous decades are vanishing (or, at least, diminishing), and this has been largely responsible, together with negative economic conditions, for the flattening of car travel observed in the past ten years (approximately, from 2004 to 2013). The underlying regime of growth of travel demand of the previous decades has lost strength: nowadays, the effects of factors like the gender gap (both in drivers' licensing and in employment) and the role of age on drivers' licensing are not determinant anymore, after they had been important reasons for growth in passenger travel in the previous 50 years. With an auto ownership ratio of approximately one vehicle per licensed driver, and almost all adults of driving age that desire to obtain a license already having one, it is unlikely that passenger travel will resume increasing with growth rates similar to those observed in the past. Instead, more limited adjustments will likely depend on the specific factors affecting demand, or combination of factors, whose effects will prevail in future years.

A number of uncertainties affect the results discussed in this report, and the implications that can be drawn for future mobility. The effects of some factors are more persistent than others, thus suggesting potential ways in which mobility patterns will evolve, after the temporary conditions disappear. In addition, the impact of some factors (e.g. *lifecycle* and *cohort* effects) seem to have been better understood, to date, than others (e.g. impact of innovative technology) that remain largely uncertain. More research specifically focusing on these topics will help better understand future effects on passenger travel. Furthermore, local trends in specific region might differ significantly from national trends due to a combination of policy environments, and local conditions. Thus, forecasts for any specific region will need to be based on a careful assessment of what factors will be predominant in each area, and of the eventual interaction effects among these factors.

Overall, there are reasons to believe that future patterns in passenger travel will feature increased *heterogeneity* among individuals and among regions, also as an effect of the availability of new travel options, the increased *uncertainty* due to the number of unknown effects, and the impact of emerging drivers of travel demand. In such a continuously evolving scenario, the development of policies that can affect car use will contribute to shaping individuals' behaviors: attention in the development of these policies should be focused on identifying policy levers that are more robust to uncertainty, i.e. that are likely to be successful under a wider set of eventual future conditions (Van Dender and Clever 2013). If the goal of transportation planning processes is to reduce transportation dependence on cars, and improve the environmental effects of transportation, policy-makers and transportation planners may wish to consider policies and investments that might align well with some of the observed trends already happening in society. This might include the supply of better biking and walking infrastructure in areas where changes in urban form are already driving an increase in the travel choices alternative to driving, such as the adoption of active modes of travel. It might also include the introduction of services that particularly target specific categories of users, e.g. by adding additional real-time information through smartphone apps to facilitate the adoption of public transportation and to encourage its use among the multimodal tech-friendly segments of the population.

We identify several knowledge gaps and areas of uncertainty on which a better understanding of the behavioral processes associated with travel demand would be needed. Additional research will be crucial to improving the understanding of future trends in transportation, in particular on the following topics:

1. *Travel behavior of immigrants*: in an increasingly diverse society, it will be important to better understand the driving forces behind the mobility-related decisions of immigrants. Previous research has highlighted significant differences among first and second generations of immigrants (in particular in terms of attitudes towards the use of cars and/or public transit).

2. *Mobility choices of millennials*: we have compiled evidence that young adults (members of the Generation Y) are driving less than past generations at similar ages, but it is unclear to what extent this is due to temporary conditions (e.g. negative effects of the economic recession, or higher college debts), delays in life events (e.g. tendency to delay marriage and child-bearing), or to more permanent generational differences in personal preferences towards urban lifestyles and in the adoption of emerging transportation services. Most conclusions in this area, to date, are still largely based on speculations due to lack of appropriate data (although some research efforts are currently under way in this field; see Circella et al., 2015).
3. *Mobility of senior population*: as baby boomers transition into retirement, more research is needed to understand what impacts their new conditions will have on residential locations, and on short-distance vs. long-distance travel patterns.
4. *Impact of new vehicle technology on passenger travel*: more research is needed to understand what impact the transition from conventional vehicles to electric and other alternative fuel vehicles (AFVs) will have on travel patterns, at a time in which electric vehicles and other AFVs are becoming a common presence on the road network.
5. *Impact of shared mobility services*: the impact of shared mobility services on travel patterns is still largely unknown, as many of these programs are in their infancy. It will be particularly important to understand which (if any) of the new mobility programs are complementary to driving, replace driving, and/or tend to replace the use of active modes or public transit (and other what conditions).
6. *The role of autonomous vehicles*: the role that new connected and autonomous vehicles will have in shaping future transportation deserves a special place in the transportation research agenda. Many features of autonomous vehicles have the potential to revolutionize many attributes of car travel, and dramatically change the transportation landscape.

The development of research on these topics and the achievement of a better understanding of the factors that may affect individual's travel behavior will be fundamental to support planning processes that can meet individuals' expectations and transportation needs in future years.

Table 1. Dominant impact of various groups of factors on vehicle miles traveled according to a review of the literature

Type of Factor	Main Effect on VMT per Capita	Additional Impacts on Travel Demand	Direct or Indirect Effect	Strength	Time Horizon of Effects	Permanent vs. Temporary	Degree of Certainty
Economic Activity							
- Increasing income gap	*Reduction in VMT per capita*	*Substitution with other modes*	*Direct*	*Medium*	*Short-/Medium-/Long-term*	*Temporary or Permanent*	*Rather certain*
- Growth in financial and service sector	*Slower growth in VMT per capita*	*Changes to travel patterns (distances and frequencies)*	*Indirect*	*Probably weak*	*Short-term*	*Permanent*	*Uncertain*
Gas Price and Fuel Efficiency Standards							
- Changes in gas prices	*Reduction or increase in VMT per capita*	*Changes in driving pattern and use of other modes*	*Direct*	*Weak*	*Short-term*	*Temporary*	*Rather certain*
- Increased fuel efficiency	*Potential increase in VMT per capita*	*Changes in vehicle fleet*	*Indirect*	*Medium*	*Medium-/Long-term*	*Permanent*	*Certain*
Urban Form							
- Resurgence of the core of urban areas	*Reduction in VMT per capita*	*Increase in active travel modes*	*Direct*	*Medium/ Strong*	*Short-term*	*Temporary or Permanent*	*Uncertain*
- Better accessibility in all NH types	*Reduction in VMT per capita*	*Increased travel options for short-distance trips*	*Direct*	*Medium*	*Short-/Medium-term*	*Permanent*	*Certain*
		Reduced auto ownership	*Indirect*	*Medium*	*Medium-/Long-term*	*Permanent*	*Rather certain*

Type of Factor	Main Effect on VMT per Capita	Additional Impacts on Travel Demand	Direct or Indirect Effect	Strength	Time Horizon of Effects	Permanent vs. Temporary	Degree of Certainty
(Urban Form - *continued)*							
- Investments in highway infrastructure	*Increase in VMT per capita*	*Increased "automobility" (latent demand)*	*Direct*	*Medium/ Strong*	*Medium Term*	*Temporary or Permanent*	*Certain*
- Investments in transit and multimodal accessibility	*Reduction in VMT per capita*	*Increase in transit ridership*	*Direct*	*Weak/ Medium*	*Short-/Medium-term*	*Permanent*	*Rather certain*
		Increase in walking/cycling	*Direct*	*Weak/ Medium*	*Short-/Medium-term*	*Permanent*	*Rather certain*
Socio-Demographic Patterns and Generational Effects							
- Reduced HH size and delayed childbearing	*Reduction in VMT per capita*	*Reduction in trip generation*	*Direct*	*Strong*	*Short-term*	*Permanent*	*Rather certain*
	Reduction in VMT per capita	*Change in mode share and auto ownership*	*Direct/ Indirect*	*Medium*	*Short-/Medium-term*	*Temporary or permanent*	*Rather certain*
- Urban lifestyles	*Reduction in VMT per capita*	*Increase in use of non-auto modes*	*Indirect*	*Weak/ Medium*	*Short-/ Medium-term*	*Permanent*	*Uncertain*
	Reduction in VMT per capita	*Change in residential location*	*Indirect*	*Medium*	*Medium-/ Long-term*	*Permanent*	*Rather certain*
		Reduction in auto ownership	*Indirect*	*Weak/ Medium*	*Medium-term*	*Temporary or permanent*	*Rather certain*
- Baby Boomers	*Reduction in/ Neutrality with VMT per capita*	*Reduction in commuting trips, more discretionary travel*	*Direct and indirect*	*Weak/ Medium*	*Short-/ Medium-term*	*Permanent*	*Rather certain*

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Type of Factor	Main Effect on VMT per Capita	Additional Impacts on Travel Demand	Direct or Indirect Effect	Strength	Time Horizon of Effects	Permanent vs. Temporary	Degree of Certainty
(Socio-Demographic Patterns and Generational Effects - *continued*)							
- Generation X	*Reduction in VMT per capita*	*Adoption of other modes*	*Direct and Indirect*	*Weak*	*Short-term*	*Still unknown*	*Uncertain*
- Millennials (Generation Y)	*Reduction in VMT per capita*	*Changes in lifestyles, residential location and mode choice*	*Direct and indirect*	*Medium*	*Short-/ Medium-term*	*Still unknown*	*Rather certain*
- Generation Z	*Unknown (probable reduction)*	*Adoption of technology, unknown behaviors*	*Still unknown*	*Still unknown*	*Still unknown*	*Still unknown*	*Still unknown*
Impact of Technology							
- Telecommuting	*Neutrality with VMT per capita*	*Reduction of commuting trips*	*Direct*	*Weak/ medium*	*Short-term*	*Permanent*	*Uncertain*
		Impact on mode choices	*Indirect*	*Weak/ medium*	*Short-/Medium-term*	*Temporary or permanent*	*Rather certain*
- E-shopping	*Neutrality with/increase in VMT per capita*	*Change in trip patterns*	*Direct*	*Weak/ medium*	*Short-term*	*Permanent*	*Uncertain*
- Online social media	*Neutrality with/increase in VMT per capita*	*Impact on leisure trip patterns*	*Indirect*	*Weak*	*Short-term*	*Temporary or Permanent*	*Uncertain*

Type of Factor	Main Effect on VMT per Capita	Additional Impacts on Travel Demand	Direct or Indirect Effect	Strength	Time Horizon of Effects	Permanent vs. Temporary	Degree of Certainty
Shared Mobility Services							
- Car-sharing	*Decrease in VMT per capita*	*Decrease in auto ownership*	*Indirect*	*Weak/ medium*	*Medium-term*	*Permanent*	*Uncertain*
- Bike-sharing	*Decrease in VMT per capita*	*Substitution of other travel modes*	*Direct*	*Weak/ medium*	*Short-term*	*Temporary or Permanent*	*Rather certain*
- Dynamic ridesharing	*Decrease in VMT per capita*	*Increased auto occupancy*	*Direct*	*Medium*	*Short-term*	*Temporary or Permanent*	*Uncertain*
- On-demand ride services	*Decrease or increase in VMT per capita*	*Substitution of other travel modes*	*Direct*	*Medium*	*Short-term*	*Permanent*	*Uncertain*
		Latent demand	*Indirect*	*Weak*	*Short-/ Medium-term*	*Temporary or Permanent*	*Uncertain*
Connected and Autonomous Vehicles							
- Availability of C/AVs	*Increase in VMT per capita*	*Latent Demand*	*Direct/ Indirect*	*Probably Strong*	*Medium-/Long-term*	*Probably permanent*	*Uncertain*
		Reduction of use of other modes	*Direct/ Indirect*	*Probably Strong*	*Medium-/Long-term*	*Probably permanent*	*Uncertain*

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Appendix A

Total population, total annual VMT and average per-capita VMT by US State in 2003 and 2013

Year	2003					2013				
State Name	Annual VMT (millions)	% of US VMT	State Population	% of US Population	Per capita VMT	Annual VMT (millions)	% of US VMT	State Population	% of US Population	Per capita VMT
Alabama	58,637	2%	4,500,752	2%	13,028	65,046	2%	4,833,722	2%	13,457
Alaska	4,942	0%	648,818	0%	7,617	4,848	0%	735,132	0%	6,595
Arizona	53,896	2%	5,580,811	2%	9,657	60,586	2%	6,626,624	2%	9,143
Arkansas	30,639	1%	2,725,714	1%	11,241	33,493	1%	2,959,373	1%	11,318
California	323,592	11%	35,484,453	12%	9,119	329,534	11%	38,332,521	12%	8,597
Colorado	43,379	2%	4,550,688	2%	9,532	46,968	2%	5,268,367	2%	8,915
Connecticut	31,432	1%	3,483,372	1%	9,023	30,941	1%	3,596,080	1%	8,604
Delaware	9,044	0%	817,491	0%	11,063	9,308	0%	925,749	0%	10,054
Dist. of Columbia	4,150	0%	563,384	0%	7,366	3,527	0%	646,449	0%	5,456
Florida	185,511	6%	17,019,068	6%	10,900	192,702	6%	19,552,860	6%	9,855
Georgia	109,246	4%	8,684,715	3%	12,579	109,355	4%	9,992,167	3%	10,944
Hawaii	9,312	0%	1,257,608	0%	7,405	10,099	0%	1,404,054	0%	7,193
Idaho	14,290	0%	1,366,332	0%	10,459	15,980	1%	1,612,136	1%	9,912

Illinois	106,536	4%	12,653,544	4%	8,419	105,297	4%	12,882,135	4%	8,174
Indiana	72,511	3%	6,195,643	2%	11,704	78,311	3%	6,570,902	2%	11,918
Iowa	31,108	1%	2,944,062	1%	10,566	31,641	1%	3,090,416	1%	10,238
Kansas	28,672	1%	2,723,507	1%	10,528	30,208	1%	2,893,957	1%	10,438
Kentucky	46,748	2%	4,117,827	1%	11,353	46,996	2%	4,395,295	1%	10,692
Louisiana	44,156	2%	4,496,334	2%	9,820	47,758	2%	4,625,470	1%	10,325
Maine	14,912	1%	1,305,728	0%	11,420	14,129	0%	1,328,302	0%	10,637
Maryland	54,701	2%	5,508,909	2%	9,930	56,688	2%	5,928,814	2%	9,561
Massachusetts	53,709	2%	6,433,422	2%	8,348	56,311	2%	6,692,824	2%	8,414
Michigan	100,756	3%	10,079,985	3%	9,996	95,132	3%	9,895,622	3%	9,614
Minnesota	55,296	2%	5,059,375	2%	10,929	56,974	2%	5,420,380	2%	10,511
Mississippi	37,467	1%	2,881,281	1%	13,004	38,758	1%	2,991,207	1%	12,957
Missouri	68,163	2%	5,704,484	2%	11,949	69,458	2%	6,044,171	2%	11,492
Montana	10,874	0%	917,621	0%	11,850	12,033	0%	1,015,165	0%	11,853
Nebraska	19,016	1%	1,739,291	1%	10,933	19,322	1%	1,868,516	1%	10,341
Nevada	19,301	1%	2,241,154	1%	8,612	24,649	1%	2,790,136	1%	8,834
New Hampshire	13,180	0%	1,287,687	0%	10,235	12,903	0%	1,323,459	0%	9,749

New Jersey	69,778	2%	8,638,396	3%	8,078	74,530	2%	8,899,339	3%	8,375
New Mexico	22,844	1%	1,874,614	1%	12,186	25,086	1%	2,085,287	1%	12,030
New York	135,047	5%	19,190,115	7%	7,037	129,737	4%	19,651,127	6%	6,602
North Carolina	93,759	3%	8,407,248	3%	11,152	105,213	4%	9,848,060	3%	10,684
North Dakota	7,468	0%	633,837	0%	11,782	10,100	0%	723,393	0%	13,961
Ohio	108,938	4%	11,435,798	4%	9,526	112,767	4%	11,570,808	4%	9,746
Oklahoma	45,725	2%	3,511,532	1%	13,021	47,999	2%	3,850,568	1%	12,465
Oregon	35,098	1%	3,559,596	1%	9,860	33,706	1%	3,930,065	1%	8,576
Pennsylvania	106,347	4%	12,365,455	4%	8,600	98,628	3%	12,773,801	4%	7,721
Rhode Island	8,365	0%	1,076,164	0%	7,773	7,775	0%	1,051,511	0%	7,394
South Carolina	48,120	2%	4,147,152	1%	11,603	48,986	2%	4,774,839	2%	10,259
South Dakota	8,527	0%	764,309	0%	11,156	9,122	0%	844,877	0%	10,797
Tennessee	69,154	2%	5,841,748	2%	11,838	71,067	2%	6,495,978	2%	10,940
Texas	223,418	8%	22,118,509	8%	10,101	244,525	8%	26,448,193	8%	9,245
Utah	24,029	1%	2,351,467	1%	10,219	27,005	1%	2,900,872	1%	9,309
Vermont	8,309	0%	619,107	0%	13,421	7,116	0%	626,630	0%	11,356
Virginia	76,868	3%	7,386,330	3%	10,407	80,767	3%	8,260,405	3%	9,778

Washington	55,015	2%	6,131,445	2%	8,973	57,211	2%	6,971,406	2%	8,207
West Virginia	20,082	1%	1,810,354	1%	11,093	19,232	1%	1,854,304	1%	10,372
Wisconsin	59,615	2%	5,472,299	2%	10,894	59,486	2%	5,742,713	2%	10,359
Wyoming	9,211	0%	501,242	0%	18,376	9,309	0%	582,658	0%	15,977
US Total	***2,890,893***		***290,809,777***		***9,941***	***2,988,323***	-	***316,128,839***		***9,453***