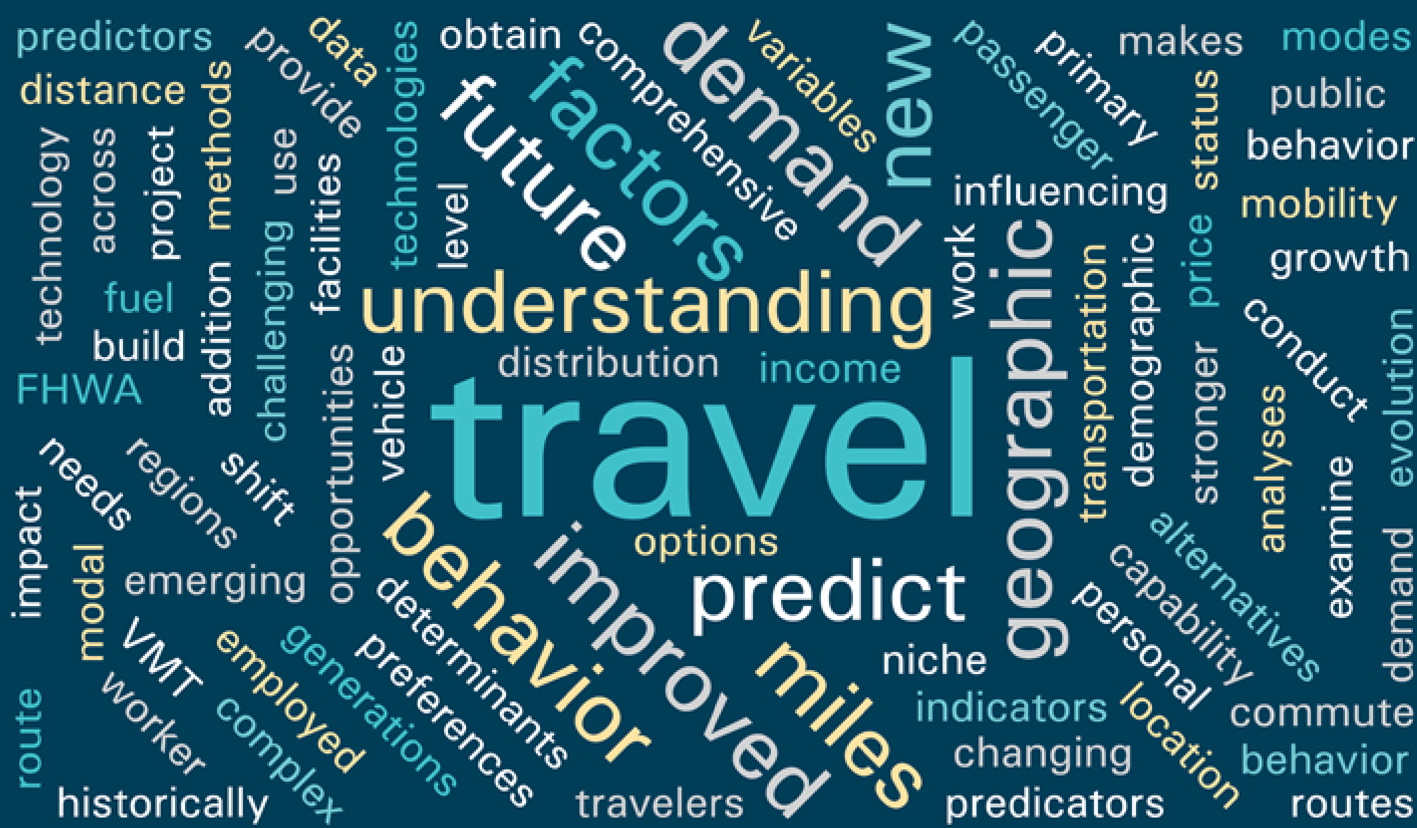

UNDERSTANDING TRAVEL BEHAVIOR

Research Scan

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Federal Highway Administration

**Produced by
Booz Allen Hamilton**

UNDERSTANDING TRAVEL BEHAVIOR

Research Scan

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EXECUTIVE SUMMARY

Travel behavior is undergoing a period of significant change in the United States, and this change is beginning to reveal itself in long-standing measures of transportation. While the United States is still heavily dependent on the personal automobile for mobility, changes in technology, demographics, economics, and attitudes are transforming how mobility is attained. At the same time, advances in information technology are opening new ways for transportation activity to be measured more comprehensively. These transformative trends are reshaping how we think about transportation policy, operations, and planning.

This report presents a research scan of the state of knowledge in transportation to enhance understanding of travel behavior and various influencing factors on future travel. It provides an overview of the current state of travel behavior as measured today, as well as background on the current understanding from literature in travel behavior research. It also explores what is known about the socio-demographic portrait of Americans and how demographics influence travel behavior. The report discusses emerging information technology and its impact on new mobility options. It also presents emerging methodologies and new forms of data that show significant potential to improve the resolution and comprehensiveness of travel behavior information. Finally, it identifies gaps in understanding that could be addressed in the future with appropriate applications of emerging data and technological resources.

Chapter 1 is an introduction to the report. **Chapter 2**, *Present Day Travel Behavior Measurement and Research within the United States*, discusses key measures in surface transportation data that inform our current understanding of travel behavior. Transportation measures that are commonly used to understand travel behavior in the United States are presented in six key sections. These sections are:

1. Vehicle miles traveled (VMT)
2. Person miles traveled (PMT)
3. Modal splits and vehicle ownership
4. Energy and emissions
5. Telework and telecommuting
6. Non-work travel.

VMT as measured with nationwide traffic sensors has a long and consistent history of reporting at regular monthly intervals. Moreover, the National Household Travel Survey (NHTS) measures VMT through travel diaries, allowing for VMT disaggregation by trip purpose. Since World War II, VMT has been growing steadily and consistently, except for brief interruptions due to major wars, recessions or oil crises. There was a significant decline in November 2007 due to the Great Recession; however, VMT has since rebounded, surpassing its 2007 peak in February 2015. While the recent decline in VMT was not the largest ever recorded (this happened during World War II), it has been the longest *stagnation* of VMT growth in U.S. history. In recognition of the possible overestimation of future VMT growth exhibited by traditional forecast methods, the Federal Highway Administration (FHWA) has developed a new model for VMT forecasting, which uses predictions in demographic and economic changes to deliver better forecasts for VMT. The measurement of VMT alone has a number of limitations for understanding travel behavior. Namely, it lacks the means to track mobility that is achieved without the use of motor vehicles (e.g., public transit use, bicycling, walking). To gain a more complete picture of travel behavior, other measurements are required.

Person miles traveled (PMT) measures the number of miles traveled by each person on a trip. Unlike VMT, PMT includes both motorized and non-motorized modes, including higher-occupancy modes such as public transit or carpool. PMT more comprehensively covers travel across all modes, and is becoming increasingly important for understanding the overall picture of travel activity in the United States. But measuring PMT is far more demanding because it requires data that is difficult to obtain. Today, measuring PMT often requires large-scale surveying with travel diaries; thus, PMT is measured far less frequently than the sensor-based VMT. However, smartphone technology has the potential for measuring PMT with greater accuracy and sampling in the future.

Modal split refers to which mode of transportation people use to make trips, such as in private vehicles, by rail or bus, or by walking or cycling. In additional to local and regional travel surveys, the NHTS and the Journey to Work section of the American Community Survey (ACS) collect mode split data. Among commute trips, the NHTS showed us that mode share of private vehicles fell slightly from 92.8% in 2001 to 91.4% in 2009. Public transit, walking, and bicycling modes each have experienced increases in mode share, to varying degrees in different regions of the United States. Moreover, there is evidence that vehicle ownership rates in the United States are in decline. As the U.S. economy continues to recover, it will become clearer as to whether the changes in ownership rates were solely due to economics, or are also due to societal shifts in travel behavior.

Telework, or telecommuting, is an alternative arrangement in which an employee can work remotely from a centralized workplace using available information and communications technology (ICT), such as telecommunications and personal computers. Research in telework has typically relied on survey and travel diaries. The 2009 NHTS estimated that work-at-home activity in 2001 saved approximately 18 million gallons of gasoline per day. Similar significant impacts have likely grown as company telework policies have become more flexible and as enabling technology has improved.

Non-work travel describes trips made for purposes other than the journey to and from work, such as shopping, personal business, accessing healthcare, and schooling. Because of its diversity in purpose and time, non-work travel can be hard to measure. Recent NHTS data suggest that there is an upward trend of non-work travel. This is not occurring with the average length of the trip, but in the number of trips made. The sustainability of this trend is uncertain, however, due to a change in survey techniques within the NHTS.

Chapter 3, *Socio-Demographic Factors Changing Travel Behavior Today*, discusses the state of knowledge of socio-demographic trends and how they are known to impact travel choices. This chapter is divided into five sections:

1. Population growth and immigration
2. Income
3. Age distribution
4. Gender
5. Social and cultural factors.

The U.S. population has been growing for decades, at a rate between 0.7% and 1.7% since the 1960s. This growth rate has been declining, yet the U.S. population is still one of the fastest growing among industrialized countries. The Census Bureau estimates that the U.S. population is presently almost 322 million people; by 2060, the population will grow to approximately 417 million, with an annualized growth rate of 0.6%. Much of the nation's population growth has been driven by immigration rather than high fertility. The current foreign-born population is 41.3 million or about 13%. This share is expected to rise—the Census Bureau estimates one out of five Americans will be foreign-born by 2060. Thus, it is important to understand the travel choices of immigrants and how they evolve. Research has shown that immigrants tend to travel in ways that are different from the general U.S. population, but also adapt to the standard "American" travel lifestyle the longer they reside in the country—namely, they gradually shift from public transit, carpooling, walking, and bicycling to driving alone.

Income is a socio-demographic metric that has one of the strongest positive correlations to increased trip making and distance traveled by automobile. As income rises, the number of person trips also increases. Across all incomes, those dwelling in urban areas take more trips per capita than their cohorts in rural areas; however, urban VMT per person is lower. In rural areas, income appears to not impact the likelihood of an individual to take public transit. In urban areas, however, public transit use is highest among lower income populations and appears to decrease slightly as income rises, except among high-income households.

Age also significantly impacts an individual's travel choices. Two age cohorts that demonstrate distinctive travel habits are Millennials (born between 1981 and 1996) and Baby Boomers (born between 1946 and 1964). Millennials appear to be driving less than their predecessors did when they were the same age, whereas the Boomer generation is driving more than their predecessors. Having grown up in an era of technological advancement, Millennials are much more likely to take advantage of technology to substitute unnecessary travel, such as engaging in online shopping, online socializing, and utilizing innovative mobility programs such as carsharing. While Boomers have maintained a high rate of driving throughout their life, it is unclear whether Millennials will maintain their lower rates of driving as they grow older and start families in their 30s and 40s.

Social shifts surrounding gender have impacted U.S. travel during the 20th century. There was an increase of women drivers as they entered the labor force, yet continued to hold many household responsibilities. Past research has suggested that women were more likely to drive a private car because of the flexibility offered to chain trips. Household structures also impact trip chaining. Single-person households, as well as single mothers, are more likely to form complex trip chains.

There is growing evidence in the United States that attitudes towards driving are shifting. In particular, Millennials are the first generation perhaps since the Great Depression to show less desire for car ownership than previous generations. Even as awareness of the threat of global climate change among Americans grows, there remains limited research towards understand how this awareness impacts travel. Technology, however, is enabling society to engage in new forms of sharing, revealing attitudinal preferences that were previously unseen. App-based, on-demand ride services (e.g., Lyft and Uber) connect riders to nearby drivers using their mobile devices. Because technology is rapidly evolving, little research has been done to accurately capture the impacts on travel. The most direct evidence of shifting attitudes towards sharing is the increased use of shared mobility systems and their direct impact on driving alone. In January 2015, there were over 1.1 million carsharing members in the United States sharing 16,750 vehicles.

Gaps remain in existing datasets of U.S. travel behavior. Pertaining to immigration, there remains information barriers that accompany undocumented immigrants. When analyzing age and generation data, research conclusions can quickly become outdated as generations grow older and enter new phases of life. Lastly, there remains a large data gap in travelers' preferences and actions. To address these gaps, future survey and travel diaries should contain revealed preference questions to determine how behavior has actually shifted due to various factors. Questions on technology must play a larger role. Study methodologies should consider other modes of data collection beyond the telephone. One possible solution might be to foster the development a more frequent sampling of the type of data collected by the NHTS. This could be a sort of an "ACS for the NHTS," comprising a subsample of travel behavior that could be used at the national level, perhaps derived from the continually ongoing regional travel surveys conducted by MPOs and states across the country.

Chapter 4, *Transformative Technology and Systems Changing Travel Behavior Today*, explores the technologies and systems that are currently changing travel behavior in the United States. It focuses on the emerging technologies that have been most influential within the 21st century. There are six key sections in this chapter:

1. Emerging modes of travel
2. Alternatives to work travel
3. Alternatives to non-work travel
4. Innovative business models
5. Multi-modal traveler information
6. Advanced infrastructure and pricing.

Shared mobility—the shared use of a vehicle, bicycle, or other low-speed mode—is an innovative transportation strategy that enables users to have short-term access to transportation modes on an as-needed basis. Shared mobility systems leverage information and communications technologies (ICT) to facilitate their operations. The benefits of shared mobility include reduction of vehicle use, reduction of vehicle ownership, and reduction of VMT/VKT, as well as extending the catchment area of public transit. Carsharing, or short-term auto use, is a major segment of the shared mobility industry. Research has found a 27% reduction of annual VMT (up to 43% reduction when taking into account driving on vehicles that would have been acquired) among carsharing users. It is estimated that one carsharing vehicle replaces 9 to 13 vehicles in North America. Overall, these effects equate to an aggregate reduction of 1.1 billion miles driven for members of roundtrip carsharing (estimated in January 2013).

New technologies have reduced the need for workers to be physically present in an office, and have thus allowed for telework/telecommuting options for many employees. The growth of telework accelerated with personal computing in the 1990s, and a large body of literature evaluated the impacts of telework in the United States during this decade. Specific technologies that enable telecommuting include phone, email, video conferencing, instant messaging, Virtual Private Network (VPN) access, collaborative calendar scheduling, screen sharing, cloud access, file sharing, and real-time document collaboration tools. Technologies have also allowed for alternatives to non-work travel, such as online shopping. Still emerging is telemedicine, which is the exchange of medical information via electronic communications to improve a patient’s health status. Telemedicine may eliminate the need to make some healthcare-related trips.

Innovative business models in the form of Internet-based apps have the ability to provide basic services that reduce travel. These businesses include valet parking service, on-demand goods delivery, courier network services, and privately-run transit services. As these apps continue to emerge, research is needed to better understand their impact on travel. At the same time, multi-modal traveler information has seen expanding application as transit providers and public agencies have made their data more easily accessible to the public. Moreover, developers have created apps that convey driving routes, departure times, and travel modes available when the user provides their planned origin and destination. Some examples include Google Maps, Waze, Ridescout, Citymapper, and ParkWhiz.

All of these cutting edge technologies leverage the better provision and use of information to achieve enhanced mobility. Existing research evaluates how these technologies are influencing travel behavior at their different stages of maturity. Because the technology and applications are rapidly evolving, continued evaluation research will be needed, as shared mobility, automated vehicle (AV) applications, innovative business models, IT, and infrastructure converge to form new and advanced applications for mobility and improved transportation sustainability.

Chapter 5, *Emerging Methodologies and Data for Measuring Travel Behavior*, reviews the existing research on alternative and emerging methods for measuring travel behavior, and discusses approaches that could be used with new forms of data to generate metrics similar to, or in addition to, those approaches discussed in Chapter 2.

Several new methodologies have emerged in the past five years that heavily leverage the new advances in smartphone and GPS technologies. Probe person surveys collect stated preference data through Internet web diaries supplemented with actual travel choices through GPS-assisted mobile phones. Cloud-based travel diaries can replace paper-based surveys, reducing error and manpower needed to transcribe and analyze. Space-time behavior surveys are a mixed-mode method used to create enhanced datasets involving traditional data generation methods as well as geospatial data and analytics. Online social networking can provide information on travel behavior. Location-based social networking utilizes social networking "check-ins" for dynamic origin/destination data.

While traditional intercept and telephone surveys remain important data collection instruments, the collection of real-time data is emerging as a resource that may more accurately reflect travelers' preferences and travel choices on a timely basis. Mobile device data from cellular phones, smartphones, tablets, and other mobile devices are emerging forms of data applicable for travel behavior studies. Mobile devices have the ability to capture large amounts of real-time data from the general public. However, the acquisition and use of such data comes with a variety of challenges. Most importantly, mobile device data can contain personally identifiable information (PII), raising privacy concerns. Companies can partner with telecommunication companies and other partners to remove customer proprietary network information (CPNI) and other PII. Global positioning systems (GPS) data is also becoming a prevalent data source. While mobile device data is collected from most cellular phones, GPS data is limited to smartphones, tablets, and navigation systems connected to telecommunication companies' data networks or Wi-Fi networks. GPS data has been used to generate prompted recall (PR) surveys, which ask respondents to recall their actual travel from GPS-generated maps and make necessary changes to improve data accuracy. Lastly, automatic vehicle location (AVL) systems and connected vehicle (CV) technology are emerging and being explored by public agencies for wireless communication and tracking transit vehicles. Overall, the ability to harness real-time data to observe and analyze actual travel choices is a major step forward. Future research can leverage these datasets, but will need to overcome institutional and technological barriers, such as data sharing, data accuracy, cyber security, and privacy.

The **final two chapters** of this report contain conclusions and key findings. In the United States, it is becoming evident that broader changes in travel behavior are beginning to have effects significant enough to influence large scale measurements of travel activity, such as national VMT, PMT, and energy use. Americans are still highly dependent on the personal automobile, but they are beginning to travel in ways that utilize other modes more often. Moreover, vehicle ownership rates have at least stagnated alongside rising fuel economy. Technology is playing a greater role in making travel more efficient or replacing trips altogether. Technology is also allowing transportation researchers and practitioners to understand travel behavior at an unprecedented level of resolution.

The results of this research scan have yielded a number of insights and conclusions related to the state of travel behavior understanding. There are several recommendations that can be made for future research towards addressing gaps in understanding travel behavior. These recommendations are briefly outlined as follows:

Better of Understanding of Emerging Modes

- Shared mobility modes have changed the transportation landscape of many US cities. Improved research is needed to understand the impacts and dynamics of shared-use mobility modes, including carsharing, bikesharing, ridesourcing, microtransit, and others. Research supportive of understanding shared mobility can better advance effective policies maximizing and directing their benefits to all populations.

- As telework applications continue to improve, the mode has grown in all regions of the country. Yet, telework has remained difficult to measure and understand from the perspective of supportive policies and overall impacts. As telework reduces transportation energy use, emissions, and congestion, a better understanding and measurement of telework should be advanced.

- A better understanding of emerging alternatives to non-work travel (e.g., e-commerce, telemedicine) and innovative business models (e.g., courier network services) is needed to measure their impacts on travel behavior, which are likely to grow in the future.

- Connected vehicles (CVs) and autonomous vehicles (AVs) are certain to have profound impact on travel behavior in ways that could be both positive and negative. Research is needed to better determine the projected impacts of CVs and AVs on travel behavior, public policy, and linkages to shared mobility.

Improvements to Surveys, Methods, and Data

- National travel surveys such as the NHTS have played a critical role in our understanding of travel behavior. While the NHTS is comprehensive, its main disadvantage has been the relative infrequency in which it is conducted. State and regional travel surveys conducted around the country could serve to fill this gap by providing a sample with which to construct an interim national picture during the intervening years.

- Leverage smartphone and GPS technology to capture PMT data to supplement traditional travel diaries.

- Evaluate methods to better collect, manage, and store real-time data on various scales (local, regional, national) for future analyses of travel behavior.

- Facilitate the leverage and application of advanced data sources to better measure vehicle occupancy, VMT, PMT, as well as trip counts and distances traveled or walking, bicycling, and other mode shares. Better measurement of avoided miles from telecommuting are also needed.

- Improve surveys to more comprehensively understand distributions in trip purpose and forecasting changing attitudes and public perceptions of travel modes (such as attitude shifts towards the personal automobile).

These and other recommendations are presented in the report that follows.

CHAPTER 1.0. INTRODUCTION

Travel behavior is undergoing a period of significant change in the United States. The nature of how Americans travel is evolving, and this evolution is beginning to reveal itself in long-standing measures of transportation. While the United States has been and is still heavily dependent on the personal automobile for mobility; changes in technology, demographics, economics, and attitudes are transforming how mobility is attained. At the same time, advances in information technology are opening new ways for transportation activity to be measured more comprehensively. These transformative trends are reshaping how we think about transportation policy, operations, and planning.

This report presents a research scan of the state of knowledge in transportation to obtain a better understanding of travel behavior and the key influential factors on the amount and distribution of future travel across geographic regions, facilities, and modes of travel. It provides an overview of the current state of travel behavior today, as well as background on our current understanding from literature in travel behavior research.

As part of this effort, the report presents an overview of how transportation is measured and what those measurements convey about trends in travel behavior through the present day. It also explores what is known about how the changing socio-demographic portrait of Americans is likely to influence travel in the coming decades. Furthermore, the report devotes a chapter to technology, and details the new mobility options that are emerging through the application of IT-based applications, smart phones, and the broader shared mobility industry that has gained momentum in recent years. Finally, the report presents an overview of new methodologies and forms of data that are emerging with great potential to vastly improve the resolution and comprehensiveness of travel behavior information. All of this information is brought together in a synthesis that identifies gaps in understanding that can potentially be addressed with emerging forms of data and technology.

In summary, the research scan is divided into seven chapters, the outline of which is as follows:

Chapter 1: Introduction
This chapter presents the project background and an overview of the chapters on understanding travel behavior and measurement.

Chapter 2: Present Day Travel Behavior Measurement and Research within the United States

Chapter 2 presents an overview of travel behavior measurement and research within the United States today. It presents empirical data on existing metrics as well as a review of the methods of measurement and estimation that are currently applied as part of a state-of-practice assessment.

Chapter 3: Socio-demographic Factors Changing Travel Behavior Today
Chapter 3 discusses what is known about the socio-demographic factors that have influenced travel behavior today. It explores previous research that has identified key underlying trends in sociological, demographic, and economic factors that have been associated with movements in existing travel behavior metrics.

Chapter 4: Technologies and Transformative Systems Changing Travel Behavior Today
Chapter 4 focuses on how advances in technology are influencing travel behavior today. This chapter provides a review of the where, why, and how of travel behavior changes in light of key transformative factors that have arisen through technology and infrastructure.

Chapter 5: Emerging Methodologies and Data for Measuring Travel Behavior
Chapter 5 reviews existing research on alternative and emerging methods for measuring travel behavior. This section includes the development of a comprehensive database of available public and private datasets that could potentially be used to better measure and monitor new changes in travel behavior.

Chapter 6: Conclusion
Chapter 6 presents a summary of conclusions that have emerged from the research scan.

Chapter 7: Key Findings
Chapter 7 summarizes the key takeaways of the travel behavior research scan, including identified gaps for future research.

CHAPTER 2.0. PRESENT DAY TRAVEL BEHAVIOR MEASUREMENT AND RESEARCH WITHIN THE UNITED STATES

Introduction

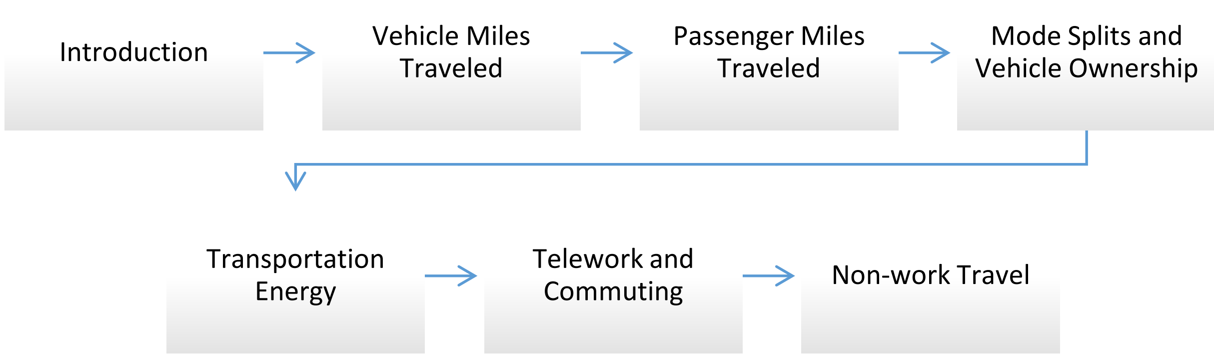
Travel behavior in the United States has been evolving rapidly in the 21st century. The changes underway within the urban, suburban, and rural transportation landscapes have profoundly influenced the way in which we interact with our infrastructure, our vehicles, and each other. In many ways, the intersection of economics and technology is driving these changes, and the aggregate of all these effects is starting to impact nation-level measures in unprecedented ways.

This chapter explores trends and research covering the key transportation measures commonly used to understand travel behavior in America. The chapter presents these measurements within six sections: (1) Vehicle Miles Traveled (VMT), (2) Person Miles Traveled (PMT), (3) Modal Splits and Vehicle Ownership, (4) Energy and Emissions, (5) Telework and Telecommuting, and (6) Non-Work Travel. Each section captures different aspects of travel, and together they provide a robust picture of travel behavior using different data sources and methodologies.

A number of strengths and weaknesses characterize the differences across these measurements. Some measurements, such as the VMT measured with nationwide traffic sensors, have a long and consistent history of reporting at regular monthly intervals. However, because VMT measures the activity of vehicles only, it lacks the means to track mobility that is achieved without the use of motor vehicles. In the 21st century, the role of the vehicle in delivering mobility is changing, and measurements of vehicle activity could become less reliable indicators of overall travel activity in the future. Alternatively, measurements such as PMT, which more comprehensively cover travel across all modes, could become increasingly important for understanding the overall picture of travel activity in America. However, reliable PMT measurements are far more demanding of data that is difficult to obtain, such as from bicycling, walking, riding public transit, and other forms of mobility. As a result, PMT is measured far more infrequently than sensor-based VMT. These and other challenges characterize some of the advantages and disadvantages of measurements as they are applied to understand travel behavior in America.

Understanding travel behavior is also more than just following aggregate measures of movement. The details matter in relation to modal splits, household vehicle ownership, and environmental measures such as energy use and emissions. Furthermore, understanding the nature of certain types of travel, such as commuting, telework, and non-work travel, are essential for assessing the direction of transportation needs of the future. Hence, following an overview of trends in, and measurement of VMT and PMT, this chapter explores the underlying trends of these descriptors of transportation activity in more detail. Insights drawn from this chapter will serve as a foundation for subsequent chapters that further analyze the fundamental drivers of changes in travel behavior within the United States. To provide an overview of this structure, Figure 2-1 presents a graphical flow of Chapter 2.

Figure 2-1: Content Flow of Chapter 2



At the end of Chapter 2, the reader should have a comprehensive understanding of the evolution of travel activity within the United States. This includes an understanding of what the common measures of travel activity tell us about the state of travel in America today, and the likely direction of those trends in the near term. Chapter 2 concludes with an overview of these insights and provides a segue into the subsequent chapters, which will review the state of knowledge in demographics, economics, technology, and emerging data resources that will support insights about the likely evolution of travel behavior in United States within the coming decades.

Trends and Measurement of Vehicle Miles Traveled (VMT)

One of the longstanding measurements of transportation activity is VMT, which is regularly referenced in the context of economic growth as well as overall mobility within the country. In some form, VMT has been measured or estimated for the United States since the beginning of the 20th century. There are several different types of VMT measurement used today, each of which is derived from different data sources. One of the main VMT measurements is based on data from continuously reporting sensors and an estimation methodology that translates that information into an aggregate measure across all modes.

The other main measure is derived from the National Household Travel Survey (NHTS). The former provides a monthly measurement of all vehicle activity, but with limited insight as to who is traveling and why. The latter provides a rich assessment of household VMT as practiced through personal travel, but the data is a sample of activity captured in irregular intervals several years apart. Together, these measurements offer the public and policymakers the best available insights on vehicle-based travel in the United States.

VMT Measurement in Traffic Volume Trends

The FHWA Office of Highway Policy Information releases in their monthly report "Traffic Volume Trends" (TVT), a sensor-based measurement of VMT, called the "Moving 12-Month Total on All Roads." This measurement is the sum of the reported monthly VMT for the current month and the 11 months immediately preceding it.

How VMT is measured in the Traffic Volume Trends

The VMT measurement reported in the TVT is currently produced from two primary sources including: (1) the Highway Performance Monitoring System (HPMS) and (2) monthly traffic counts from about 4,000 continuous automatic traffic recorders (ATRs) across all states (FHWA, 2015). The HPMS (1) provides a baseline estimate for total mileage through its calculation of the annual average daily traffic (AADT) on all road segments. When aggregated across road segments, it produces a single annual measurement for VMT. The traffic counts (2) are submitted each month to the FHWA. Following some processing, these data are used to compute a monthly average daily traffic (MADT) value. The MADT is used to estimate the *change rates* in traffic as compared to the MADT measurement for the same month a year earlier. The change rates from each month are then combined with the most recent estimate of annual VMT as supplied by the HPMS (1). This produces the monthly VMT values that are then used to sum up to the Moving 12-Month Total VMT.

The HPMS requires that each state submit data of annual average daily traffic (AADT) for all public roads that are eligible for federal highway funds (FHWA, 2014). States report AADT for each road segment within the domain of public roadway mileage, which includes all roads classified as interstates, freeways, expressways or other principal arterials, and minor arterials, major collectors, and local roads. Because the VMT estimates reported by the HPMS and by the traffic counts may be updated with new information, the historical VMT data in the Traffic Volume Trends are regularly updated. These revisions can extend back a few years from the most current report. Hence, current VMT estimates usually undergo several modest revisions before becoming set and final.

The sensor-based methodology described above permits the FHWA to evaluate VMT by region and roadway type. It also provides information on vehicle classification and for example informs how much of the mileage applies to trucks versus light-duty vehicles. Because the information is disaggregated by roadway type, total VMT by vehicle type on roadway type (e.g., an estimate of VMT of motorcycles on rural interstates) is extractable from the HPMS data. However, only annual estimates at this resolution are published in the Highway Statistics Series (FHWA). Furthermore, a distinction cannot be made between commercial versus personal travel in light-duty vehicles.

VMT Trends from the Traffic Volume Trends

The recent decline in VMT is not the largest recorded but it is the longest stagnation of VMT growth in U.S. history.

The Public Roads Administration of the Federal Works Agency published the first TVT report (based on archives) in April of 1942 (FHWA, 2011b). The modern TVT data begins in January 1970. Because 12 months of data is required to calculate this value, the first moving 12-month VMT measurement was produced for January 1971 and has been reported monthly ever since. As it is an estimate encompassing all vehicles on American roads, it is influenced by changes in driving distances, changes in population, and changes in freight activity from over-the-road shipping.

Since World War II, VMT has been growing rather steadily, but at a gradually decreasing rate. Brief interruptions in the trend occurred during recessions, but outside of these anomalies, VMT growth has been remarkably consistent and predictable for much of its measured history. That was the case until November 2007, when the series peaked at 3,039 billion miles and then exhibited a decline in magnitude not seen at any other time during the post-World War II era. This decline was followed by an extended period of no growth. More recently, VMT passed the 2007 peak and is currently increasing to new record highs. Figure 2-2 shows the TVT-reported trend of VMT through November 2015.

Figure 2-2: Trend of National VMT for 1971-2015

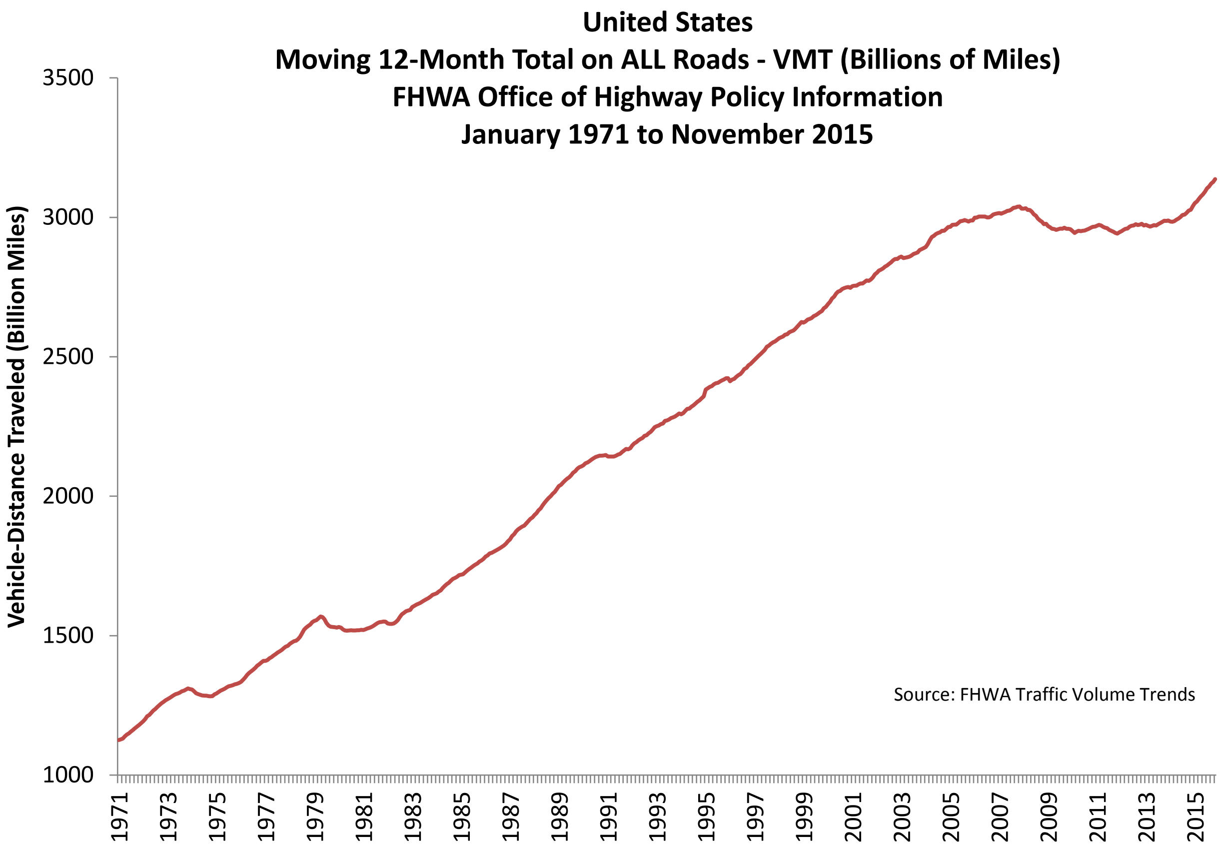
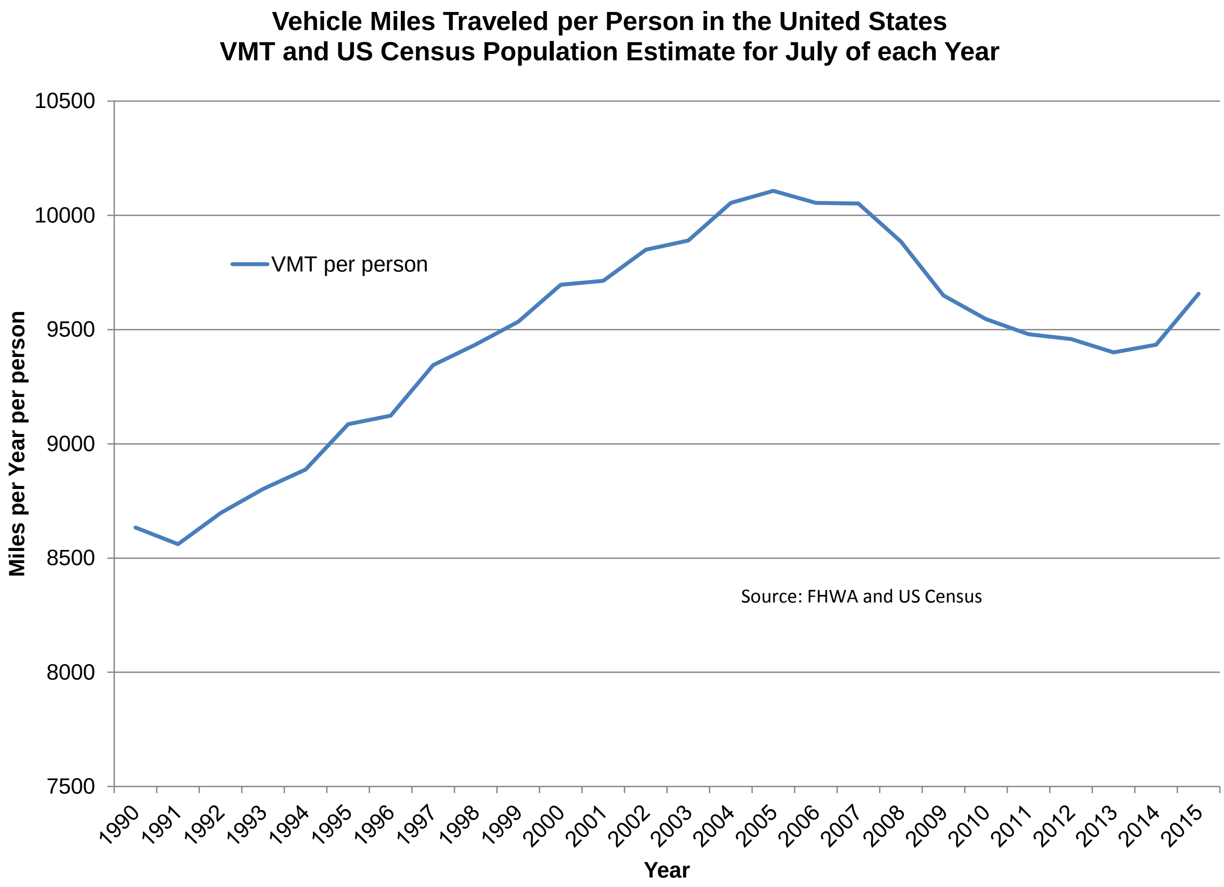


Figure 2-2 shows that VMT is once again growing after a sizable decline and an unprecedented period of stagnation during the economic recovery following the Great Recession. Historically, only the middle of World War II saw a larger decline in VMT. From 1941 to 1943, annual VMT declined from 334 billion miles to 208 billion miles, larger in both magnitude and percentage than the most recent VMT decline after 2007 (which was about 97 billion miles). However, by 1946, annual VMT had fully recovered to 341 billion miles, a peak-to-recovery period of five years (FHWA, 2015). The most recent peak-to-recovery time is 7.25 years, spanning November 2007 to February 2015. The recent decline in VMT is not the largest recorded, but it is the longest stagnation of VMT growth in U.S. history.

Because VMT includes the effects of population growth, a measure of VMT per person is needed to understand whether Americans are on average driving more. This is shown in Figure 2-3 and is calculated by dividing the series in Figure 2-2, above, by the U.S. Census estimate of the population of the whole United States in July of each year.

Figure 2-3: VMT per Person in the United States



Since 1990, the U.S. population, estimated to be 321 million as of July 2015, has been growing an average of 1% per year, and this rate of growth has been slowly declining. Recently, from July 2014 to July 2015, the U.S. population was estimated to have grown about 0.75%. Figure 2-3 shows that the average VMT per person has thus far peaked in 2005, which is a full two years before the 2007 peak of VMT before the Great Recession. Since then, it had been in continuous decline through 2014 to about 9,433 miles driven per person, before rapidly increasing to 9656 in 2015. This most recent increase is among the fastest year-over-year increases in the last 25 years. Low gas prices are likely contributors to this recent increase, and may indicate a return to record levels of driving.

Prior to 2015, VMT per person had been on a gentle downward slope. But the latest data point breaks this trend. It may be the result of what is now a robust economy coupled with persistently low gasoline prices.   Because VMT per person is appears to be recovering rapidly, a continuation of low gas prices under current economic conditions could usher in a return to driving levels experienced back when VMT per person peaked in the middle of last decade. Alternatively, the surge may be a temporary recovery, as the conditions for more driving are currently ideal (e.g, good economy, cheap energy). If gasoline prices increase or the economy begins to experience a slowing recovery, VMT per person may remain below its present peak for the foreseeable future.

Highway Statistics Series Measurement of VMT

The Highway Statistics Series is another federal publication that reports VMT (as well as other measures like PMT) using inputs similar to those for the data reported by the Traffic Volume Trends (FHWA, 2013). The Highway Statistics Series publishes VMT as disaggregated by roadway and vehicle type on an annual basis, whereas the TVT does not disaggregate by vehicle type. This additional dimension is naturally useful for understanding the relative contribution of other modes like truck traffic to overall VMT. The Highway Statistics Series has a unique history of publication. VMT data reported by the publication has been collected as far back as 1900, but these data were rendered in individual tables rather than as part of any single publication. Based on FHWA archives, disaggregation of VMT by vehicle type began in 1936. At that time, however, the data were still rendered in individual tables. The first Highway Statistics Series was later published in 1945, placing all of the data tables into a single pamphlet. The series has been published annually ever since.

During the most recent years following the Great Recession, passenger VMT has increased modestly, while truck VMT has decreased modestly.

Figure 2-4 shows a plot of annual VMT data from an assembly of the measurements produced across these publications back to 1900 (FHWA, 2013c). This series shows all of the major events in VMT history, including the unprecedented decline during World War II and the recent stagnation. Beginning in 1936, the series shows the disaggregation of VMT by trucks and passenger vehicles. In two separate years, the FHWA reclassified how it aggregated VMT across vehicle types; this resulted in two separate years in which these disaggregated series are disjointed, 1966 and 2007. The latter was unfortunately timed, as it coincided with the year VMT peaked prior to the Great Recession. Nonetheless, this disaggregation shows that passenger vehicles are responsible for the overwhelming share of VMT. During the most recent years following the Great Recession, passenger VMT has increased modestly, while truck VMT has decreased modestly.

Figure 2-4: Annual VMT by Freight and Passenger Vehicle Type

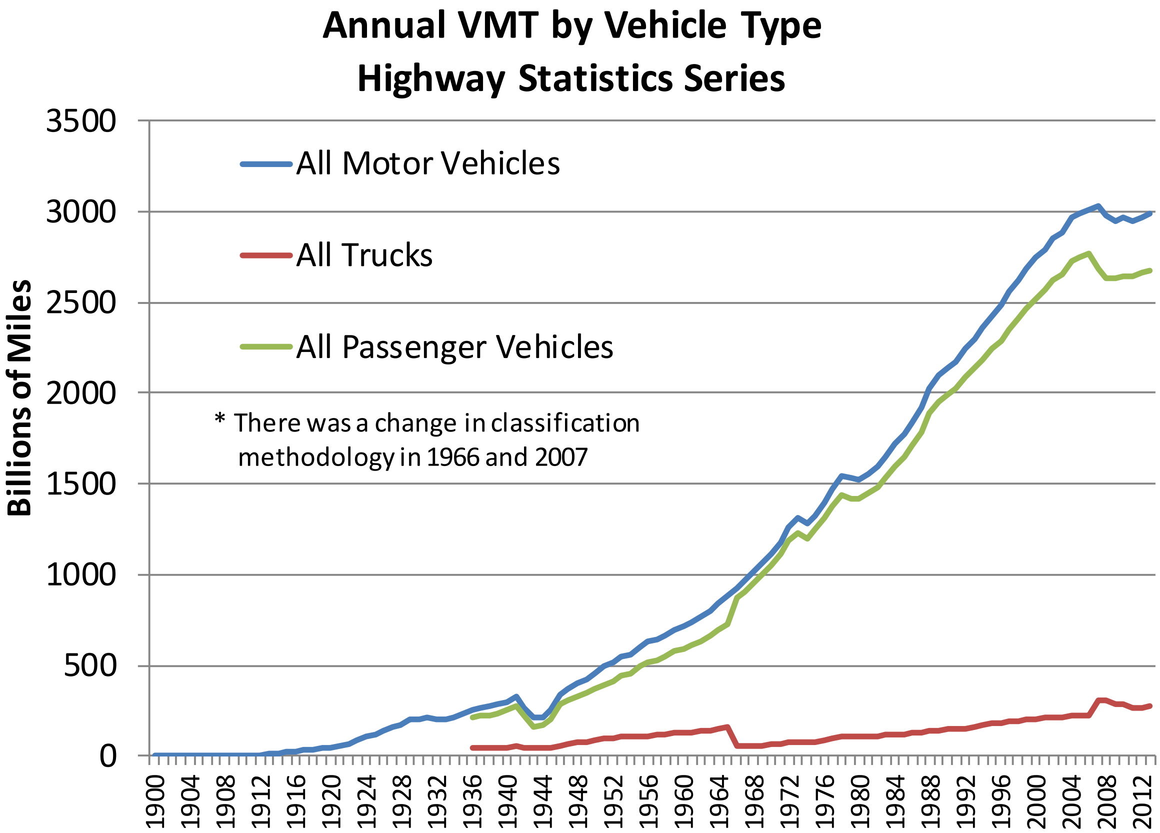


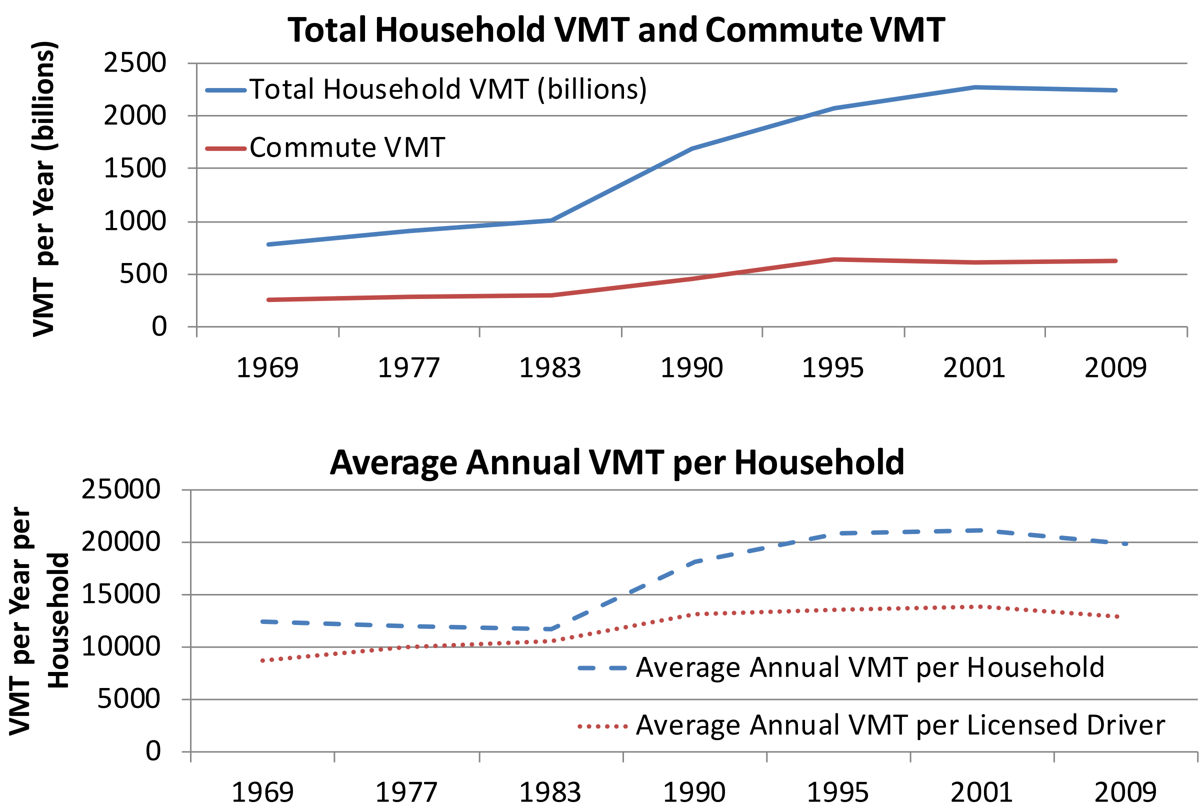
Figure 2-4 shows that passenger transportation has strongly driven VMT. In 2013, nearly 90% of VMT was from passenger vehicles, while 9% was from large trucks, and the remaining 1% belonged to buses and motorcycles. However, the break in trend of VMT is evident as well in both passenger and truck transportation. This insight is not apparent in the aggregate measurement shown in Figure 2-2. Figure 2-4 shows that the major drivers of VMT growth experienced a change in the rate of growth following 2007.

NHTS Measurement of VMT

Beyond the measurements produced through sensor-based sources such as the TVT and the Highway Statistics Series, VMT is also separately measured by the NHTS. The NHTS has been completed in 1969, 1977, 1983, 1990, 1995, 2001, and 2009, providing comparative snapshots of travel spanning four decades. The NHTS focuses on non-commercial personal travel and does not include any measurement of large-scale freight activity. Moreover, because NHTS is informed by the weighted observations of thousands of travel diaries, it allows the disaggregation of travel activity in a myriad of ways not possible with the aggregate statistics of the TVT or the Highway Statistics Series. For example, the NHTS permits a disaggregation of VMT by trip purpose, including a measurement of VMT for commuting and other types of non-work travel. Breakdowns of travel by region and demographics are also possible with NHTS data.

Figure 2-5 shows a collection of high-level measurements of VMT from the NHTS. The top figure shows the NHTS measurement of total annual household VMT. In 2009, the NHTS estimated that total household VMT was 2,245 billion miles traveled, and total commute VMT was 623 billion miles traveled. The NHTS-derived VMT was also modestly lower (by 1.5%) in 2009 versus in 2001. The lower graph of Figure 2-5 shows the NHTS measurement of VMT per household and VMT per licensed driver, which also registered a decline with the 2009 survey. It is estimated that the average household VMT was 19,850 per year in 2009, down about 6.3% from the peak of 21,187 in 2001. The average VMT per licensed driver was 12,888 in 2009, also down 6.8% from 13,827 in 2001.

Figure 2-5: VMT Measurements as Derived from the NHTS



Although not perfectly aligned, the measurements of VMT as derived from the NHTS exhibit general agreement with the trends derived from the TVT and Highway Statistics Series measurements. All of these sources state that VMT growth has experienced a general attenuation during the most recent decade. The 2009 NHTS was the first to show a decline in Total Household VMT, Average Annual VMT per Household, and Average Annual VMT per Licensed Driver. Only Total Commute VMT registered its first decline earlier in 2001.

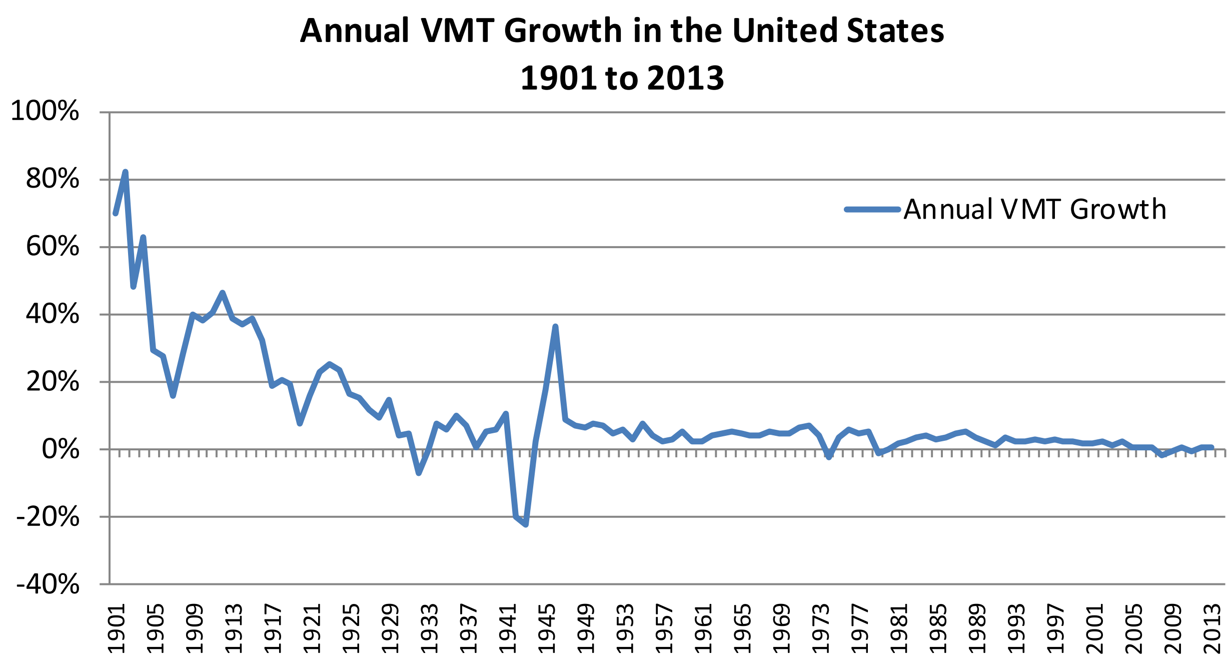
Both the NHTS and TVT assessments of VMT have suggested a broader change in travel behavior in recent years. Driving a car clearly still plays a major role in American travel behavior, but the rate of increase of driving per person has experienced some unique and unprecedented changes in recent years. This dynamic was evident within measures that include and exclude freight, and appeared to persist even during much of the economic recovery following 2009. In fact, the declining growth of VMT appears to be part of a larger trend that has been ongoing for decades, as opposed to strictly an anomaly of the recent recession. Evidence to this effect will be presented in the following section.

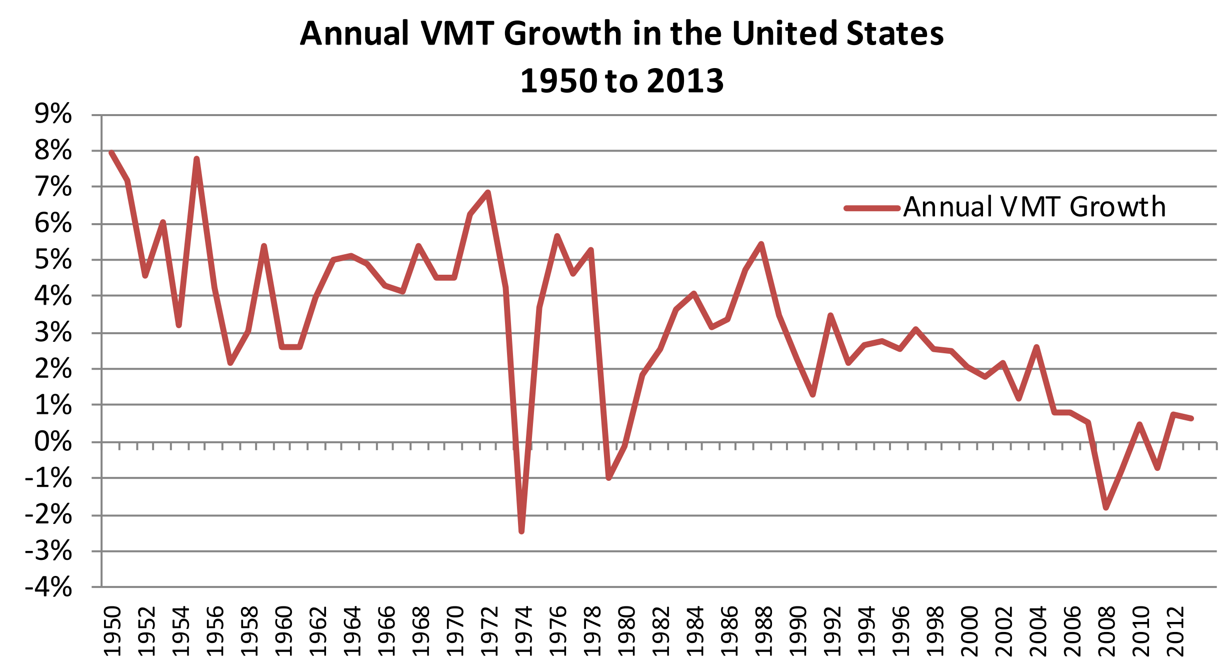
FHWA Forecasting of VMT

The forecasting of VMT is an important exercise conducted by local, state, and federal governments that is used to project funding needs for the coming years. These forecasts are reported to Congress on an annual basis in the form of the Conditions and Performance Report (FHWA, 2013d). The report covers all aspects of conditions and performance, including infrastructure and safety, and one of the key discussions includes the scenarios of VMT growth. FHWA has traditionally assumed two scenarios for forecasting VMT growth. One scenario is called the “forecast VMT growth,” and the other is called the “trend VMT growth.” The “forecast VMT growth” is derived from the HPMS, as an aggregation of forecasts submitted to the FHWA by the states. For each of the roughly 100,000 sections of highway in the HPMS, the states annually submit a current AADT value and a forecasted AADT value. The “forecast VMT growth” is a compilation of these individual AADT forecasts from these individual sections. The advantage of this approach is that the forecasts reflect the states’ local knowledge of traffic conditions as well as their own long-range planning assumptions. The “trend VMT growth” is an alternative forecast, which adjusts the “forecast VMT growth” to match the 15-year trend (or average growth rate) from 1995 to 2010. The downward adjustment is applied uniformly to all of the submitted HPMS forecasts (FHWA, 2013d). Both of these growth rates are considered constant (on average) for 20 years to achieve year-by-year estimates through 2013. In the 2013 conditions report, the HPMS-based “forecast VMT growth” rate was 1.85 percent and the “trend VMT growth” was 1.36 percent (FHWA, 2013d). These VMT forecasts are fed into the Highway Economic Requirements System (HERS) model to determine Capital Investment Needs for the intervening 20-year period.

Given the recent stagnation in VMT growth, it has become rational to question whether the forecasted growth rates produced by these traditional methods are too high. However, it is also plausible to argue that the recent period is more of an anomaly, to be followed by a robust recovery, such as what happened after World War II. This robust recovery may in fact be happening as seen in the latest data within Figure 2-2. However, a review of the historical growth rates of VMT suggests that the recovery may not be as robust or sustained as projected in the “trend” or “forecast” growth rates suggest over the long-term, and that the lower VMT growth rates witnessed today are part of a broader dynamic that has been ongoing for decades. Figure 2-6 shows this dynamic through a plot of the annual growth rate of VMT in two graphs through 2013 using data from the Highway Statistics publication.

Figure 2-6: VMT Growth Rates in the United States during the 20th and Early 21st Century





The top graph shows the entire series of annual growth since 1900, while the bottom shows the same growth rate just from 1950 to get a better resolution on the events of today. The exponential rate of decline is evident in the top graph, while a more linear trend in decline is evident in the "zoomed in" bottom graph. Both suggest that the decline in VMT growth observed today is part of a longer-term dynamic that extends beyond the influence of any single economic period. The trends evident in Figure 2-6 suggests that a sustained recovery of VMT growth rates at or above levels above 1% would counter a process that has been ongoing throughout boom and bust cycles spanning decades. However, the bottom portion of Figure 2-6 also shows that temporary periods of high growth have occurred in recent decades, and that growth in VMT is subject to some considerable volatility over short periods.

In recognition of a possible overestimation of VMT growth exhibited by the traditional forecast methods, the FHWA has developed a newer model for VMT forecasting (Sundquist, 2013). This method was advanced by researchers at the Volpe Center and the first forecast from it was released in 2014 (Pickrell et al., 2014). This modeling framework uses predictions in demographic and economic changes to determine likely VMT responses. The model framework is developed based on a number of considerations following the economic theory of travel demand. Different factors are selected for the four vehicular categories: light-duty vehicles, single-unit trucks, combination trucks, and buses. A number of explanatory variables were tested for each model. These explanatory variables fall under the general categories of:

1. Demographic characteristics
2. Economic activity or income measures
3. Cost of driving
4. Vehicle price
5. Road supply
6. Employment
7. Transit service

Data for these variables are retrieved from the Highway Statistics publication of the FHWA, the Energy Information Administration (EIA), R.L. Polk, the U.S. Bureau of the Census, and the U.S. Department of Labor (Pickrell et al., 2014). The data range from 43 to 47 consecutive years. The Volpe Center method developed forecasts of road supply and fuel efficiency, and all input forecasts were scenario-based. An application of this modeling framework using baseline, pessimistic, and optimistic economic outlooks was released in 2014 (Office of Highway Policy and Information, 2014). The estimates of VMT growth from this model are lower than those released in the Conditions and Performance Reports of recent years (Woodruff and Baxandall, 2015). These forecasts generated annualized growth rates, which are reproduced in Table 2-1.

Table 2-1: Projected Growth in Vehicle Miles Traveled (VMT), May 2014

Vehicle Class	Pessimistic Economic Outlook		Baseline Economic Outlook		Optimistic Economic Outlook	
	2012-2032 (20 Year)	2012-2042 (30 Year)	2012-2032 (20 Year)	2012-2042 (30 Year)	2012-2032 (20 Year)	2012-2042 (30 Year)
Light-Duty Vehicles	0.92%	0.65%	0.98%	0.67%	1.04%	0.71%
Single-Unit Trucks	0.65%	0.53%	1.46%	1.16%	2.06%	1.57%
Combination Trucks	1.39%	1.30%	1.75%	1.60%	2.06%	1.87%
TOTAL	0.94%	0.69%	1.04%	0.75%	1.14%	0.82%

[Reproduced from Office of Highway Policy and Information, 2014]

It remains to be seen how accurate these new forecasts of VMT will be. As they are all lower than the generally overestimated "trend VMT growth" forecast, these new rates are likely to be closer to the growth rates actually observed than the previously used VMT forecast methods. The pessimistic 20-year forecast is still higher than the average annual VMT growth rate from 2001 to 2010 (0.78% annually, but this includes the Great Recession). From 2000 to 2013, the average growth rate was 0.66%, and this wholly includes the Great Recession and VMT stagnation. If these are anomalies in the broader trend of VMT growth, then the revised FHWA forecast may be closer to being correct. For this to be the case, the next twenty years will have to exhibit a more robust VMT growth than witnessed thus far during the first 15 years of the 21st century.

The Limitation of the VMT Measure

VMT has a number of limitations for understanding travel behavior. Namely, VMT counts vehicles and not people, so increased use of public transit will not be observed in VMT (other than in the form of a decline in VMT or lack of expected growth). The same is true for walking and bicycling, both of which occur primarily on local roads and would be unmeasured by existing sensor-based VMT measurement methodologies. Furthermore, the VMT metric is generally a highway-focused estimate with a number of assumptions and sampling embedded in its calculation. If transportation activity shifts away from the reliance on single occupancy vehicles, VMT will only reflect these shifts in the form of declines or unrealized growth. In addition, VMT data derived from the HPMS and TVT do not distinguish between commercial and household travel. It may be less able to provide policy insights as to how travel behavior has shifted and thus has limited ability to inform effective investment strategies. Nevertheless, VMT is important for its ability to track travel consistently over time. While the association of VMT with economic growth may be decoupling, it still has implications for mobility and safety that are likely to persist for many years.

To gain a more complete picture of travel behavior, other measurements can also provide insights as to how travel is changing. In the sections that follow, we explore trends in PMT as well as other key travel descriptors, such as mode shift and vehicle ownership, to gain better insights as to how travel is evolving outside of the personal vehicle.

Trends and Measurement of Person Miles Traveled (PMT)

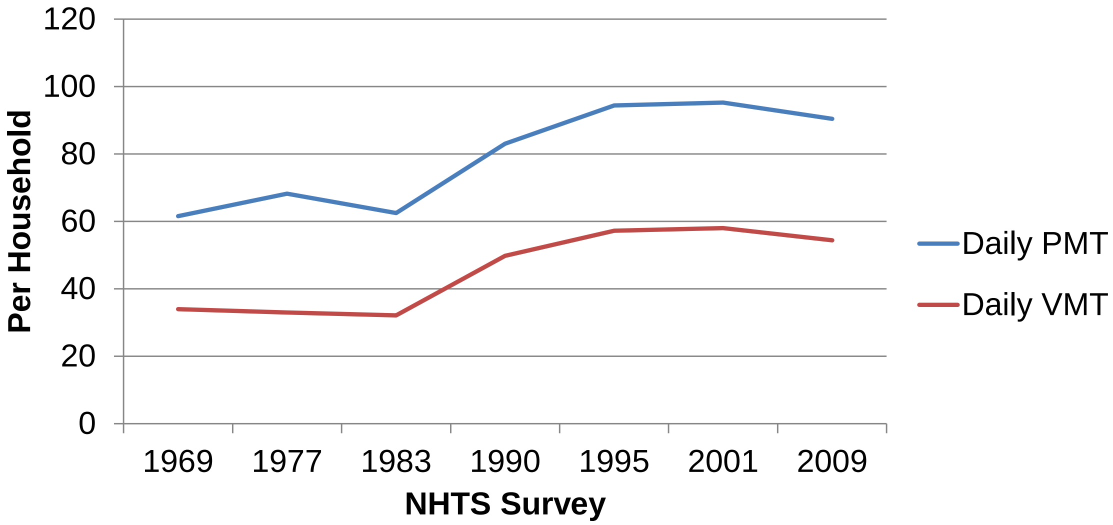
PMT is another very important measurement of transportation activity. It measures the number of miles traveled by each person on a trip. Unlike VMT, PMT includes both motorized and non-motorized modes, and it includes all persons taking that same trip together. It includes high-occupancy modes such as public transit, for example bus and rail. Because the travel measured in PMT is more difficult to detect with sensors, it is primarily informed by self-reported data as supplied by surveys, and can also be measured by wearable or in-vehicle GPS-enabled technology. A GPS-based travel survey was first sponsored by the FHWA in 1996 in Kentucky, and applications using GPS have become more common with the proliferation of smartphones and improved satellite capabilities. While this approach is useful for capturing modes other than driving, there are data collection concerns associated with the ubiquitous use of it. Thus, in one form or another, the PMT data available today are primarily derived from the NHTS or similar surveys conducted at the state or local level.

PMT Measurement in the NHTS

The NHTS effectively constructs its travel measurements through respondent travel diaries. The travel diaries are distributed to respondents across all 365 days of the year. The data from each travel diary are weighted to represent the number of people in the population that are engaged in similar travel. An aggregation of all weighted activity is used to extract population-level measurements of PMT, as well as any other measures collected within the survey.

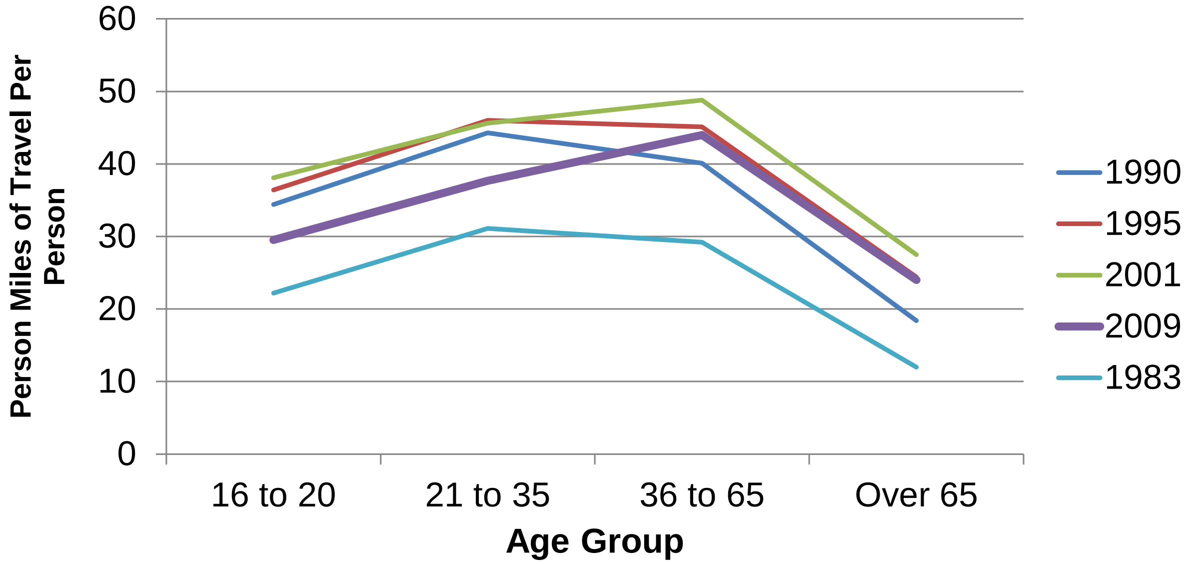
The NHTS has found that people traveled fewer miles in 2009, as compared to 1995 and 2001, as well as made fewer trips per person (FHWA, 2009). The 2009 NHTS also showed that daily VMT was lower than reported in 2001 and 1995 (McGuckin, 2011). This is somewhat in contrast with the VMT series reported in the previous section where VMT in 1995 is lower than in 2009. One key difference is that NHTS reports VMT derived from household travel, and the HPMS reports all VMT derived from counting vehicles on roadways. The falling PMT and VMT per household uncovered in the more recent NHTS survey suggest that travel demand on a per household basis has been stagnant or modestly declining. Figure 2-7 shows the trends in household VMT and PMT over all NHTS surveys.

Figure 2-7: PMT and VMT Trends



The NHTS provides rich detail on why this travel is shifting in a number of ways. One example is an apparent generational gap in travel, with younger cohorts traveling considerably less than the same younger cohorts have in earlier surveys. Figure 2-8 shows data from four NHTS surveys from 1990 to 2009, as presented in FHWA (2011a). The NHTS also showed that the daily PMT was about the same for public transit, yet 10% less for personal vehicles and other modes (FHWA, 2011a). These data showed that the decline in PMT by private vehicle was across most trip types (though not by the same magnitude).

Figure 2-8: Person Miles of Travel across Age Groups between 1990 and 2009 (FHWA, 2011a)



PMT Measurement in the Highway Statistics Series

The data from the NHTS has also informed measures of PMT that are derived from other data that are outside of the NHTS. The occupancy data supplied by successive NHTS surveys have been applied to generate aggregate estimates of PMT using the aggregate VMT estimates as segregated by vehicle class. Effectively, average occupancy rates as derived from the NHTS were applied to the VMT observed within vehicle classes. These PMT estimates began in 1996 within the Highway Statistics Series. Because the classification scheme changed in 2007, the data series before and after this year are not comparable. Figure 2-9 shows the estimated PMT trend prior to and after the 2007 vehicle reclassification.

Figure 2-9: Person Miles Traveled by Motorized Mode (1996 to 2006)

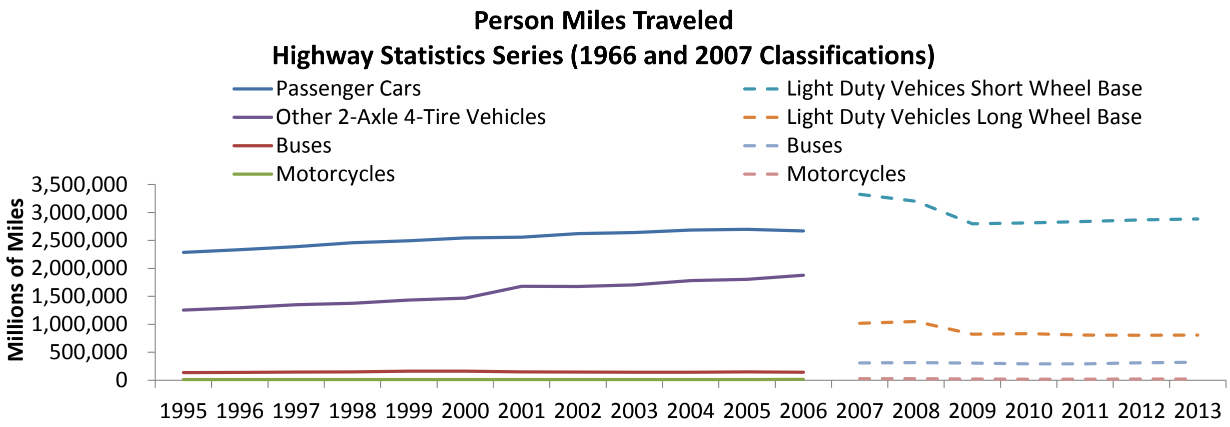


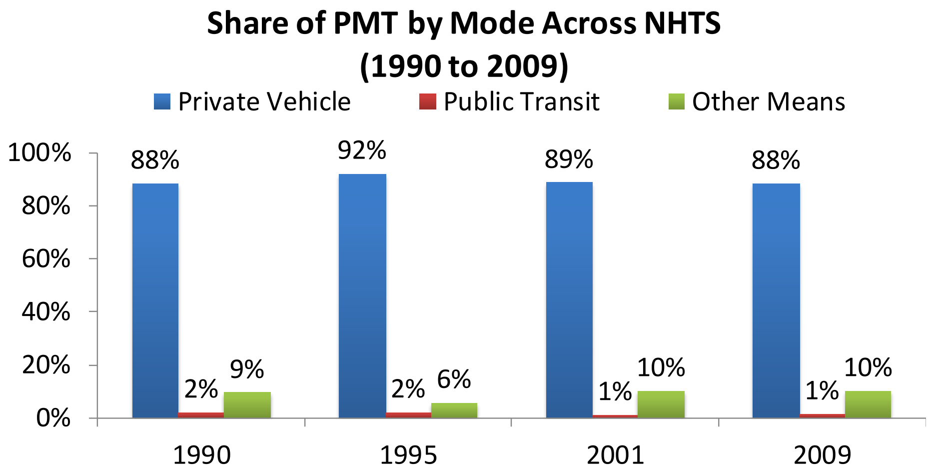
Figure 2-9 shows increasing PMT prior to 2007, which is synonymous with the increase in VMT during this period. The 2007 reclassification allocates more vehicles from the “Other 2-Axle 4-Tire” class to the “Light-Duty Short Wheel Base” class. The most notable change observed with the Highway Statistics translation of the PMT trend is the decline observed solely among light-duty vehicles. The change in bus PMT is negligible, and in fact it increased slightly.

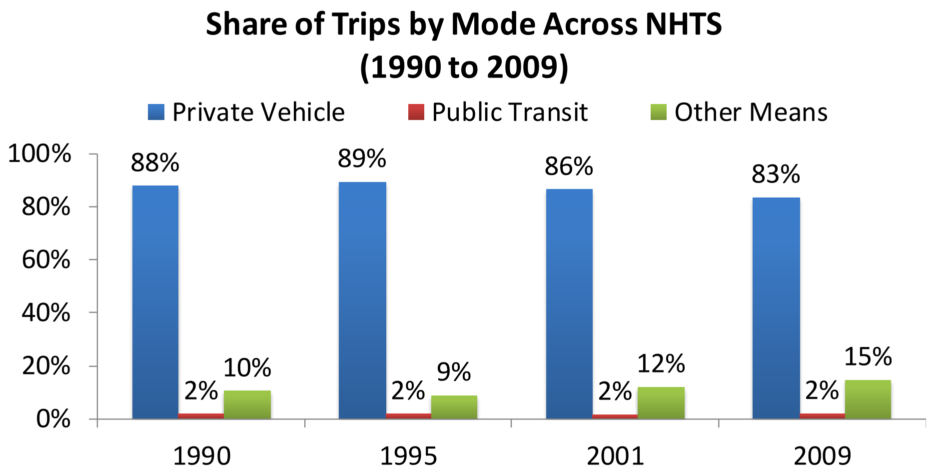
The Highway Statistics Series data on PMT by mode is a very rough estimate of activity by mode. As it is an application of constant occupancy factors taken from the NHTS to vehicle activity, it is subject to great uncertainty since the occupancy is assumed over a very large population. Furthermore, it is not inclusive of either PMT from walking, bicycling, or rail modes, or from activity not measured by the traditional HMPS data. The NHTS and similar travel surveys are the only sources that cover these gaps on mode share PMT.

Measurements of PMT by Mode and Related Challenges

The NHTS indicates that the majority of PMT in 2009 was achieved by automobile in 2009, and that PMT by public transportation has not changed much. Figure 2-10 shows data processed from the summary travel trends of the NHTS for the surveys since 1990. The top graph plots the percentage of PMT across all trips by private vehicle, public transit, and other means, which includes walking and bicycling. The graph shows the dominance of private vehicles through the most recent 2009 survey, with only a modest decline since 1995. Because private vehicles are generally used for longer trips, the balance of PMT toward private vehicles is perhaps not surprising. A similar dominance, however, is evident in the bottom graph of Figure 2-10, which shows the NHTS mode split by number of trips. Here a shift away from private vehicles is more evident in 2009 for trip choice, with most of the substitution occurring toward non-public transit modes, like walking and bicycling, which here are defined as other means.

Figure 2-10: PMT and Trips by Mode by NHTS





Measurements of PMT thus far through the NHTS and Highway Statistics Series broadly show a continued dominance of the private vehicle in American travel. The NHTS does show that there has been a shift away from the personal vehicle for what are likely shorter trips. Americans opted to walk or use bicycles for trips that were within practical distances for these modes.

As these and other modes become more prominent, accurate measurement of PMT will be increasingly important for understanding the implications on mobility, safety, and economic growth. Different populations will obtain mobility in different ways, as some demographic groups will rely heavily on modes that add to PMT but not VMT. Understanding these and other changes draws attention to the measurement of PMT. PMT is far more challenging to measure than VMT given prevailing technologies. VMT measurement is supported by a vast sensing infrastructure and sampling efforts across the country. Measurement of PMT requires information on vehicle occupancy and distance measurements that are difficult to capture over a large population, such as with walking and bicycling.

Accurate measurement of PMT will be increasingly important for understanding the implications on mobility, safety, and economic growth.

Through the past several decades to 2009, the prevailing technology for measuring PMT has been predominantly through travel surveys with travel diaries. At the national level, the only source for PMT is the NHTS. The NHTS includes self-reported mileage on all modes of travel. While this is a source of error, it is the only national data source with which one can construct both VMT and PMT by vehicle type, demographics, geography, mode, and other survey-collected attributes. The advent of the smartphone, which emerged in the middle of the 2000s, has opened new possibilities for PMT measurement that will become standard in the future. Smartphone applications that leverage GPS data collection over mass populations have great potential to improve the measurement of travel in the future, particularly PMT. Indeed, some of the first efforts to incorporate GPS measurement have occurred with the implementation of regional travel surveys, such as in Chicago (CMAP, 2011). A more detailed description of these and other emerging methods is covered in Chapter 5 of this report.

Measurements of PMT provide insights into the broader level of travel, accounting for all modes. One of the key factors governing PMT movements is how modal splits have evolved over time and across regions. Further, vehicle ownership plays an important role in defining the travel options available, as well as the propensity to drive. The underlying trends of these contributing factors to PMT are addressed in greater detail in the following section.

Trends in Modal Splits and Vehicle Ownership

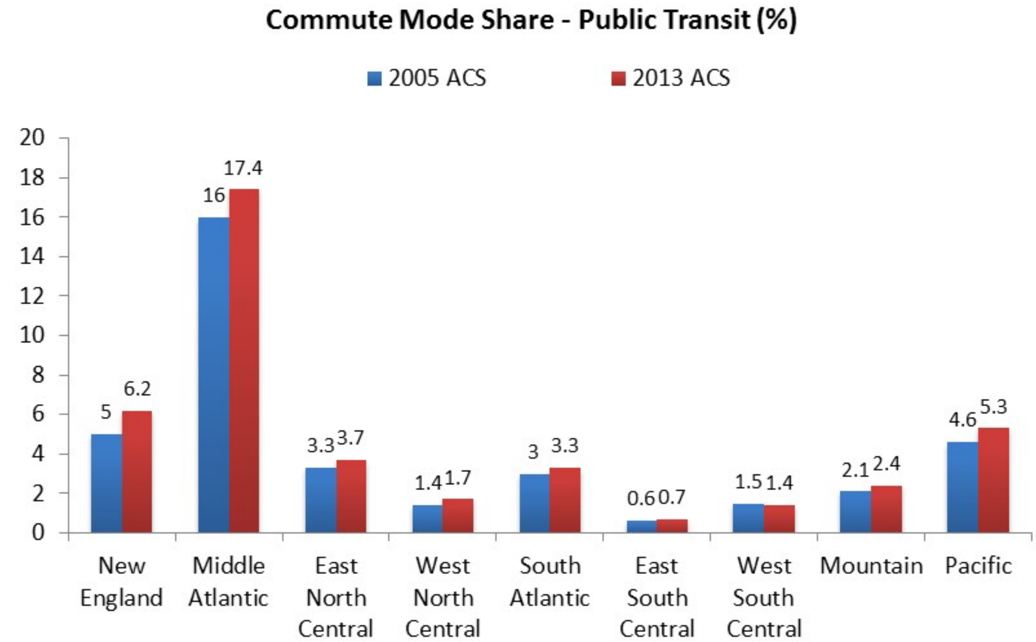
“Modal split” refers to which mode of transportation (e.g., private vehicle, bus, rail, walking, bicycling) people use to make trips, either for work or for non-work purposes. By understanding the trends of how people choose to travel, policymakers and planners can make informed decisions related to infrastructure investment, as well as mitigating transportation-related emissions and energy consumption.

Regional Changes in Modal Share for Commuting

At the national level, mode split data are collected by the NHTS and the Journey to Work section of the American Community Survey (ACS). As outlined before, private vehicles comprise the largest portion of the national modal split. Among commute trips, the mode share of private vehicles fell slightly from 92.8% in 2001 to 91.4% in 2009.

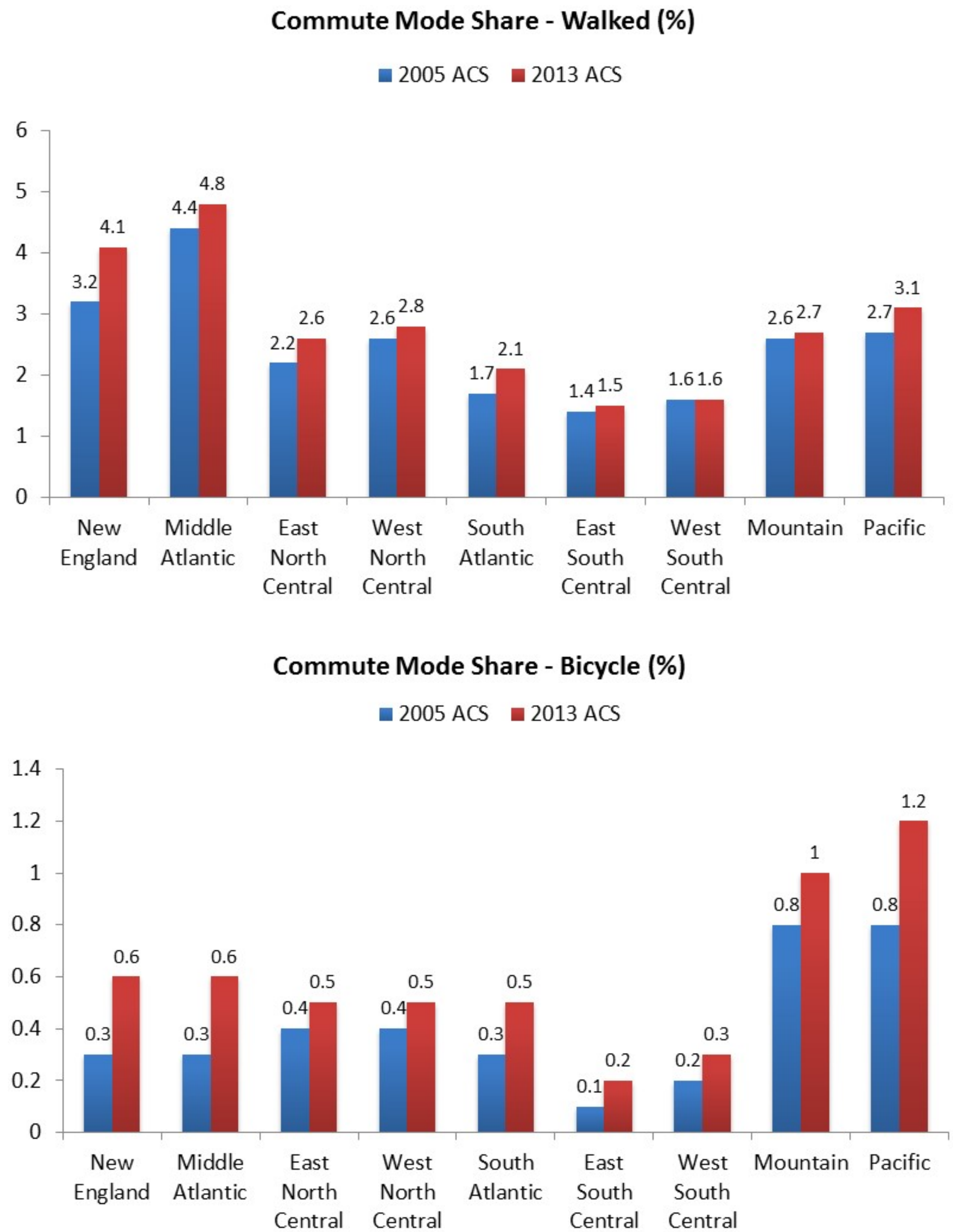
There has been a modest change in the public transit mode share observed at the national level across NHTS surveys. A regional breakdown of more recent public transit modal shifts for commuting shows distinctions in areas of the country that have greater public transit accessibility. Figure 2-11 shows the shift in the commute share of public transit in nine regions of the country, as classified by the U.S. Census. More public transit intensive regions, such as New England, the Mid-Atlantic, and the Pacific, saw some gains in public transit modal share. Most other regions also witnessed some shifts toward transit, though of smaller magnitude. Only one region, the West South Central, experienced a decline in public transit use. Though these gains are small, they run counter to a multi-decadal trend of decline in public transit use and are relatively wide-spread across the country.

Figure 2-11: Commute Mode Share of Public Transit by Region of the Country (2005 v. 2013)



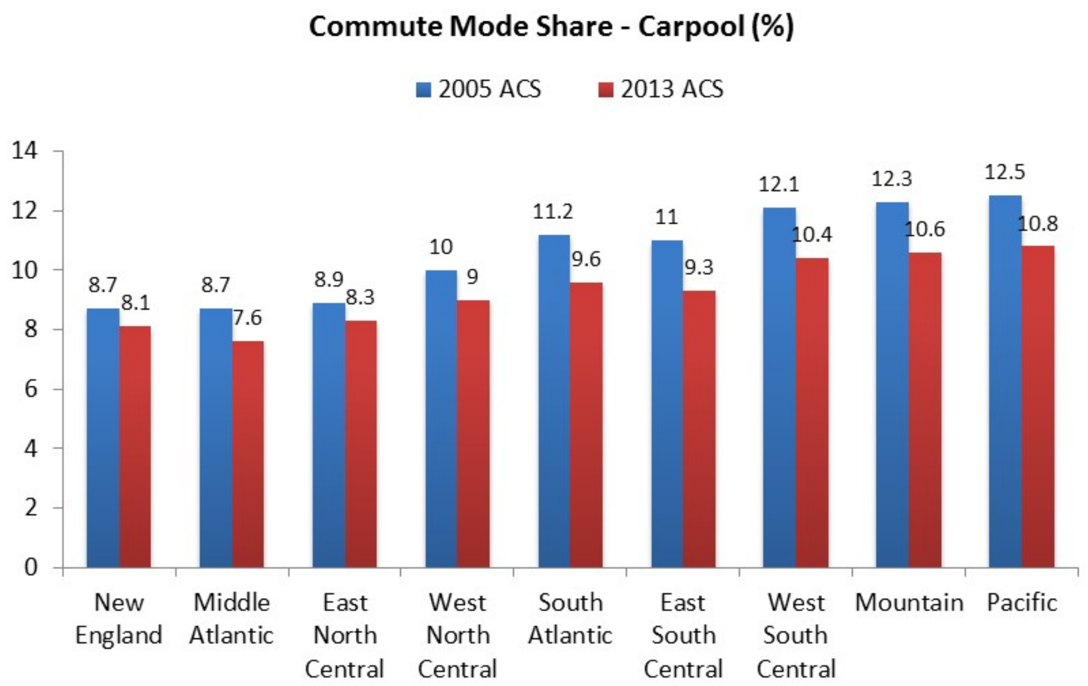
The mode split for walking has also shown a significant increase since the mid-1990s, increasing from 5.4% in 1995 to 10.4% in 2009 through the NHTS. A comparison of ACS-measured mode splits for commuting also shows a rise in the modal share of walking from 2005 to 2013 for commuting. Bicycling is the other major mode that has shown gains over the past decade in relation to walking, but these gains are not as high as walking. Figure 2-12 shows the split in regional differences in modal share for both walking and bicycling. Walking increased almost everywhere, except in the West South Central Division. Bicycling increased everywhere and doubled in New England, the Middle Atlantic, and the East South Central.

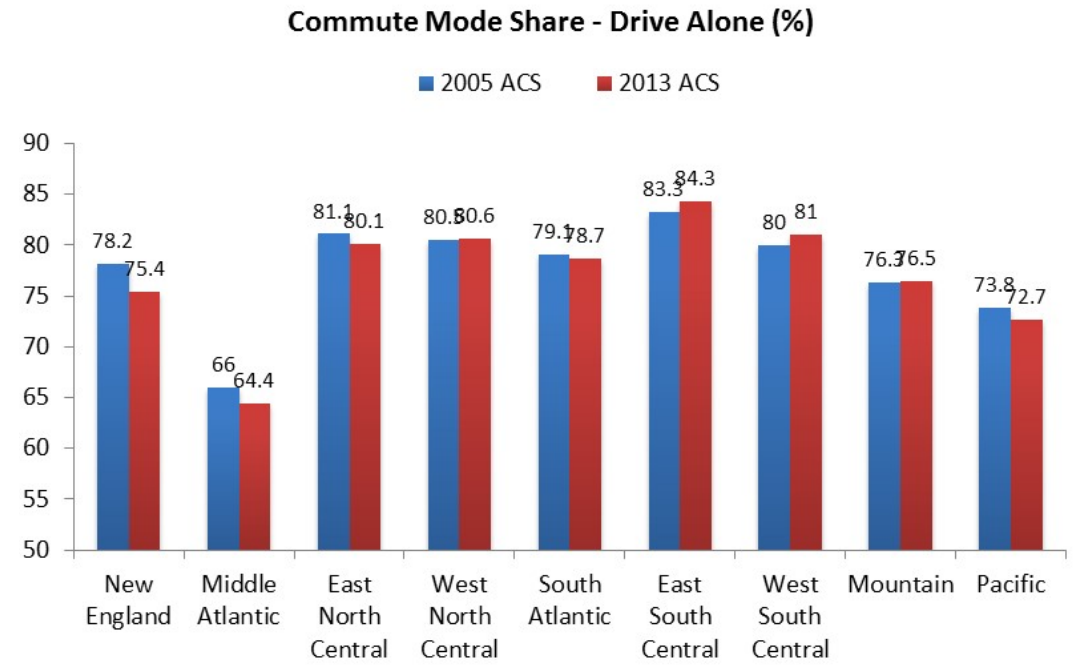
Figure 2-12: Commute Mode Share of Walking and Bicycling by the Country Region (2005 v. 2013)



Naturally, bicycle mode shares have been mostly rising in urban centers, where modal shares within the most bicycle-friendly cities are even higher and can exceed 5%. Portland, Oregon has long been among the most prominent bicycle-friendly cities, with commute modal shares exceeding 6% in recent years. Other top cities, such as Minneapolis, Washington DC, and San Francisco, have bicycle commute mode shares between 3% and 5%. With gains in walking, bicycling, and public transit, there has been a decline in driving. Much of the decline occurred through a reduction in reported carpooling, with more limited declines in driving alone, as shown in Figure 2-13.

Figure 2-13: Commute Mode Share of Driving by Region of the Country (2005 to 2013)





Demographic Associations with Travel Behavior

Demographics are often associated with distinctions in travel behavior. These distinctions occur along the dimensions of gender, age, income, and race. Other contributing factors, such as vehicles available in the household and general occupation, are also critical for determining transportation choices. This section provides an overview of key demographic attributes associated with travel behavior, based on existing data from the ACS and NHTS. Research on demographics and travel behavior are explored in greater depth in Chapter 3, which is devoted to the topic.

Gender

Between 2000 and 2010, women accounted for 60% of the increase in the workforce. As the number of female workers has increased, their commuting patterns have come to more closely reflect those of men. From 2004 onwards, licensed female drivers have outnumbered licensed male drivers on the road (Schwartz, 2014). There are, however, some differences between the modal split of men and woman across trip types. According to the 2009 NHTS, men and women take an equal number of walking trips, but bicycle trips are heavily skewed towards men. Although men comprise up to 49% of the U.S. population, they make 76% of all bicycle trips (Milne, 2014). Nevertheless, bicycle trips represent a small percentage of overall travel.

Age

Among commuters, the modal shares of carpool, public transit, and bicycling are greatest in the 25 to 34 age range and then start to decline as age increases, with the greatest fall in the bicycling mode (ACS, 2010). The NHTS shows not just commuting trips: it reveals that the highest public transit modal share is among 15- to 24-year-olds at around 3% of trips within this age bracket (Polzin et al., 2011). FHWA data show that while the percentage of 20- to 40-year-olds with a driving license has always remained above 80% since 1963; the percent of people who are 60+ and have driver's licenses has been increasing to levels similar to younger people today (Schwartz, 2014).

The 2009 NHTS shows that those under the age of 16, and not eligible to drive, make up 39% of all bicycling trips despite comprising 21% of the U.S. population. Those between the ages of 16 and 64 make up 66% of the U.S. population and account for 73% of all walking trips and 54% of all bicycle trips. Older adults aged over 65 years comprise 13% of the population, but make only 10% of walking trips and 13% of bicycle trips (Milne, 2014).

Race and Ethnicity

> Hispanics carpool, take public transit, bicycle, and walk more than White, non-Hispanic populations.

Race- and ethnicity-related data are important metrics when examining the relationship among socio-economic factors and travel behavior trends. The overall breakdown of modal shares by race and ethnicity is shown in Table 2-2 below. When comparing the travel behavior of Hispanic populations with that of White (non-Hispanic) populations, Hispanics are currently found to carpool, take public transit, bicycle, and walk more than White populations to varying degrees. White non-Hispanics are more likely to drive alone and work at home. According to the Commuting in America report by AASHTO (Pisarski, 2013), there is an even greater disparity between Hispanic and White commuters when looking at carpools that contain four or more participants. Further, the report states that between 2000 and 2010, Hispanics have been driving alone more (rising from 61% to 68%), carpooled less (falling from 23% to 16%), and taken public transit less by about one percent. African-American and Asian populations also showed similar drops in carpooling and increases in driving alone between 2000 and 2010.

Table 2-2: Mode Share Breakdown by Race and Ethnicity

	White*	Hispanic	Asian*	Black*	American Indian*
Drive alone	80.1%	67.8%	67.2%	72.5%	75.0%
Carpool	8.0%	15.8%	13.1%	9.7%	12.6%
Public Transportation	2.9%	7.8%	10.4%	10.9%	3.0%
Bicycle	0.5%	0.7%	0.5%	0.2%	0.3%
Walk	2.6%	3.2%	4.0%	2.6%	3.7%
Work at Home	4.9%	2.8%	3.8%	2.6%	3.8%
Other	1.0%	1.8%	1.0%	1.4%	1.5%
Total	100%	100%	100%	100%	100%

*Non-Hispanic
Source: 2010 ACS (Recreated from AASHTO Report on Commuting)

Income

Increased income within a household has several effects on travel behavior. With increased income, the number of trips increases, the percentage of those who drive alone rises, and commensurately the percent of those taking public transit decreases. According to NHTS surveys over the past two decades, the public transit modal share of those that earn under $15,000 has increased from about 5% in 1995 to around 6% in 2009. Those that earned between $15,000 and $50,000 also experienced a rise in public transit mode share between the 2001 and 2009 NHTS; from about 1.4% to about 2.3%. Among those that earn greater than $50,000, the public transit modal share has remained close to 1% between 1995 and 2009 (Polzin et al., 2011).

The NHTS 2009 data also reveal walking and bicycling mode shares by income distribution. The number of walking and bicycle trips by various income groups is shown to be roughly proportional to each income group's distribution in the U.S. population. The walking mode share across all incomes is 10.4% but is 16.3% among those that earn under $20,000, meaning those with lower incomes are taking more walking trips. The bicycle mode share is roughly 1.0% across all income groups (Milne, 2014).

Vehicles Available in Household

The 2009 NHTS shows that zero-car households with one or more members of the labor force have the highest public transit mode share, which increased from 22% to 25% between 2001 and 2009. In fact, the public transit mode share has increased between the last two iterations of the NHTS in all types of households except those that have one car and one worker in the labor force (Polzin et al., 2011). The AASHTO Commuting in America report cites 2010 ACS figures showing that only 4% of households are without cars and 22% have one car (Pisarski, 2013). Carless households have a heavy transit-oriented modal share travel pattern, but not surprisingly mode share shifts considerably toward drive alone once the household obtains one or more vehicles.

Occupation

The 2009 NHTS asks respondents to categorize their job by general occupation with a focus on identifying which occupations allow employees to work from home more. Over the years, the incidence of working from home has increased with greater technological advancements. The NHTS found that of all workers, about 35% had a flexible arrival time. Those in Professional, Managerial, or Technical professions were most likely to have a flexible arrival time to work (47%), while those in Manufacturing/Construction, Maintenance, and Farming least likely to have flexible hours (21%). Out of all workers, 8.7% worked exclusively from home.

Vehicle Ownership

Vehicle ownership is an important trend to look at for understanding travel behavior, as the number of vehicles that household members have access to greatly affects their mode share and general travel habits. Vehicle ownership is recorded in several ways, including absolute number of registrations, ownership rates per person, per licensed driver, per worker, and per household. There is some evidence to suggest that vehicle ownership rates in the United States may have already peaked and that rates are now in a state of long-term stagnation.

According to the Highway Statistics 2014 report, there were approximately 260 million registered motor vehicles in the United States in 2014 (FHWA, 2015). Light-duty vehicle registrations are of particular interest, as they are primarily used by individuals and are thus important factors governing travel behavior. According to Sivak (2013) the number of registered light-duty vehicles peaked in 2008 at 236.4 million, despite the fact that the population, number of licensed drivers, and households were still increasing.. Sivak (2013) looks at various vehicle ownership rates of private, commercial, and public light-duty vehicles and concludes they all have already peaked:

- The number of vehicles per capita reached a maximum of 0.79 in 2006 and stood at 0.75 as of 2011.
- The number of vehicles per licensed driver was 1.01 in 1984, but peaked at 1.16 in 2001, 2005, and 2006. As of 2011, it was 1.11.

- The vehicles per household reached a maximum of 2.05 in these same years (2001, 2005, and 2006) but fell to 2.00 in 2009 and further down to 1.95 in 2011. This modest decline is also in part corroborated by the 2009 NHTS survey, which showed an all-time peak of 1.89 vehicles per household in 2001 followed by a decline to 1.86 in 2009 (U.S. Department of Transportation, 2011).

Sivak also shows a shift toward older people in the distribution of drivers by age. Moreover, the peak probability of purchasing a vehicle per licensed driver is now among the 55 to 64 age range. It used to be among those who were between 35- and 44-years-old.

Those living in areas with higher population densities were more likely to own fewer vehicles. Furthermore, there has been a slight increase in the percent of households with no vehicles or one vehicle, and a slight decrease in households with two vehicles or three or more vehicles.

While current low rates in vehicle ownership can be attributed to the United States' economic downturn that started in 2008, Sivak (2013) points out that the peaks of all three ownership rates occurred before 2008. This, when coupled with other survey data showing greater public transportation usage and greater incidences of working from home, indicates that lower vehicle ownership rates might be becoming a longer-term trend. As discussed previously, there has been a decrease in private vehicle mode share over the past decade and an increase in public transit, walking, and bicycling (also in telecommuting, as presented later). Thus, there could be the beginnings of a longer-term lifestyle change among Americans that is causing vehicle ownership rates to fall independent of the state of the economy.

Caution should be exercised when looking at these trends due to both the narrow rates of change over previous years. As the U.S. economy continues to recover, it will become clearer whether the changes in ownership rates were solely due to early 21st century economics or also due to societal shifts in travel habits occurring during this period.

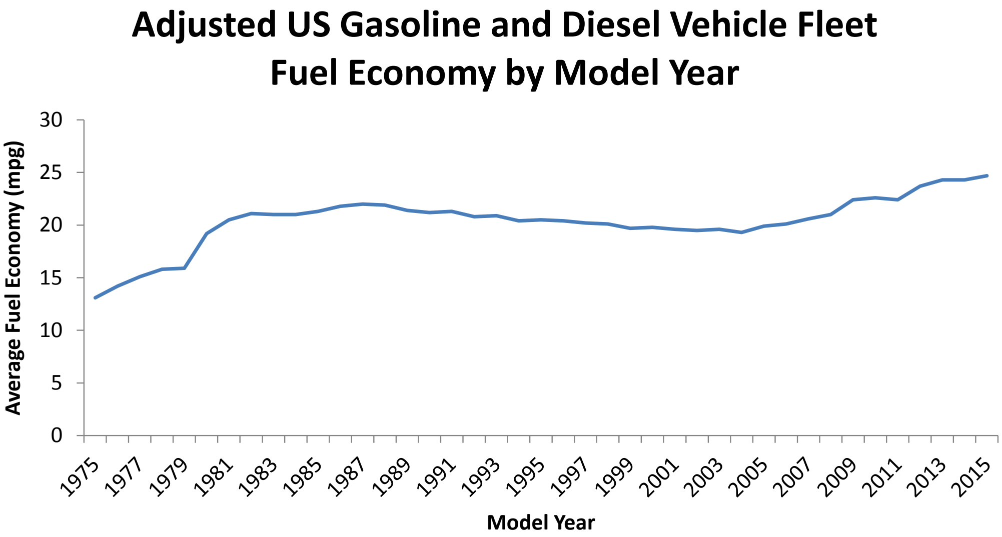
Trends in Alternative Fuel Vehicle Ownership

Electric vehicle sales have seen among the greatest growth in recent years. Plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) both started being sold in 2010. That year, only 326 PHEVs were sold in the form of the Chevrolet Volt, and 19 EVs were sold as Nissan Leafs. Since then, the market has diversified considerably. As of the end of 2015, 193,615 PHEVs and 212,662 EVs have been have been sold in the US (hybridcars.com). While this represents a small fraction of all 260 million registered vehicles in the U.S. (in 2015), the percentage of total new car sales made up by PHEVs has been steadily increasing over the years, from 0.4% in 2012 to 0.7% in 2014. California and Washington lead with the most electric vehicles as a percentage of their total light-duty vehicle fleet, followed by Oregon, Georgia, and Maryland (EIA, 2014a). All these states have at least two EVs per 1,000 registered vehicles. These states offer tax incentives in addition to a federal tax credit for alternative fuel vehicle owners that ranges from $2,500 to $7,500. In addition to tax incentives, states like California have policies such as the zero-emission vehicles credits (ZEV credits) (e.g., EVs, fuel cell vehicles). This policy further incentivizes automakers to sell EVs, particularly in California.

Fuel Economy of Vehicle Fleet

The U.S. Environmental Protection Agency (EPA) has published an annual report on fuel economy trends since 1975. The preliminary 2015 numbers reveal an all-time high for fuel economy at 24.7 miles per gallon (mpg) and an all-time low for CO_2 emissions at 360 grams per mile (g/mi). These numbers are an improvement over the 2014 numbers that showed an average U.S. vehicle fleet fuel economy of 24.3 mpg and CO_2 emissions at 366 g/mi. Figure 2-14 shows this historical trend as the fuel economy by model year.

Figure 2-14: Trend in Average Fuel Economy by Model Year in the U.S.



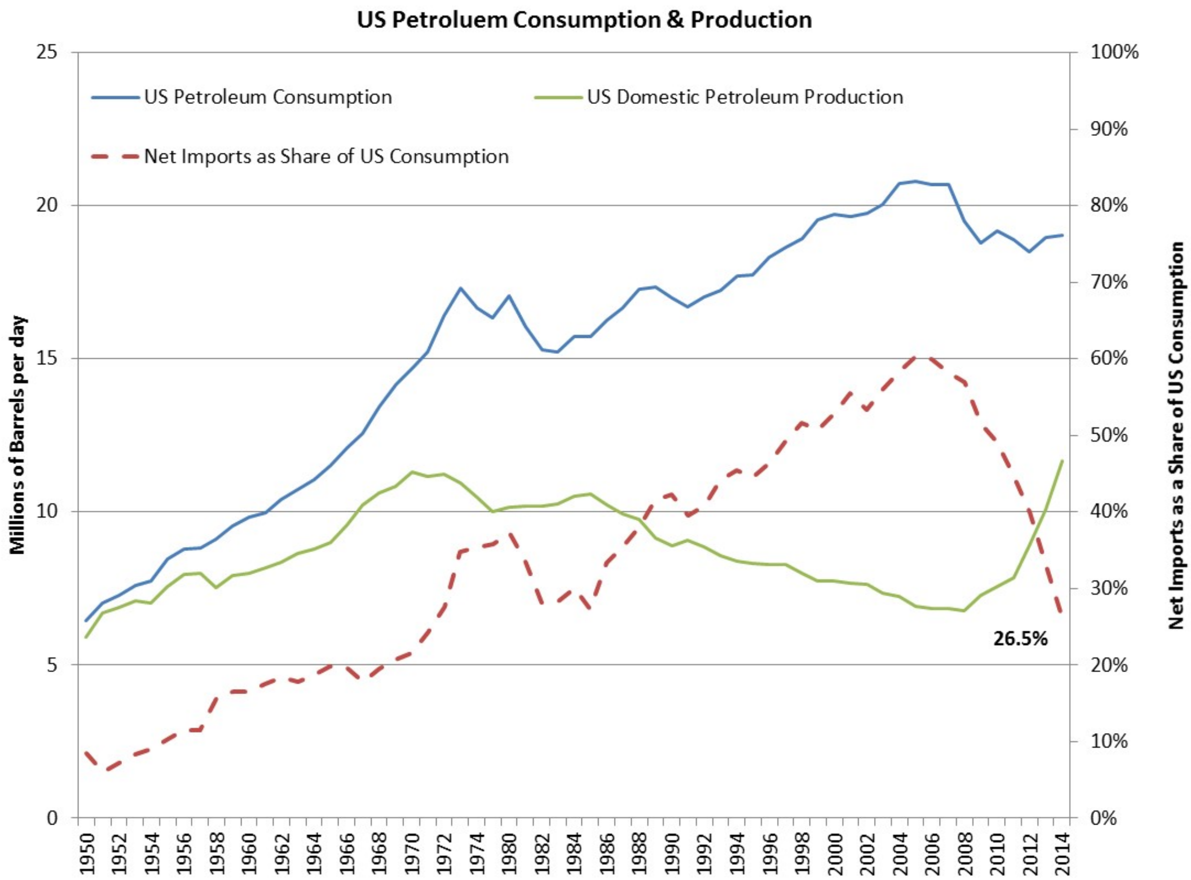
Source: US EPA, Table 2.1, *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2015*, December 2015. Note that these are adjusted values, which reflect real-world performance.

Brief Summary of Trends in Transportation Energy Consumption and Emissions

In 2014, transportation energy consumption made up 27.5% of total energy consumed in the United States (EIA Monthly Review, 2015). This is an increase from 24.6% in 1973, though it is less than the peak of 28.9%, which occurred in 2006. As of 2013, the transportation sector obtained 92.2% of its energy from petroleum, 2.9% from natural gas, and 4.6% from renewable sources. While transportation has long been predominantly powered by petroleum and other fossil fuels, the reduction of transportation energy to 92.2% petroleum represents considerable progress from just a few years ago. In 1973, transportation was 99.8% fossil fuel powered, with 95.8% energy derived from petroleum and 4% derived from natural gas. However, as recently as 2003, these percentages were nearly the same, as 98.9% of transportation was derived from fossil fuels. Petroleum consumption more broadly has been on the decline in the U.S., driven by a combination of an increasing mix of fuel sources, increased efficiency, and reduced VMT.

Figure 2-15 shows the trend in U.S. petroleum consumption and production since the 1950 to 2014, as derived from data in Davis et al. (2015). The left axis shows consumption (blue line) and domestic production (green line), while the dotted line shows the net imports as a share of U.S. consumption. The net imports measure applies to the right axis and shows that foreign petroleum dependence has fallen steeply and is at levels (26.5%) not seen since the mid-1980s. This is in part due to fall in consumption, but it is more due to the steep rise in domestic production occurring during the past five years as a result of growth in domestic shale oil production.

Figure 2-15: Trend in U.S. Petroleum Consumption, Production, and Net Imports



In 2013, light vehicles and trucks accounted for 80.5% of all transportation energy usage in the U.S., while buses and rail made up 3.1% of all transportation energy use. The remaining 16.4% of transportation energy is used by air, water, and pipeline transportation (Davis, et al, 2015). Between 1970 and 2013, energy consumption for cars decreased by an average of 0.4% a year, but between 2003 and 2013 it decreased by an average of 2.7% a year, which further reflects the accelerating factors reducing transportation energy consumption in recent years (Davis et al., 2015). This trend is repeated

The EPA has found that between 1990 and 2013, transportation-related emissions as an absolute figure grew more than any other end-use sector.

across all modes *except* motorcycles—between 1970 and 2013 the energy consumption by motorcycles increased 5.2% per annum, which then shot up to a 9.2% increase per annum in the 2003-2013 period.

Greenhouse Gas Emissions from Transportation

An EPA report on greenhouse gas (GHG) emissions between 1990 and 2013 has found that transportation contributed 27% of total U.S. GHG emissions in 2013 (including cars, trucks, commercial aircraft, railroads, and others). Within the transportation sector, light-duty vehicles (passenger cars, light-duty trucks) contributed 60% of GHG emissions, whereas freight trucks contributed 22.5% of GHG emissions. The EPA has also found that between 1990 and 2013, transportation-related emissions as an absolute figure grew more than any other end-use sector, including the industrial, agriculture, and residential sectors. Transportation-related emissions grew by 16.5% during this period. Between 1990 and 2013, the emissions attributed to light-duty motor vehicles (passenger cars and light-duty trucks) have increased by 9.5%, whereas the VMT of these vehicles increased by 35%. This can largely be attributed to improved fuel efficiency standards of vehicles in this period (US EPA, 2015a).

Telework and Telecommuting

Telecommuting is an alternative arrangement in which an employee can work remotely from a centralized workplace (e.g., home, café, library, and shared workspaces). This is accomplished by utilizing available information and communications technology (ICT), such as telecommunications and personal computers. Nilles (1975) is often cited as having first coined the term “telecommuting.” Telecommuting is also known as “telework,” “teleworking,” “home-working,” and “working remotely.” Telecommuting can vary in its frequency (i.e., working remotely sometimes or all the time) and location (i.e., working from home or elsewhere). Because there is no uniform definition of telecommuting, it has been difficult to compare research studies (Baruch, 2001).

There are several objectives to promoting telecommuting. From a transportation standpoint, companies often utilize telecommuting to reduce the high real estate and operational costs for a centralized office, and address the negative externalities of commuting, such as traffic congestion, parking, air pollution, and greenhouse gas emissions.

In the early-1990s, between three and nine million Americans were telecommuting at least one day per month (Baruch, 2001). A 1993 survey estimated that four to five percent of the U.S. workforce was telecommuting at least part time (Gordon, 1993). By 2000, there were 11.5 million U.S. telecommuters (Cyber Dialogue Inc., 2000). Olszewski and Mokhtarian (1994) found that in the 1990s, telecommuters had an average age of 43.

Trends

Past studies (Nilles, 1988; Mokhtarian, 1991) have noted that empirical evidence of impacts to travel from telecommuting policies have been difficult to measure and compare. This is because although employers may have programs to encourage telework, they often do not monitor or survey their employees. Moreover, the term "telecommuting" has not been consistently defined and previous research has noted little reliable data on trends (Handy and Mokhtarian, 1996). The availability of data describing teleworking, at least through ACS journey-to-work data, has since become more abundant and is detailed later in this section. Among the earlier analyses of teleworking include Nilles et al. (1974), who studied over 100 employees at a firm in Los Angeles who began to telecommute to a satellite center (i.e., a location remote from the main office, but where telecommuters travel to and from for accessing computing technology and telecommunications). The pilot program reduced the one-way commute distance by 65% without increasing other non-commute trips.

The USDOT (1993) conducted annual telephone surveys to create projections of telecommuting trends from 1992 to 2002. Back then, the DOT forecasted that between 5.2% and 10.4% of the American workforce (7.5 to 15 million) would be telecommuting in 2002. When the frequency of telecommuting (i.e., part-time or full-time) is taken into consideration, the forecast ranges from 1.0% to 8.3% of the workforce telecommuting on a given day in 2002. In 2008, the DOT released an NHTS brief that characterized the propensity of telework reported in the 1995 and 2001 surveys. The data found that of those working at home, the percentage of men versus women had increased from 1995 to 2001. In addition, the distribution of income of people working at home had increased toward higher incomes, and the average distance to work had increased. The results from this brief are replicated in Table 2-3.

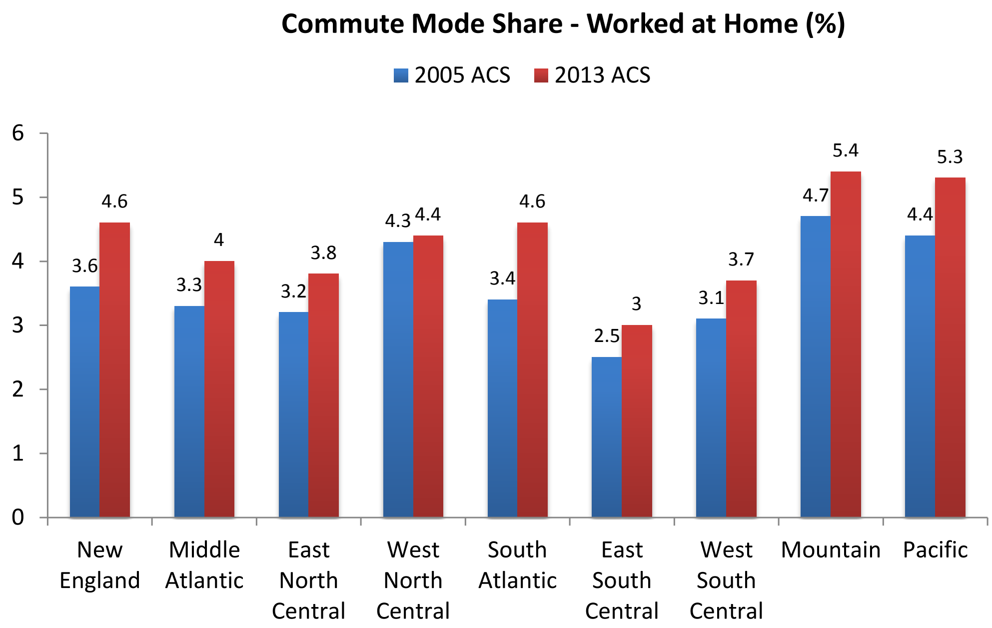
Table 2-3: Characteristics of People who occasionally Work At Home

NHTS Year	1995	2001
	GENDER	
Men	56.9%	61.7%
Women	43.1%	38.3%
	INCOME	
Less than $40K	31.3%	10.4%
$40 to $75K	22.0%	17.4%
$75K or more	23.4%	53.2%
Not Reported	23.4%	19.0%
Mean Age	40.4	41.5
Average distance to work (miles)	14.7	17.5
	HOME LOCATION (percent of those working at home)	
Suburban	68.9%	78.5%
Urban	15.6%	8.6%
Rural	14.7%	12.9%

Source: NHTS Brief, July 2008, Working at Home – The Quiet Revolution

Further, the ACS has found that there has been an increase in the share of people commuting via telework between the 2005 and 2013 based on US Census Journey to Work data. Figure 2-16 shows the change by region of the country between the two surveys.

Figure 2-16: Commute Mode Share of Telework by Region of the Country (2005 v. 2013)



Methodologies to measure telecommuting have typically relied on surveys and travel diaries from respondents. This focus has led to an understanding of telecommuter demographics and frequency, whereas understanding the impacts on the urban transportation network and congestion have been less of a focus. The 2009 NHTS briefly provides an estimate of impacts that have resulted from telecommuting as measured in the 2001 NHTS survey. The results are shown in Table 2-4, and they suggest that the fuel (and thus emissions) savings from work at home activity in 2001 were sizable, about 18 million gallons of gasoline a day.

Table 2-4: Fuel Saved for Each Work-at-Home Day

Number of workers	145,272,000
Number of workers who sometimes work at home	10,389,672
Percent	7.2%
Average one-way distance to work for those workers (miles)	18
Miles not driven each work-at-home day (miles)	363,638,520
Gas saved each work-at-home day (gallons)	17,913,228

Source: NHTS Brief, July 2008, Working at Home – The Quiet Revolution

The impacts shown in Table 2-4 have likely grown with the increase in telework that has been shown across the country, as presented in Figure 2-16. These impacts have likely since further increased as company policies become even more flexible to remote work and as technology enables more advanced interfaces with operations and colleagues from remote locations.

Non-Work Travel

Non-work travel is among the more challenging travel activities to study. It is non-systematic, and in many cases, non-discretionary, and difficult to measure. Even so, it constitutes the majority of trips. Described as trips made for purposes other than a journey-to-work, non-work travel encompasses several travel activities including shopping, personal business, and accessing healthcare, schooling, and others (Horner and O'Kelly, 2007). In addition, there is teleshopping, which has existed in numerous forms for decades. Teleshopping is defined as "the activity of obtaining information on products through electronic means and [it] usually provides the shopper with attribute information on a defined set of products" (Manski and Salomon, 1987). In this section, the measurement and trends of non-work travel and teleshopping are discussed and approaches to measurements are highlighted.

Understanding Non-Work Travel

An understanding of the purpose of the non-work trips is essential for the analysis of its measurement. Because of its diversity, non-work travel can be hard to measure in terms of total VMT. To illustrate such discrepancy, one can think about the shopping demands of a particular customer. Based on the product selection at a store or on the availability of shops in a particular geographical location, there is a wide range of choice built in the non-work travel trip, which will be initiated. For this reason, deviations in non-work travel have been hard to account for, adding to the difficulty in its measurement.

Amount of Non-Work Travel

Analyses using the NHTS data allow for the examination of household travel by trip purpose. The 2009 NHTS Summary of Travel Trends provides updated information about the NHTS conducted in prior years (U.S. Department of Transportation, 2011). Regarding non-work trips, an upward trend was reported. From 1983 to 1990, a 27.5% increase was observed and 1990 to 1995 saw a 26.5% increase. The increase in non-work trips was attributed to the increase in the number of trips that were made (Handy et al., 2002). Even though these specific trends have been emphasized, it is important to note that the evidence remains inconclusive, as pointed out by Handy et al. (2002). This can be attributed to the switch in survey techniques employed by the NHTS and its predecessor, the NPTS. Within the periods of 1983 to 1990 and 1990 to 1995, the observed trends might have been muddled by the changes made in the survey. This issue makes it more difficult for a direct comparison between the two time periods. Nevertheless, the measurement of overall growth in VMT is unlikely to have been impacted.

The 2009 NHTS shows that the share of non-work trips has remained relatively stable since the NHTS was first administered. Over past surveys, it has comprised 87% to 90% of all trips on the weekend, and 68% to 72% of all weekday trips (FHWA, 2011a). In the most recent 2009 NHTS survey, the share of non-work trips was been 69% on the weekday and 90% on the weekend. As with other measures within the NHTS, analysis of average annual PMT per household shows a decline in miles driven for non-work purposes for most trip categories from the 1995 survey, onward. This includes shopping, personal errands, and social/recreational trips. Only household VMT for school and church has risen relative to 1995.

Trip Purpose Distributions

While numbers have shown that there has been growth in non-work VMT, some changes in the distribution of trip purpose have also occurred. Table 2-5 illustrates trips by trip purpose as a percent of all trips within each NHTS survey back to 1990. The table shows a modest decline in the share of trips to and from work. At the same time, there is a modest increase in work-related business trips. Overall, 18% of trips in 1990 were work-related, while 19% of trips in 2009 were work-related. Thus, while some change is evident in trip purposes over the twenty years spanning these surveys, the distribution of trip purpose, and thus non-work trips, is relatively stable. Table 2-5 also shows that a little more than 80% of trips are generally for non-work purposes.

Table 2-5 Household Travel By Trip Purpose, 1990, 1995, 2001, 2009

Total	1990	1995	2001	2009
To or From Work	17%	18%	16%	16%
Work Related Business	1%	3%	3%	3%
Family/Personal Errands	46%	46%	44%	42%
School/Church	9%	9%	10%	10%
Social and Recreational	27%	25%	27%	27%
Other	1%	0%	1%	2%
Total Across Modes	**100%**	**100%**	**100%**	**100%**

Source: FHWA, 2011a

Summary

This chapter summarized what is known about trends and measurements of key metrics of transportation today, setting the context to understand the broader body of research that has explored these subjects in more depth. The chapter summarized the general state of knowledge with respect to VMT and PMT trends and measurement. Both of these metrics play a major role in understanding and monitoring transportation for policymakers, and both metrics have their respective advantages and disadvantages. As VMT misses much of the underlying shifts in travel behavior towards public transit and non-motorized modes, it is far from a comprehensive measurement of household travel activity. PMT has played a critical role in providing the deeper understanding of why travel activity is shifting and how. The resolution of PMT, which can be associated with demographic characteristics, shows us that in spite of the relentless rise of VMT through 2006, household travel demand has been leveling off for at about two decades. Furthermore, the measurement of PMT across age groups provides insight that the decline in travel demand is partially the result of a reduced demand for travel among younger cohorts. This demand is reduced relative to the travel demand of previous generations when they were the same age as today's Millennials. The underlying factors behind these trends shall be explored as subsequent chapters take a deeper dive into research addressing the present day and expected innovations impacting of these metrics in the future.

This chapter also explored recent trends and measurement of mode shift and vehicle ownership. Recent data show that mode shift is slowly veering towards greater use of public transportation as well as walking and bicycling. Vehicle ownership rates, though high relative to the world, have stagnated in recent years. Though transportation is a consumer of roughly 27% of the nation's energy, and responsible for a similar share of greenhouse gas emissions, it is getting more efficient and less petroleum dependent. The share of energy for transportation supplied by petroleum is now 92%—still high, but also at a historical low since the early 20th century, and still declining. Oil consumption overall has declined from its peak in the previous decade, and foreign oil dependence is at 26%, levels not seen since about 30 years ago.

Trends in telework, commuting, and non-work travel reveal that much work needs to be done to better understand these subsectors of transportation. In particular, telework is on the rise, but is among the most poorly measured of transportation activities. Telework suffers from a lack of universal definition and a lack of clear data on the changing patterns of home-based work. Nonetheless, the available data suggests that this "mode" continues to grow. Travel for non-work is another area with limited data resources. The NHTS is undoubtedly the most comprehensive resource outlining changes in non-work travel over the years. The data shows that the VMT of most types of non-work travel has generally been in decline, but that the share of non-work trips during the week has been more or less stable. Further investigation of the aforementioned issues will be addressed in greater detail within the subsequent chapters of this report.

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CHAPTER 3.0. SOCIO-DEMOGRAPHIC FACTORS CHANGING TRAVEL BEHAVIOR TODAY

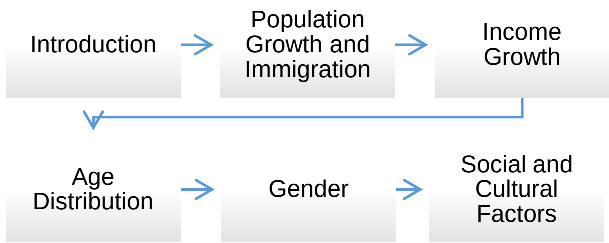
Introduction

Travel behavior in the United States has continually evolved with shifts in socio-demographics throughout the 20th century and into the 21st century. Chapter 3 discusses the high-level state of knowledge of socio-demographic trends and how they are known to have influenced travel behavior. This chapter summarizes the state of knowledge in five key sections that are focused on: 1) Population Growth and Immigration, 2) Income, 3) Age Distributions, 4) Gender, and 5) Social and Cultural Factors. Taken together, these sections aim to provide a comprehensive picture of the underlying factors contributing to travel behavior changes in the United States.

A number of population related changes have arisen to influence travel behavior over the past several decades. Demographic shifts have been particularly pronounced during the latter half of the 20th century. For example, since 1970, the share of immigrants within the overall population has been continually rising, and is expected to keep rising for some time. As immigrants have historically travelled in ways that are distinct from the native-born U.S. population, understanding the projected trends of this demographic is important. Further, migration patterns within the United States also have a large impact on travel behavior. The migration between cities and the suburbs has undergone some interesting changes in recent years that will be further explored in this chapter. In addition, migration across regions of the United States is an influential process that can play a role in transportation demand, as well as the travel options available to the local public. These patterns, which are ever present, but have changed less dramatically, are also discussed.

This chapter further explores how changes in income, age, gender, and other cultural factors influence travel behavior. Household income has been found to correlate with the number of trips and with vehicle miles traveled (VMT). Age and gender are demographic factors that influence trip purpose and the distribution of trip distance. Chapter 3 also details cultural factors, such as the acceptance of shared mobility modes, that are becoming increasingly relevant for understanding how travel behavior may evolve in the coming decades. These and other insights are presented in Chapter 3, the flow of which is depicted in Figure 3-1.

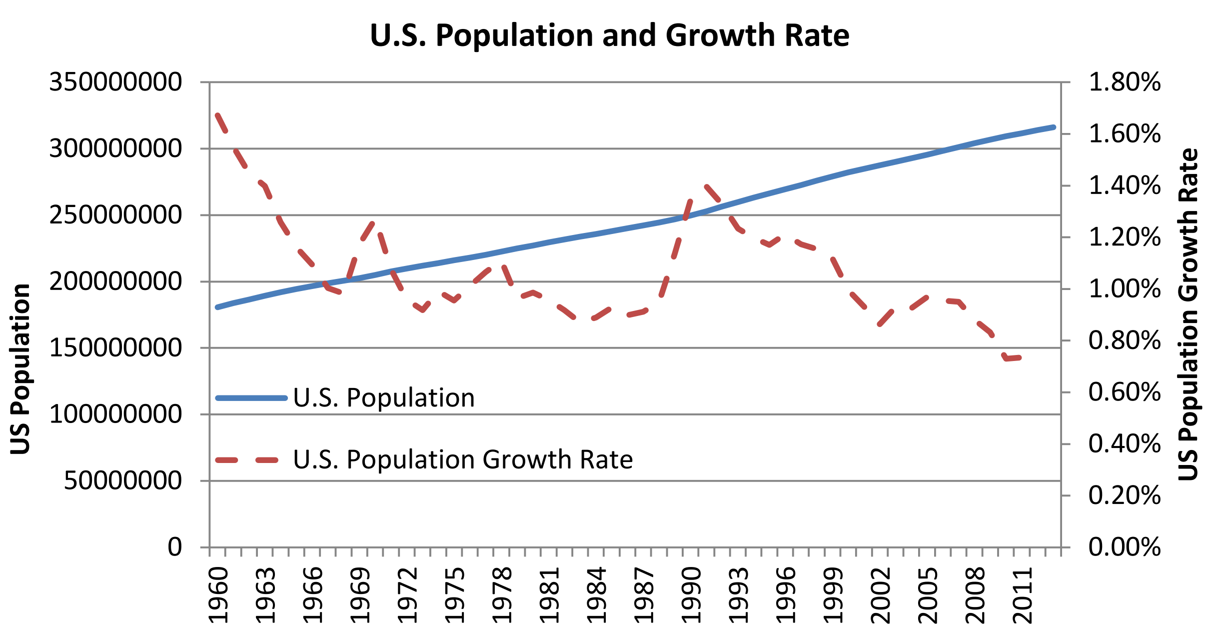
Figure 3-1: Content Flow of Chapter 3



Population Growth and Immigration

The U.S. population has been growing for decades. From 1960 to the present day, the annual rate of growth in the U.S. population has been between 0.7% and 1.7%; and this growth rate has generally been in decline. In the 1960s, the annual population growth rate fell from 1.7% to 1.0%, after which it remained relatively steady until 1989. Between 1989 and 1992, there was a temporary increase in the annual growth rate, and since 1992 there has been a steady decline underway through 2013. The U.S. Census Bureau estimates that the U.S. population is presently about 323 million people (as of February 2016). Figure 3-2 shows the trend in the U.S. population and the annual growth rate from 1960 to 2013 (World Bank, 2015).

Figure 3-2: U.S. Population and Growth Rate from 1960 to 2013

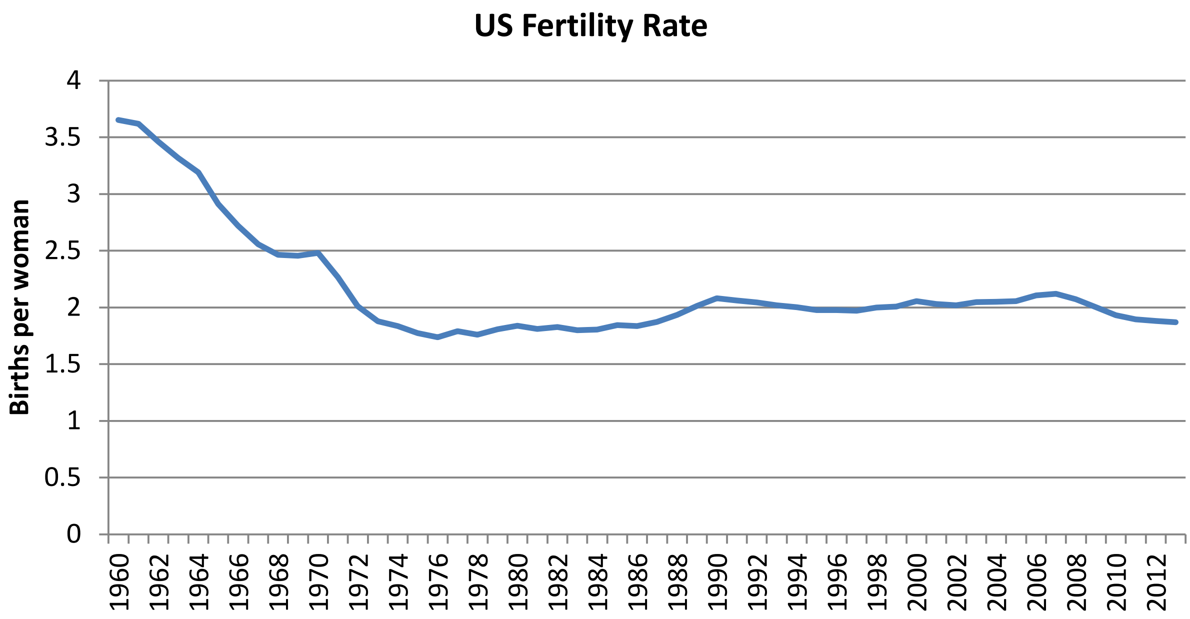


Even with its declining growth rate, the U.S. population is still one of the fastest growing among industrialized countries (CIA World Factbook, 2015). The United States is not expected to experience major declines in its growth according to recent forecasts, but the rate of growth is expected to continue slowing (Kochhar, 2014). The U.S. Census projects that between 2014 and 2060, the country's population will grow to about 417 million (Colby and Ortman, 2015). This amounts to an average annualized growth rate of just under 0.6%. During this time, the U.S. population is expected to age, with one in five Americans projected to be 65 and over by 2030. Despite this, the comparative predictions are that the United States will stay young relative to other major economic powers such as Japan, South Korea, and Germany. Even China, Brazil, and Mexico are forecasted to have higher medians ages than the United States in 2050 according to the United Nations (Kochhar, 2014).

An important source of America's competitive population growth has been driven by immigration. The fertility rate of the United States has been slowly rising since the 1970s, but during the Great Recession dropped from 2.1 births per woman in 2007 to 1.88 births per woman in 2013 as shown in Figure 3-3, and is now at a historic low since 1960. The crude U.S. birth and death rate in 2013 was 13 births and 8 deaths per 1000 people respectively (World Bank, 2015). Based on these factors as applied to today's population, if the United States was relying solely on births for population growth, it would only be growing at about 0.48% in 2015.

> Though its growth rate has been in decline, the U.S. population is still one of the fastest growing among industrialized countries. The U.S. Census projects that between 2014 and 2060, the country's population will grow to about 417 million.

Figure 3-3: U.S. Fertility Rate from 1960 to 2013



The current immigrant (or foreign-born) population in the United States is 41.3 million, which is about 13% or nearly one in every eight U.S. residents (Zong and Batalova, 2015). This share has been increasing over the past four decades and continues to rise. The share was 4.7% in 1970, 6.2% in 1980, 7.9% in 1990, 11.1% in 2000, and 12.9% in 2010 (Zong and Batalova, 2015). While there are natural limits to the maximum size of this share, immigration is likely to continue to play a critical and sustained role in the U.S. population's growth during the coming decades. In fact, the U.S. Census projects that by 2060, nearly one in five members of the nation's population will be foreign-born (Colby and Ortman, 2015). With immigrants making up an increasingly sizable component of the population, understanding how they travel in ways that are distinct from native-born citizens is particularly important. Previous research detailing the impact that immigrants have on travel behavior is presented in the following section.

Immigrants and Travel

Research has shown that immigrants tend to travel in ways that are different from the general U.S. population, but over time adapt more to the standard "American" travel lifestyle the longer they live in the country. This transition can be seen with data presented in Chatman and Klein (2009), which shows a breakdown of commute mode from the 2007 Public Use Micro Sample (PUMS) data of the ACS, and is reproduced in Table 3-1. The modal split by time in the United States shows that 33% of foreign-born U.S. residents commute by Drive Alone when they have been living in the country for less than one year. The remainder carpool (25%), use transit (18%), walk or bike (14.5%), or work and home/other (9%). This contrasts the Drive Alone share found for the U.S.-born population of 79.1%.

Table 3-1: Commute Mode by Nativity and Years in the United States

Population Segment	Drive Alone (%)	Carpool (%)	Transit (%)	Walk or Bike (%)	Work-at-Home or Other (%)
Total population	77.3	10.3	4.1	3.1	5.2
U.S.-born	79.1	9.4	3.2	3	5.3
Foreign-born	65.9	16	9.4	3.9	4.8
<1 year	33	25.5	18	14.5	9
1 to 2 years	40.1	26.2	15.8	10.9	7
2 to 3 years	44.1	26.1	14.2	9.5	6.1
3 to 4 years	49.9	25	13.2	7.3	4.6
4 to 5 years	52.3	23.3	13.2	6.6	4.6
5 to 6 years	53.9	23.3	12.2	5.5	5.1
6 to 10 years	61.6	18.8	10.8	4.4	4.3
11 to 15 years	65.6	16.6	10	3.6	4.1
16 to 20 years	67.7	15.5	9.3	3.3	4.2
21+ years	73	11.9	7.4	2.6	5.1

Source: American Community Survey, Public Use Microdata Sample file, 2007. Reproduced from Chatman and Klein, 2009

Table 3-1 shows how the modal split of foreign-born citizens transitions to more closely match that of the broader population as their time in the United States increases. However, their rate of transit usage is almost three times as high as it is for U.S.-born citizens.

Chatman and Klein (2009) found that the average trip length for work trips among immigrants was not significantly longer than among U.S.-born citizens (11.6 to 11.2 miles). The average trip length for non-work travel by immigrants was found to be slightly shorter at an average length of 6.8 miles for immigrants compared to 7.6 miles for U.S.-born citizens. With respect to VMT, foreign-born residents drove an average 36.7 miles in completed NHTS travel diaries, versus 43.1 miles by U.S.-born respondents (Chatman and Klein, 2009).

Because of their reduced reliance on the private car, immigrants tend to make up a larger share of ridesharing and carpooling activity. As shown in Table 3-1, carpooling is consistently utilized more than transit regardless of years within the country. Blumberg and Smart (2010) found through an analysis of the 2001 NHTS data that immigrants were far more likely to form household carpools as well as external carpools. They even found that immigrants preferred carpools over transit more strongly than native-born citizens. While the dominance of carpooling over transit is evident as well for U.S.-born citizens, the higher levels of ridesharing among immigrants may imply greater dominance of the mode in the future as immigrant populations grow in conjunction with the expanding ridesourcing industry.

Suburbanization and its Impacts on Travel Behavior

Suburbanization of metropolitan America has been one of the great underlying trends impacting transportation in the United States during the 20th century. Scholars will note that suburbanization within the United States has been underway since the invention of railroads, but the initial phases were confined to the wealthy (Wachs, 2014). The evolution of travel from horse to railroad to streetcar to automobile was a welcome transition for most Americans. During the late 19th century, Americans made significant use of public transit via streetcars (Jackson, 1985). But many lines that serviced streetcar suburbs were not self-sustaining from their fare prices, and in fact were often built with the motivation of selling land on the urban periphery (Fredericks, 1989). The automobile was perceived as a welcome change and a provider of freedom from horse-drawn carriages and streetcar lines, the latter of which were considered poorly managed and/or monopolistically operated (Wachs, 2014).

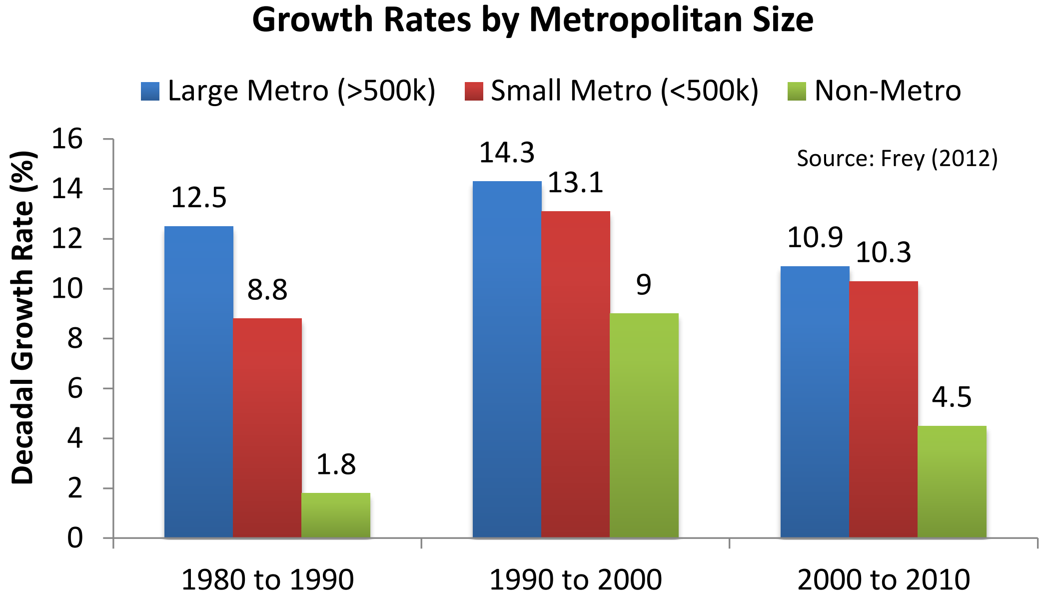
Suburbanization of metropolitan America has been one of the great underlying trends impacting transportation in the United States during the 20th century.

Today, most people tend to think of “suburbanization” as primarily the auto-driven post-World War II migration out from American cities. Indeed, this period of post-war suburbanization was a massive migration and did have an indelible effect on the transportation landscape of American culture. The origins of post-war suburbanization relate to several factors. Among them are: (1) the construction of the interstate highway system and supporting arterials, which made the peripheral areas around the urban core more accessible; (2) economic growth and the increased productivity of the automobile industry made vehicles more widely accessible to the middle-class; and (3) supportive federal housing policy that encouraged the construction and purchase of homes for reduced down payments. Following the war, the Federal Housing Administration (FHA) was charged with supporting the growth of housing for the families of returning veterans. The subsidization of home buying was an important impetus for outward urban migration, and it was accomplished through policies supporting easy home-lending, such as the Servicemen's Readjustment Act of 1944 (informally known as the G.I. Bill). Buying a home under the FHA's supportive policies was simply the financially optimal decision for many Americans, and those new homes were being constructed in the urban periphery in auto-oriented housing developments. This process evolved gradually, but resulted in a decades-long decline in transit, walking, and bicycling, as Americans moved to areas that did not support or encourage the use of any of these modes.

Contrary to the current popular notion that the U.S. is becoming urbanized (i.e., a reversal post-war suburbanization), and the recent growth in population within American downtowns, the U.S. population is still trending toward suburbanization overall. By the year 2000, more than half of the United States' population lived in the suburban neighborhoods of cities (Berger et al., 2013). According to the 2010 census, almost 75% of all households resided in single-family or mobile homes. Furthermore, except for the largest metropolitan areas, the central business districts (CBDs) of U.S. cities that have a population of greater than one million had low or negative growth as residents moved outward in search of suburban living. As residents have moved outward, jobs have followed. Growth in employment centers has been occurring outside of CBDs and in various nodes within suburbs. Between 1998 and 2006, the share of total employment within three miles of a city's CBD had decreased for 95 of the 98 most-populated metropolitan areas (Kneebone, 2009). A consequence of the auto-oriented suburbanization has been increased driving for nearly all types of travel. Kahn (2000) found that suburban households drove 31% more than their urban counterparts. Hence, because migration to post-war suburbs has had such a profound effect on increasing automotive use and dependence, understanding the expected trends in future urbanization and suburbanization is very important.

Frey (2012) provides a summary of these trends through 2010. By 2010, 65.6% of the U.S. population lived in large metropolitan regions, 18% lived in small metropolitan regions, and 16.4% lived in non-metropolitan regions. This distribution comes after at least three decades of growth. Figure 3-4 shows trends in population growth since 1980 as divided by large, small, and non-metropolitan regions as presented in Frey (2012). The trend shows that large metropolitan areas have grown the most, followed by small metro areas and then non-metropolitan areas. Figure 3-4 shows clearly that the population has been robustly urbanizing for the past three decades, and that the 1990s were a period of especially high urban growth. The 2000s was far more volatile, with robust urban growth between 2004 and 2007, and more varied growth at the beginning and end of the decade. Most (but not all) regions tended to grow faster from 2001 to 2004 than from 2007 to 2010 (Frey, 2012).

Figure 3-4: Decadal Growth Rate by Metropolitan Size



While the growth in urbanization at a metropolitan scale is abundantly clear, the distribution of growth within cities is a far more nuanced dynamic. Frey (2012) found that the suburbs generally grew faster than the primary city from 1990 through to 2010. Thus, even though there have been well-documented revivals in the media of housing and residential construction within the downtowns of many American cities, growth in the suburbs has still been faster through 2010. However, the dominance of suburban growth overall has not been uniform across all cities or decades. From 1990 to 2000, 18 cities grew faster than their surrounding suburbs, while in 2000 to 2010, 19 cities grew faster than the suburbs. The list of cities that grew faster than their suburbs changed substantively from decade to decade. Only cities within 11 metropolitan regions grew faster than their surrounding suburbs during both decades. As shown in Table 3-2, this list includes a number of smaller metropolitan regions that have traditionally auto-oriented infrastructure.

Table 3-2: Cities that Grew Faster than the Surrounding Suburbs from 1990 to 2010

City	State	Suburban Share of 2010 Metropolitan
Bakersfield	CA	59
Cape Coral-Fort Myers	FL	75
Charleston-North Charleston-Summerville	SC	82
Charlotte-Gastonia-Concord	NC-SC	58
Greensboro-High Point	NC	48
Oklahoma City	OK	54
Oxnard-Thousand Oaks-Ventura	CA	48
Palm Bay-Melbourne-Titusville	FL	81
Providence-New Bedford-Fall River	RI-MA	89
San Jose-Sunnyvale-Santa Clara	CA	35
Wichita	KS	39

Only four of these metropolitan regions, Charlotte, Oklahoma City, Providence, and San Jose, have populations over one million. During the past two decades, many cities within the United States have clearly made considerable gains in adding housing and improving quality of life in downtown areas. But in the majority of metropolitan regions, growth has still been concentrated in the suburban regions through the most recent decade, where private auto travel is the predominant mode of transportation. The difference between the growth rates of suburbs and city centers has been narrowing since 2005; however, by the end of the decade, the growth rate of suburbs was still greater overall than that of city centers (Berger et al., 2013).

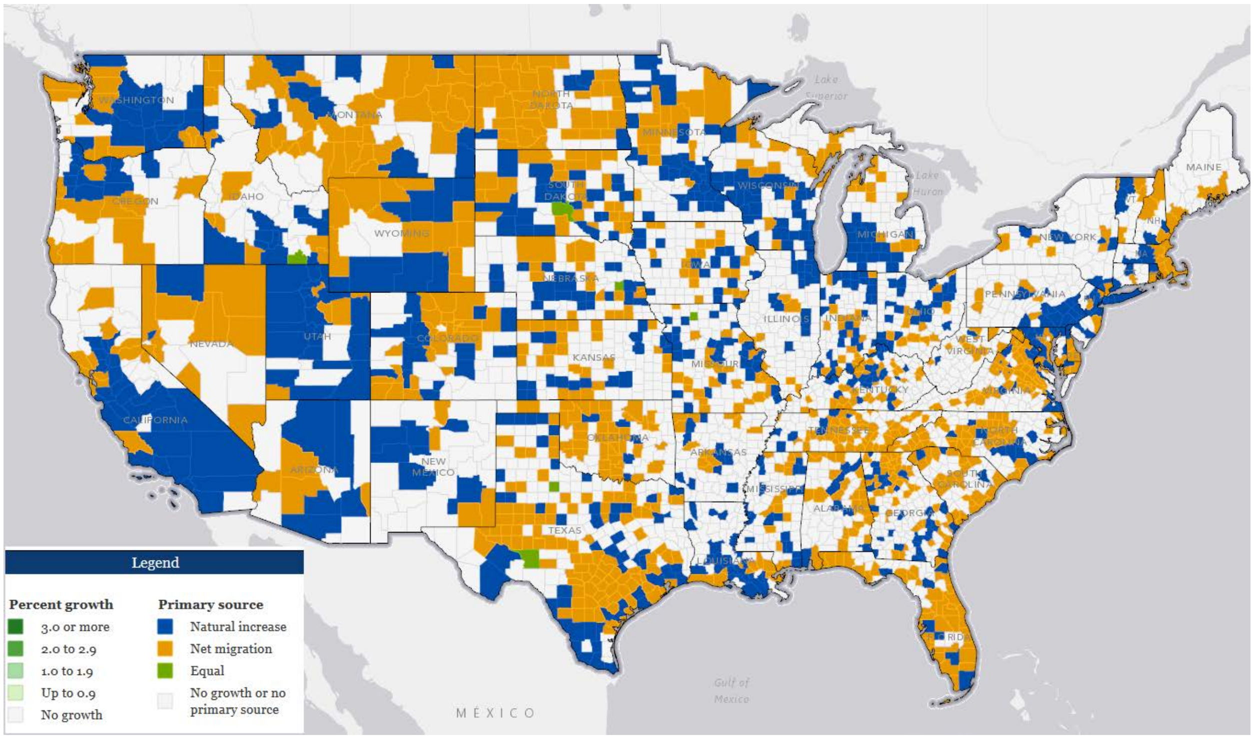
> Between 2000 and 2014, the share of residents in the American South and West has increased, whereas it has decreased in the Northeast and Midwest.

There is evidence, however, that growth may be swinging further in favor of cities during the present decade (2010 to 2020). During the first year of the decade, from July 2010 to July 2011, 27 of the 51 largest metropolitan regions in the country registered greater growth in the city centers versus in the suburbs (Dougherty and Whelan, 2012). Frey (2014) once again parsed the updated urban growth data from the ACS through 2013 in which he poses the question, “Is this city growth revival here to stay? Or, is it a lingering symptom of the recession, mortgage meltdown and the plight of still stuck-in-place young adults?” He found that cities with populations over 250,000 grew just over 1% per year. This is high, as the average annual growth rate for the same cities from 2000 to 2010 was 0.49%. Frey (2014) further found that the early years of the current decade show a reversal of the suburban dominance of growth, as 19 of the 51 major metropolitan areas showed primary city growth to be larger than growth in their surrounding suburbs from 2012 to 2013. These cities include some of the nation’s largest (unlike in previous decades): New York City; Washington, DC; Denver; and Seattle. From the trends of the early decade, Frey (2014) considered it too soon to discern whether these movements are a result of the residuals from the recession and the housing crisis. But, by 2013, the economy had been roughly four years into the recovery, and the housing market was well into recovery in most markets. Hence, early evidence exists to suggest that this decade may be different from those previously, in that central city growth may outstrip suburban growth in many of America's major cities. Naturally, developments in the second half of the decade will determine whether this is ultimately true.

Regional Migration

Another key component of population growth that influences travel behavior are the trends in interregional migration within the United States. For several decades, the American population has generally migrated from the Rust Belt of the Northeast and Midwest towards the Sun Belt of the American South and the West. This trend has continued to the present day. Between 2000 and 2014, the share of residents in the American South and West has increased, whereas it has decreased in the Northeast and Midwest. In 2000, the share of the total population residing in the South and West was 22.5% and 35.6%, respectively. It had increased by 2014 to be 23.6% and 37.6%. The share of population in the Northeast fell from 19% in 2000 to 17.6% in 2014. During the same period, the Midwest population share dropped from 22.9% to 21.2% (U.S. Census Bureau, 2015). Figure 3-5 provides some visualization of these patterns during recent years. It shows which counties grew between the years of 2012 and 2013, and whether those counties grew in size as a result of internally driven population growth or net migration. Counties in blue are growing due to internal growth, counties in orange are growing due to net migration, and counties in white are not growing or are shrinking in population. Figure 3-5 shows growth in most states is a very mixed picture. The south, west, and upper plains, are generally growing via net migration. The exception is California, which is experiencing slight net out migration (not shown), but still growing via internal population growth.

Figure 3-5: Migration Patterns within the United States between 2012 and 2013



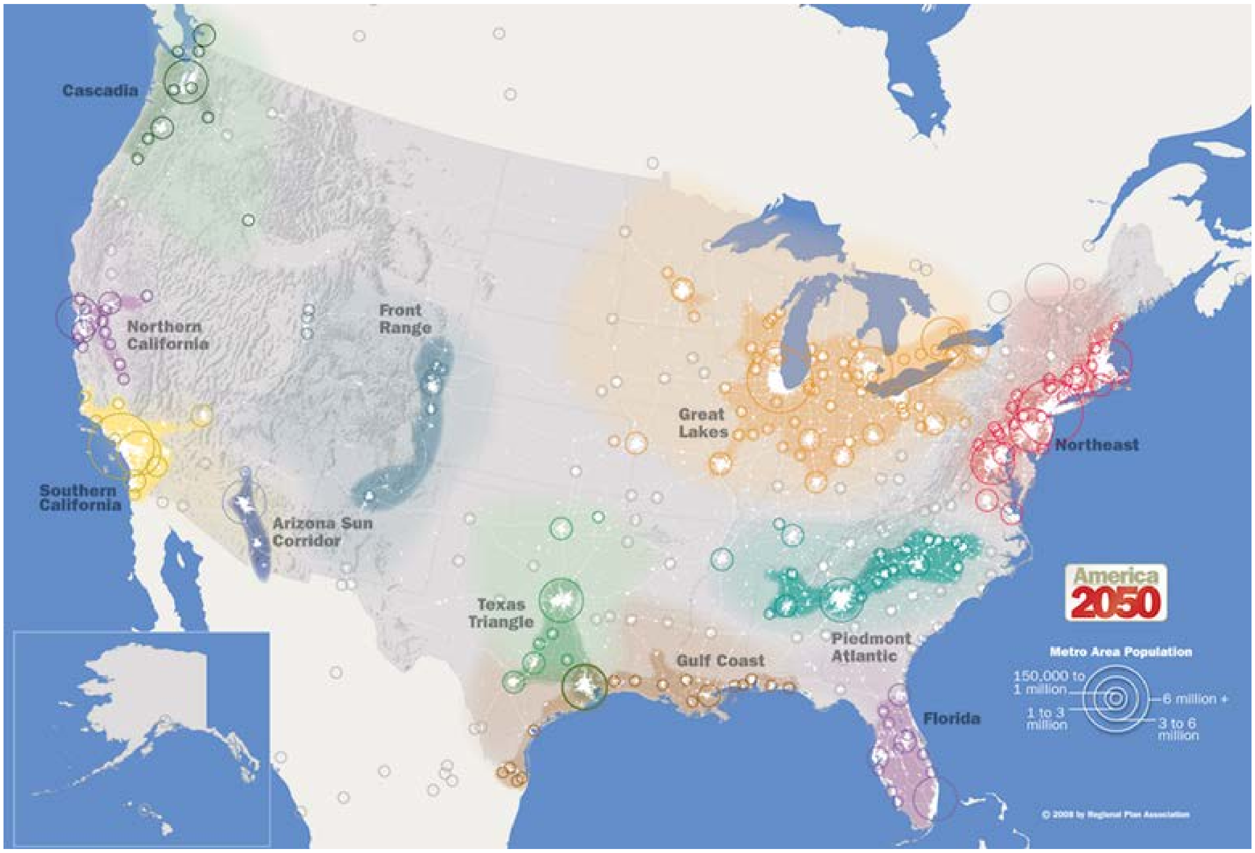
Source: US Census: http://storymaps.esri.com/stories/2014/census-county-population-change/

The broader transportation implication of these migration patterns is that they favor regions with less intensive transit, walking, and bicycling infrastructure. Kahn (2000) has suggested that Southern and Western households drove 35% more than their Northeastern counterparts. Thus, while recent urban growth data suggests that cities are gaining popularity, which should improve population access to non-auto derived-transportation, the regional patterns of migration towards more auto-dependent environments may in some ways counteract this effect. Investments in infrastructure and planning that support non-auto-derived transportation within these environments may serve to mitigate the auto-increasing effects of current migration patterns.

Development of Megaregions

Due to the increasing urbanization of the population through the growth of metropolitan regions both large and small, policy makers are beginning to think of some regions of the United States as "megaregions." Megaregions are large regions that link various but separate urban, suburban, and rural areas through shared economic, social, and cultural ties. There may be several centers of growth in a megaregion that are all more closely interlinked to each other, than they are to other regions of the United States. Lang and Dhavale (2005) were among the first to discuss the emergence of megaregions in the United States during the 21st century. Their definition of "Megapolitan Areas" was described as ten regions in which the population would exceed 10 million residents by 2040. Current maps of megaregions contain areas that easily exceed this population. There are several different maps of megaregions. The most commonly used map is that created by the organization America 2050, which is part of the Regional Plan Association, a research and advocacy organization. It cites ten megaregions for the agency's long-range planning: the Arizona Sun Corridor, Northern California, Southern California, Cascadia, Front Range, Florida, Great Lakes, Texas Triangle, Piedmont Atlantic, and the Northeast (see Figure 3-6). These are slightly different than the ones proposed by Lang and Dhavale (2005).

Figure 3-6: Proposed Megaregions by the Regional Plan Association



The megaregions outlined in Figure 3-6 are loosely-defined contiguous regions that contain sizable proportions of the population. Projections by the Federal Highway Administration (FHWA) suggest that by 2050, the megaregions will contain 75% of the United States' population. The regions are generally considered within long range plans in the context of population growth and freight planning. The megaregions define areas that are larger than the jurisdiction of MPOs and generally span multiple states. These regions are useful for defining collaborating institutions and the common needs for planning purposes within a given geographic region.

Effect of Income Growth Trends on Travel Behavior

Income is a socio-demographic metric that has one of the strongest positive correlations to increased trip making and distance traveled, particularly by motor vehicle. In contrast, low-income individuals are more likely to take fewer trips and/or stay in the same place. According to the 2009 NHTS, the average income of people that take at least one trip per day is $50,000 to $55,000. However, this average income drops to $40,000 to $55,000 for those that stayed in place all day (did not take a trip), and further falls to $25,000 to $30,000 average annual income for those that stayed in the same place all week, though this is also shown to be linked to having a medical condition (Mattson, 2012). Figure 3-7 below shows the positive correlation between income and trip making as derived from the 2009 NHTS.

Figure 3-7: Annual Person Trips per Household by Household Income, 1983-2009

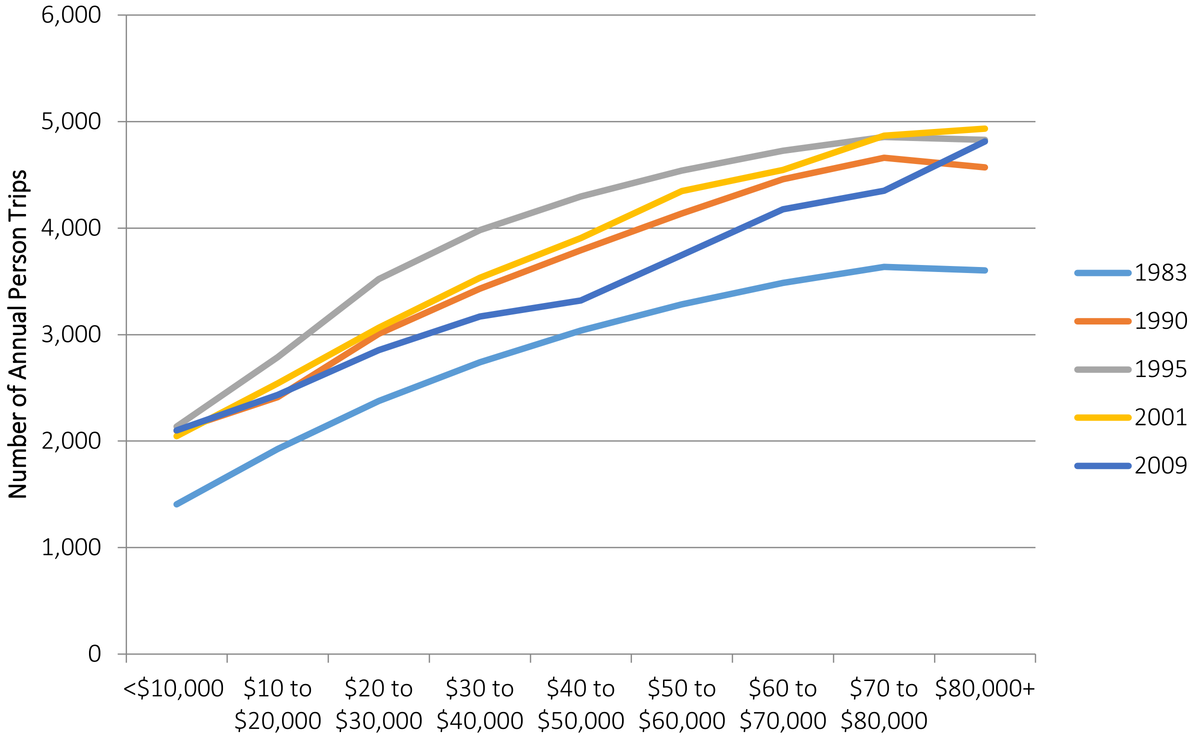


Figure 3-7 clearly shows an increase in person trips as income rises across years, except among high-income households. In 2001 and 2009, an increase in trips can be seen between the two highest income brackets, but in all other years there is a slight drop. Overall, the rate of increase of trips by income is non-linear, as a "tapering" of trips can be seen as income rises. Figure 3-7 reflects the notion that there may be a saturation level at which greater income will not necessarily yield more trips. Table 3-3 shows the average number of trips per day per person, by household income, as broken out by rural and urban environments. At lower incomes, those traveling in urban environments tend to travel less than those in rural environments. But at higher incomes, urban dwellers travel more than rural dwellers.

Table 3-3: Average Number of Trips per Day per Person, by Household Income

Household Family Income	Number of Trips per Day per Person	
	Urban	Rural
<$5,000	2.83	2.94
$15,000-$19,999	3.25	3.30
$30,000-$34,999	3.78	3.50
$45,000-$49,999	3.80	3.69
$60,000-$64,999	3.82	3.61
$75,000-$79,999	4.19	4.11
$100,000+	4.39	3.93

Source: 2009 National Household Travel Survey, Person File

At lower incomes, those traveling in urban environments tend to travel less than those in rural environments. But at higher incomes, urban dwellers travel more than rural dwellers.

Table 3-4 further shows how average annual vehicles miles driven per person has evolved from 2001 to 2009 based on NHTS data, as stratified by urban/rural living and income. A key takeaway from the two tables is that while those in urban areas, across most income strata, take more trips per capita than their counterparts in rural areas, the overall vehicle miles traveled is much lower. This is most likely because they are taking fewer vehicle-based trips and are also taking shorter trips given the proximity of destinations in an urban area. Furthermore, barring a few scattered cases, VMT per capita fell (overall) between 2001 and 2009, especially among working adult men across all incomes (Mattson, 2012).

Table 3-4: Average Annual Vehicle Miles Driven Per Person, Urban and Rural (2001 versus 2009)

Household Family Income	Urban		Rural	
	2001	2009	2001	2009
<$5,000	2,191	2,404	5,173	4,852
$15,000-$19,999	5,307	4,004	8,821	6,792
$30,000-$34,999	7,506	6,823	9,715	10,986
$45,000-$49,999	7,514	6,983	11,713	11,716
$60,000-$64,999	9,290	7,394	11,539	11,202
$75,000-$79,999	8,942	8,693	11,291	12,464
$100,000+	9,374	9,431	13,389	12,396

Source: 2009 National Household Travel Survey, Travel Day Trip File

Another important metric to compare with travel behavior and income is public transit mode share. According to the NHTS, over the past two decades the public transit mode share of those earning under $15,000 has increased by about 1% and so has that of those earning between $15,000 and $50,000, though only by 0.5%. Among those that earn greater than $50,000, the public transit mode share remained roughly around 1% between 1995 and 2009 (Polzin et al., 2011). Table 3-5 summarizes this NHTS data but isolates it by urban and rural households, where urban households naturally have higher access to transit, and use it with greater frequency at all levels of income.

Table 3-5: Percent that Used Public Transportation on Travel Day, Urban and Rural (2001 versus 2009)

Household Family Income	Urban		Rural	
	2001	2009	2001	2009
<$5,000	15.6	15.9	1.5	1.8
$15,000-$19,999	9.8	8.2	1.7	1.1
$30,000-$34,999	4.5	5.2	1.7	1.4
$45,000-$49,999	4.4	3.7	2.0	0.4
$60,000-$64,999	4.0	3.2	1.8	0.2
$75,000-$79,999	3.8	3.2	2.0	0.9
$100,000+	5.1	4.1	1.7	1.5

Source: 2009 National Household Travel Survey, Travel Day Trip File

Except for those earning under $5,000 in urban and rural areas, as well as those earning $30,000 to $35,000 in urban areas, public transit use has fallen between 2001 and 2009 across most income groups. Note, however, that overall public transit mode share increased marginally from 1.6% in 2001 to 1.9% in 2009. In rural areas, income appears to not carry much of an effect on the likelihood of an individual to take public transit, which is not surprising given the overall low accessibility rural environments present for public transit. In urban areas, however, public transit use is highest among lower income populations (most likely includes students as well) and appears to decrease slightly as income rises, except among high-income households of greater than $100,000 (NHTS, 2009).

Rising income inequality in the United States is a cause for concern not only from an economic and social perspective but also in relation to travel. Between 2003 and 2013, only those aged over 55 have seen their real incomes rise, whereas all other age groups have seen their incomes fall (US Census Bureau, 2013). As seen earlier, there is clear correlation between rising incomes and greater travel. Furthermore, a later discussion in this chapter regarding age distribution will show that those who are currently aged above 55 years are the Boomer and Silent generation, characterized by historically high rates of driving and trip making. At the same time, increasing age is associated with decreased travel. In effect, we will see a confluence of factors associated with the propensity to make multiple trips, among Boomer's in particular, and the travel-dampening effect of increasing age. Furthermore, shown earlier in Figure 3-7 was the diminishing rate of increase in travel with increase in income. If income is accumulating among older retirees with savings and not among younger working generations, the latter of whom would be most likely to take advantage of rising incomes in the form of increased trip making, then the United States may see a decrease in overall travel demand due to this income inequality (Schwartz, 2014).

Effect of Age Distribution Trends on Travel Behavior

Age has been shown to be one of the most distinctive factors affecting an individual's travel choices, and thus the United States' changing age demographics has had a strong effect on visible travel trends. The American population has often been categorized into different generations since the early 20th century, each with its own "imprint" of the economic, cultural, and political circumstances during which they grew up. Table 3-6 lays out an overview of these generations:

Table 3-6: Overview of Generations in the United States Today

Generation	Year of Birth	Age in 2014	Share of Adult Population
Silent Generation (Silents)	1928-1945	69 to 84	12%
Baby Boomer Generation (Boomers)	1946-1964	50 to 68	32%
Generation X (Gen Xers)	1965-1980	34 to 49	27%
Millennial Generation (Millennials)	1981-1996	18 to 33	27%

Source: Pew Research Center (2014)

These generations behave in distinctive manners, especially with respect to travel. Two age cohorts that demonstrate this contrast in travel behavior are Millennials and Boomers (a comparison that often includes Silents). Millennials are currently growing up in a time of great technological advancement, urbanization, and economic downturn, whereas Boomers are just entering retirement and were raised at a time of rapid motorization in the United States. Millennials have shown to be driving less than the predecessors in their age group, whereas the older generation individuals of today (Boomers and Silents) are driving more than their predecessors. Boomers and Millennials are also the two fastest growing age groups, as Boomers were born during a time of great population growth in the United States and Millennials make up an "echo boom" as a significant portion of them are the children of Boomers. Figure 3-8 and Figure 3-9 below illustrate the growing VMT by those older than 55 years of age as more members of the Silent and Baby Boomer generation enter that age group.

Figure 3-8: Annual VMT per Driver by Age Group and Year. (Source: National Household Travel Surveys 1969-2009)

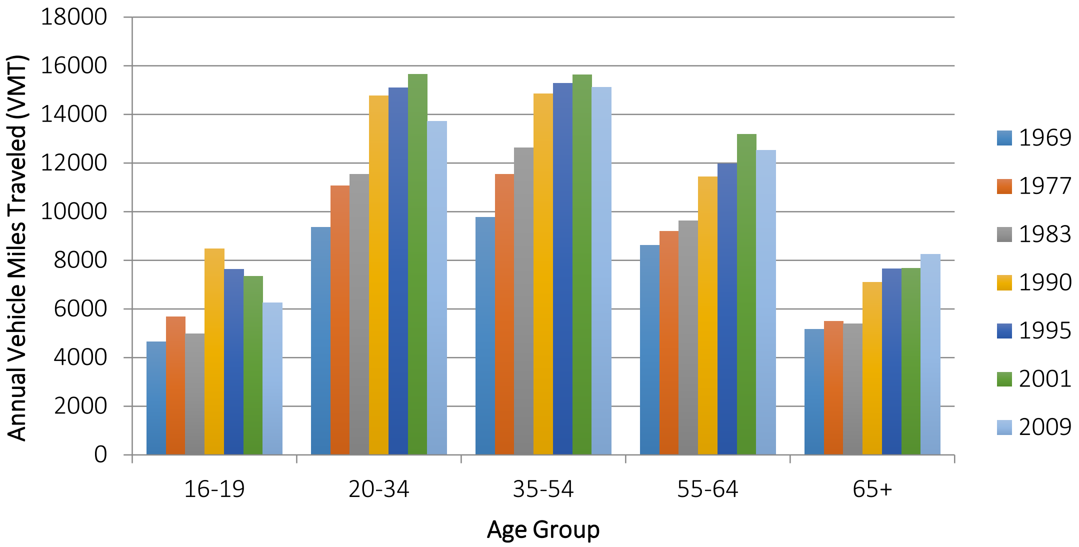
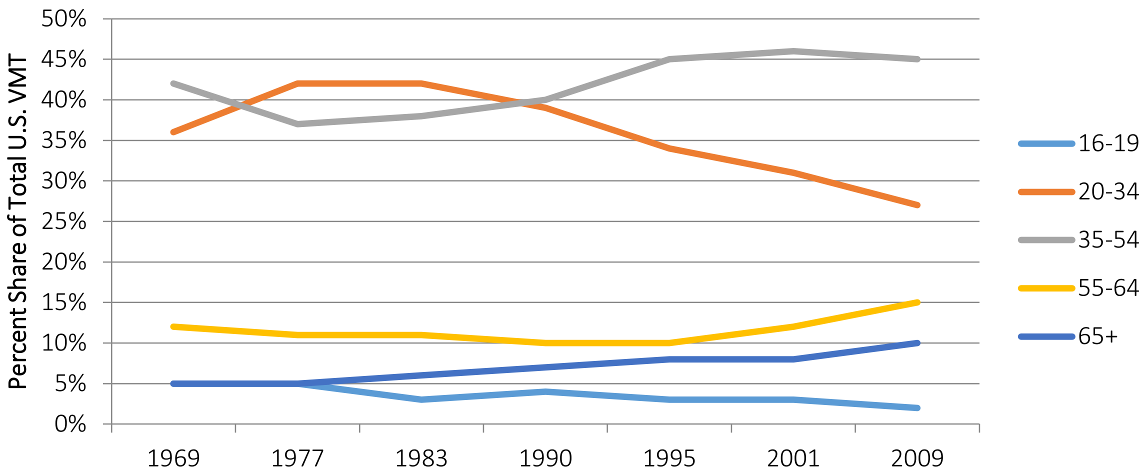


Figure 3-9: Trends in Share of Total VMT by Age Group (Source: National Household Transportation Surveys 1969-2009)



Having grown up in an era of technological advancement, Millennials have been found to be much more likely to take advantage of technology to substitute unnecessary travel. This includes a greater tendency to work from home, conduct shopping online, and engage in socializing online instead of in person (Patten and Fry, 2015; Polzin, 2014). Further, surveys of new mobility systems, such as carsharing, have shown them to be largely used by people between the ages of 20 and 40 (Martin and Shaheen, 2010). Millennials were also hard hit by the U.S. recession in 2008 as many were just entering the workforce, and so more of them who are in their 20s have been deferring marriage and home ownership until after completing further education or work (Patten and Fry, 2015; Polzin, 2014). This would, for now, lead to a delayed (if at all) move to residing in a suburban area, where there would be greater dependence on a personal vehicle. These are some possible reasons why driver-licensing rates are at an all-time low among those aged 16 to 29 years (FHWA, 2012; Schwartz, 2014).

Millennials are much more likely to take advantage of technology to substitute unnecessary travel.

By all modes and trip purposes, Baby Boomers have since 1983 traveled more per capita than any other age group (McGuckin and Lynott, 2012). Even as more Boomers enter retirement, which is often associated with less travel, those aged greater than 55 years were the only age cohort that increased their overall annual VMT between 2001 and 2009 (NHTS, 2009). However, as Boomers enter retirement and older age, they have had to reduce travel due to rising numbers of medical conditions. The 2009 NHTS found that older drivers who do not have a medical condition drive roughly twice as many vehicle miles as those with a medical condition. Furthermore, there has been a large jump in the number of medical-related trips by those aged greater than five years between 1983 and 2009, especially 1995 onwards when the oldest Boomers were entering their 50s, resulting in a greater number of elderly people in the general population (McGuckin and Lynott, 2012). Despite this, aging Boomers still drive only slightly less than Millennials and also fairly frequently (Rosenbloom and Santos, 2014). The 2009 NHTS showed that while those between 55 and 64 years of age traveled 12,500 vehicle-miles per driver in 2009, those drivers aged 20 to 34 years drove more, at 13,700 annual vehicle-miles.

Data shows that in almost all metrics, Millennials are driving less than their predecessors who once occupied their current age group of 18 to 33, and Boomers are driving more than their predecessors in their cohort. Compared to previous generations of older adults, aging Boomers today have the highest licensing rate, VMT per driver, absolute total VMT, and share of total VMT. While Boomers have maintained a high rate of driving throughout their life, it is unclear whether Millennials will maintain their lower rates of driving as they grow older and start families in their 30s and 40s. Historic trends have shown that those aged between 30 and 50 will drive more than they did in their 20s. Further, as the economy continues to recover there are bound to be higher rates of trip-making, though the mode share of these trips is uncertain. Thus, while future trends are difficult to definitively predict, it is evident that the lower rates of driving by Millennials have at least been partially offset by the increase in driving by the aging Boomer population (NHTS, 2009; Schwartz, 2014). As Boomers continue to age and require mobility in the face of impaired health, transportation programs and strategies will have to be implemented to cater to senior needs as this segment of the population continues to expand at a fast pace (McGuckin and Lynott 2012).

Millennials are driving less than their predecessors who once occupied their current age group of 18 to 33, and Boomers are driving more than their predecessors.

Gender

Social shifts surrounding gender have impacted travel in the United States during the 20th century. Namely, there has been an increase in women drivers as they have entered the workforce and continue to hold many household responsibilities. In fact, women became the majority of drivers in 2005 in the United States. Between 1963 and 2013, the proportion of female drivers in the United States has increased from 39.6% to 50.5% (Sivak, 2015). Sarmiento (1996) found that women between ages of 16 and 64 years make on average 6% to 9% more trips than men in the same age group. Furthermore, women are more likely to make a "commute-related active choice" to interruptive events, such as freeway reconstruction. These active choices include avoiding peak hours, rerouting trips, changing modes, or telecommuting (Mokhtarian et al., 2011).

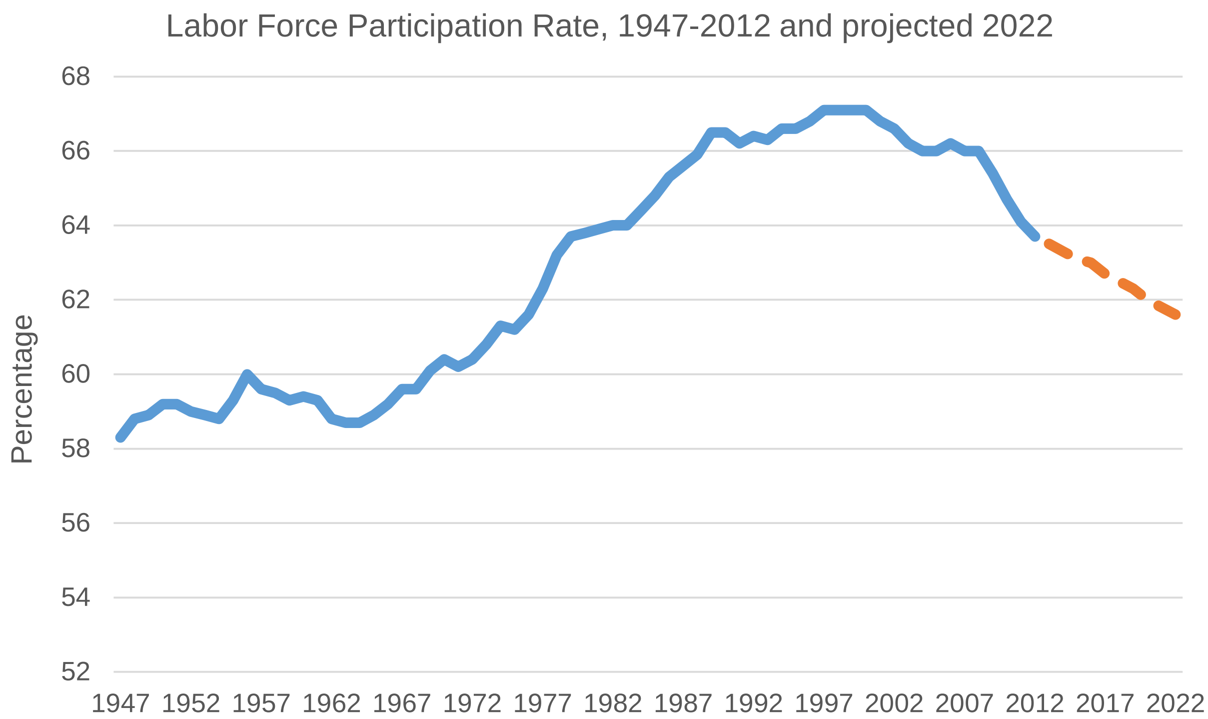
Between 1963 and 2013, the proportion of female drivers in the United States has increased from 39.6% to 50.5%

The literature consistently shows that women take more non-work trips than men. Women are primarily responsible for the majority of household-serving travel. However, this pattern can vary based on household income and race/ethnicity (Mauch and Taylor, 1997). Such household-sustaining activities include shopping, conducting family errands, and transporting children (McGuckin and Murakami, 1999).

Labor Force Participation

One of the largest demographic changes in the U.S. labor force is the participation of women in the past half-century. Since women have entered the workforce and started commuting to work during the 20th century, a number of studies have been done to understand how their travel is different. It is important to note that such gender travel studies often were conducted in the 1990s and prior; thus, these trends may have shifted as household roles and dynamics have continued to change. Figure 3-10 shows the trend in the labor force participation rate during the last 60 years and projected to 2020. It shows a "bubble" that is partly due to Boomer working years, and also increased labor force participation within that generation.

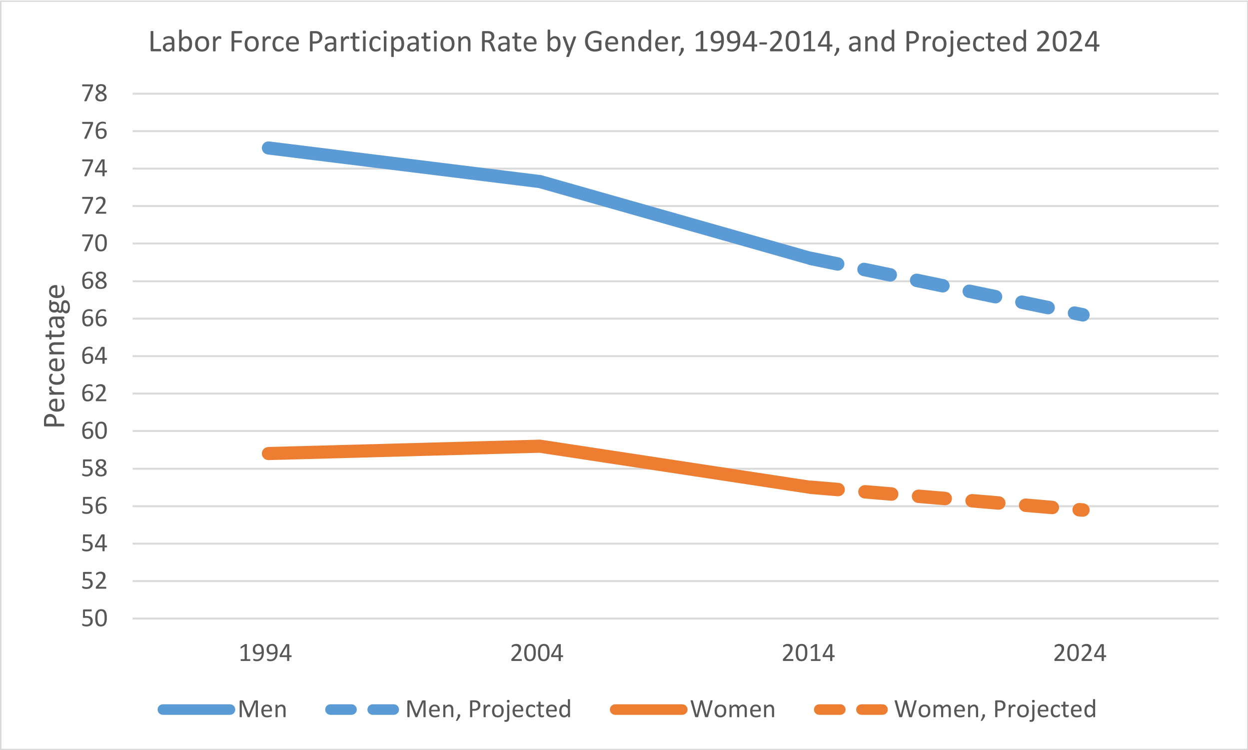
Figure 3-10: Labor Force Participation Rate, 1947-2012 and Projected 2022



Source: U.S. Bureau of Labor Statistics, 2013

The U.S. Bureau of Labor Statistics (BLS) has cataloged labor statistics including labor force participation rates (see Figure 3-10 above). In 1947, 86.8% of men and 31.5% of women were in the U.S. labor force. Juhn (1992) found that almost twice as many men were not working in 1987 as in 1967. Back then, the largest decline occurred among less-educated and low-wage men. By 2000, 74.8% of men and 60% of women were in the workforce (Blau and Kahn, 2007). Simultaneously, there has been a decline of prime age men (i.e., men aged 18 to 63) in the U.S. labor market. Moreover, the BLS (2013) noted that the participation rate of women peaked in 1999 and has been decreasing since. The latest data from 2014 puts the labor force participation rate of prime age men at 69.2%, and prime age women at 57.0% (BLS, 2015).

Figure 3-11. Labor Force Participation Rate by Gender, 1994-2014 and Projected 2024



Source: U.S. Bureau of Labor Statistics, 2015

Labor supply elasticities

Heim (2007) examined married women's labor supply elasticities (i.e., the responsiveness of labor force participation rates to changes in wages, income, taxes, etc.) and their change from 1978 to 2002. The study found that elasticities have decreased, suggesting that policies to encourage entry to the labor supply may be less effective than before. Not surprisingly, women with more years of education worked more hours. Other factors impact labor force participation, including geographic proximity to other women. Compton and Pollak (2014) studied the National Survey of Families and Households (NSFH) and the U.S. Census, and found that geographical proximity to mothers or mothers-in-law for childcare services have allowed married women with children to enter the labor market.

Commute characteristics as distinct by gender

Women tend to make different choices from men in terms of travel mode. The 1983 NHTS showed a higher proportion of women commuting by car, whether as drivers or passengers, and 1990 and 1991 commuting data from Tucson, AZ show that women are more likely to drive alone than men are (Sarmiento, 1996) . Similarly, research from the late 1990s suggested that women were more likely to choose cars as their mode of travel because of the flexibility to chain trips (McGuckin and Murakami, 1999). Guiliano and Schweitzer (2009) propose that a reason for higher car use among women relative to men is they place higher value on time and travel reliability due to household responsibilities after work.

Therefore, a policy or infrastructure that allows them to save time (e.g., high-occupancy/toll lane) will increase their travel choices and benefit them (Giuliano and Schweitzer, 2009).

Commuter distances and travel time also vary based on gender, but has changed over time. An analysis of the 1990 survey of San Francisco Bay Area residents by Mauch and Taylor found a 12.9% difference in the average travel times for work commute and for all travel between the sexes. In the 1990s, the average trip travel time for women was several minutes longer than that of men (Mauch and Taylor, 1997). In the 1970s, Ericksen (1977) found that married women had shorter commutes than unmarried women, and commute distances for women decrease with the presence of children. More recently, Crane and Takahashi (2009) analyzed the American Housing Survey dataset from 1985 to 2005 and found that overall, differences in commute times and mode choice have become less pronounced over time (i.e., men and women overall are trending towards similar commute times and mode choices). However, the authors note the importance of analyzing different variables independently. In doing so, they found that the gender gap in commute length among older workers is growing (i.e., older women are experiencing longer and longer commutes, possibly due to childcare needs), while the gap among younger workers is converging (Crane and Takahashi, 2009).

Previous research has also found that women in the work force have to make 50% more stops in between work and home. They stop to pick up and drop off passengers more often than men in all combinations of home/work trips (McGuckin and Murakami, 1999). Furthermore, according to a study performed with University of California, Los Angeles staff, women are more likely to accept employer-sponsored travel reduction programs to ride transit more. The trend is especially visible for young women—26 to 35 years old—and older women over 55 (Gould and Zhou, 2011). A study by Mokhtarian et al. (2011) found similar results when women were faced with traffic delays due to roadway construction.

Household Structure and Responsibilities

Previous research has found that roles within the household also impact the travel of women. The presence of children in the household naturally leads to carpools (colloquially known as “fampools”) (Sarmiento, 1996) . Working mothers are more likely to link trips than working fathers; moreover, they are more likely to link trips when the children are younger. Single mothers are the most likely to trip chain (Sarmiento, 1996). Women made more than twice as many child-serving stops per work trip as men. For women, 6% of all commutes to/from work included a child-serving stop, whereas this value was only 2.7% for men (Mauch and Taylor, 1997). On the other hand, higher-income households tend to subscribe to errand services, allowing women to take on fewer of the errands and trip chain less (McGuckin and Murakami, 1999). The presence of another adult in the household decreases the probability of making a side trip (a brief deviation from the planned itinerary) for men, but not for women. When a man has a non-working female household member, she is likely to complete the necessary side trips. Furthermore, the probability of making side trips for women increases with presence of children, yet one researcher found that it does not increase for men (Sarmiento, 1996) . Mauch and Taylor (1997) presented a framework of four household types to determine how household structure affects travel time:

1) Households with a single adult and no dependents,
2) Households with a single adult and dependents,
3) Households with two or more adults and no dependents, and
4) Households with two or more adults and dependents.

For the first household type (single adult, no dependents), travel times for all trip types were more consistent than for any other household type pairing (Mauch and Taylor, 1997, and McGuckin and Murakami, 1999). Moreover, Sarmiento (1996) found that single women without dependents made over 20% less person trips than single men. For single adults with dependents (single mothers or single fathers), however, the average trip duration for single mothers is higher than that for women in any other group. (Mauch and Taylor, 1997, and McGuckin and Murakami, 1999). Trips for single mothers tend to be longer than the average trip duration for single fathers, suggesting that single women have higher levels of non-work travel (Mauch and Taylor, 1997). Married women with dependents made over 20% more person trips than married men. Analysis from 1977 and 1983 data shows that married workers, especially those from two-worker households, have longer work trips than unmarried workers (Sarmiento, 1996) .

Household structures also impact trip chaining. Single-person households are the most likely to form complex trip chains, as they have no other household members to share travel activities with (Al-Kazily et al., 1994). Single adults with young children have the highest tendency to form complex trip chains on the way to and from work. As the number of people in the household increases, complex work chains decrease and simple non-work chains increase (Sarmiento, 1996) . This can be attributed to the dispersal of errands among the different members of the household, instead of concentrating them with a single member.

Social and Cultural Factors

In the previous sections, we discussed socio-demographic trends that impact travel in the United States. There are still social and cultural factors not captured in these trends, namely, perceptions and attitudes towards driving, technology, and global climate change. This last section explores research into these factors as they relate to travel behavior.

Attitudes towards Driving

There is growing evidence that attitudes among Americans towards driving are shifting. Handy et al. (2005) assert that many Americans may be driving out of necessity rather than choice. Possible explanations include the lack of alternatives to driving and urban sprawl, making driving the fastest and most flexible option. Millennials (those born between 1981 and 1996) are now the largest age group in the United States and are often cited as the generation beginning to reject car ownership. The percentage of high school seniors with driver’s licenses has decreased from 85% to 73% between 1996 and 2010 (Dutzik et al., 2014).

Attitudes towards the Environment and Climate Change

While there is growing awareness of the threat of global climate change among the American public, there is limited research in understanding trends in people's attitudes. Bord et al. (1998) conducted a study on public opinion on global warming in the United States and abroad. Overall, the public was aware of the environmental issues and was concerned about global warming. However, the perceived threat level was less than other societal challenges. A similar study of United States and European perspectives was conducted in 2006 with similar findings (Lorenzoni and Pidgeon, 2006). This may suggest that attitudes have not changed much during the late 1990s and early 2000s.

Millennials again have been noted as the generation that is more environmentally conscious and willing to change travel behavior. A study by the American Public Transportation Association (APTA) (2013) found that one third of respondents' transportation decisions were impacted by environmental concerns. However, this study and a TransitCenter report (2014) noted that other concerns often rank higher than the environment and climate change, including cost and convenience. However, the U.S. PIRG report (Ditzik et al., 2014) concluded that environmental concerns play a supporting role rather than a leading role in influencing transportation habits.

Attitudes towards Information and Communication Technology

Millennials overall have embraced emerging technologies—formally known as information and communication technology (ICT)—particularly with the proliferation of Internet access through household broadband and smartphones. This has allowed technology users to substitute some physical trips with "virtual trips." Telework and online shopping are examples of physical trips avoided due to technology, but the exact impact on overall travel demand remains unclear (see Chapter 2 for more discussion on telework). At the same time, ICT can provide access to increased mobility options. One example is app-based, on-demand ride services (also known as "ridesourcing" or "transportation network companies") such as Lyft and Uber, whereby riders are connected to nearby drivers in real-time using their mobile devices. ICT can also help users more easily access and navigate public transit, access carsharing and bikesharing locations, and stay connected during the trip. ICT can also aid driving with turn-by-turn navigation, real-time rerouting, and traffic congestion alerts.

> ICT can provide access to increased mobility options and help users more easily access and navigate public transit, access carsharing and bikesharing locations, and stay connected during the trip.

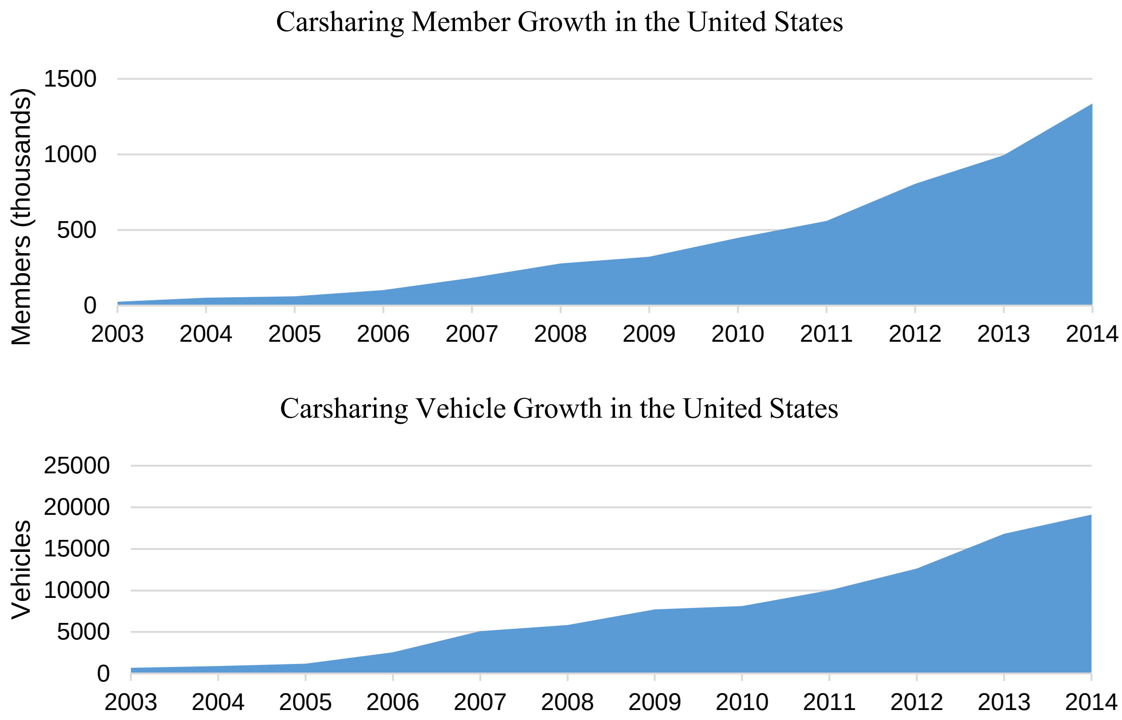
Because ICT is quickly proliferating and evolving, little research has been done in recent years to capture its impact on travel (Ditzik et al., 2014). Blumenberg et al. (2012) found no correlation between the reduction of driving among Millennials and their usage of ICT. Mans et al. (2012) developed a framework determining potential impacts of ICT on travel. The framework concluded that ICT will impact travel in multiple and complex ways (e.g., an online shopping purchase may merely replace a shopping trip with a delivery trip), and is therefore difficult to model any significant impacts. Data remain scarce to draw further conclusions. The most recent NHTS did not take into consideration latest ICT, including smartphones and social media. As ICT will only continue to grow and evolve, timely research is needed to better capture the attitudes towards ICT and its impact on travel.

Attitude towards Sharing

The sharing economy has grown alongside emerging ICT systems, which facilitate the sharing of assets that would have otherwise been used by one individual or household. Within the personal transport realm, shared mobility is an innovative transportation solution that enables users to have short-term access to a vehicle, bicycle, or another mode on an as-needed basis. Shared mobility is burgeoning and evolving to meet the needs of cities and travelers whose attitudes have begun to shift towards sharing.

The most direct evidence of shifting attitudes towards sharing is the increased use of shared mobility systems and their direct impact on decreasing driving alone. As of July 2015, there were 22 carsharing operators in the United States, with over 1.1 million members and over 19,000 shared vehicles (Shaheen and Cohen, 2015). Figure 3-12 depicts the growth in carsharing growth since 2003. Chapter 4 provides further discussion on shared mobility systems.

Figure 3-12: Carsharing Member and Vehicle Growth in the United States, 2003-2014



Source: Shaheen and Cohen, 2014

Known Data Gaps and Limitations

There are several data gaps that ideally would be covered by future developments in data collection and technology. This section covers what is known about those data gaps and provides high level suggestions as to how they could be addressed.

Data on population growth is generally well tracked by the U.S. Census. Although the official Census is conducted once a decade, the Census Bureau applies population growth modeling to track the population incrementally. The “population clock” provides instantaneous and continuous estimates of the US population. These estimates are based on constant factors of “seconds per birth”, “seconds per death”, and “seconds per net migrant”, and the factors get updated annually. While such estimates could always be improved by more frequent updates to the growth factors, the current resolution of population data is sufficient for the purposes of understanding impacts on travel behavior.

The chapter also identified immigrants as a major contributor to current and future U.S. population growth. There exist some data gaps pertaining to how immigrants travel and where they move. Naturally, some of these gaps exist because of broader information barriers that accompany undocumented immigrants. But the time-resolution of understanding the travel behavior of immigrants could be improved. Much of our understanding of the travel behavior of immigrants is derived from research using NHTS data, which allows the deep study of travel behavior by very specific demographics. Because of the relative infrequency of the NHTS, it is challenging to ascertain how technology may be changing the travel patterns of immigrants to the U.S. As information for travelers becomes more accessible, and new technologies like ridesourcing become more universal, the travel behavior of immigrants may evolve to be both more advanced and more similar to the travel behavior of the broader U.S. population sooner upon arrival. But without the data for the deep dive that NHTS facilitates, catching these changes could occur years after they happen.

Data evaluating age and generational differences heavily draws insights from the NHTS, the U.S. Census Bureau, the U.S. Bureau of Labor Statistics, and the 2011 National Health and Aging Trends Study (NHATS). When analyzing age and generation data, research conclusions can quickly become outdated as generations grow older and enter new phases of life. For example, when the 2009 NHTS was conducted, the oldest Boomers were 63 years old. By 2015, these individuals are close to 69 years old and many more Boomers have entered retirement, which would engender very different travel patterns than while working. Thus, any age-related analysis can only be a snapshot of how generations and age cohorts are behaving at that particular point in time.

As with age-related conclusions, research conclusions evaluating the impacts of income on travel are largely derived again from the National Household Transportation Survey (NHTS) and the U.S. Census Bureau. Both these sources take self-reported income data from respondents, which may not match the income tax returns they filed. Further, Schwartz (2014) uses the U.S. Census Bureau’s 2012 income estimates, which is based on a selection of 75,000 households unlike the decennial Census. At the same time, the 2009 NHTS collected respondent income from 2008, and thus there is a four-year difference in the datasets used by the papers cited. This could be a significant gap given the fact that the U.S. economy, and thus people's incomes, has faced volatility since the onset of recession in 2008.

There also remain large data gaps in travelers' preferences and actions. While there is notable evidence that global climate change and concern for the environment are more on the minds of Americans, there are few data on travelers' revealed preferences (i.e., their actual travel choices). Lack of research is also evident in attitudes towards ICT, particularly as technology continues to evolve so rapidly.

Many of the data gaps identified in this section come back to in frequency of data collection, particularly with respect to the NHTS. To address these and related challenges, one possible solution might be development of a survey capturing core travel data on a more frequent basis. Such a survey, in concept, would comprise of a subsample of travel behavior that could be used at the national level. The data informing this survey might not need to be a newly implemented survey effort, but rather a draw of data from ongoing state and local travel surveys that are being undertaken across the country at different times. Data might be drawn from such surveys so as to match the profile of the national population. Much like the ACS of the Census, there is a need to have a sub-sample based approach to understanding movements in travel behavior in between the NHTS surveys. This approach, while imperfect, may offer a cost effective way to generate interim and preliminary insights on national travel trends in advance of the next full NHTS.

Summary

This chapter discussed the socio-demographic trends that have occurred or continue to occur in the United States since the mid-20th century. We explored five key socio-demographic trends that impact travel behavior. First, population growth has increased overall travel, but as the growth rate is decreasing, so is the rate of vehicle-miles traveled. Suburbanization has generally been increasing for the last few decades, right through 2010. The existing data analyzed this decade suggests that the longstanding trend of migration from cities to suburbs may in fact be abating, as several large cities registered above-average growth rates that exceeded their surrounding suburbs. Regional Migration patterns in the country remain the same: the general flow from the Northeast to the South and West is still underway despite this emerging growth within cities.

There has been a growth in income for certain demographics of Americans, not uniformly over all regions, ages, and geographies. As Baby Boomers age into retirement and Millennials into working and family life, transportation policy and planning will need to change to accommodate differing needs and shifting desires for alternatives to car use. Similarly, women and their participation in the labor force have shifted their travel needs. As social trends and attitudes continue to shift throughout the early 21st century towards alternatives to driving alone, supporting environmental concerns, embracing technology, information dissemination, and shared mobility, continued research is crucial to understanding these trends and informing national and regional transportation policy.

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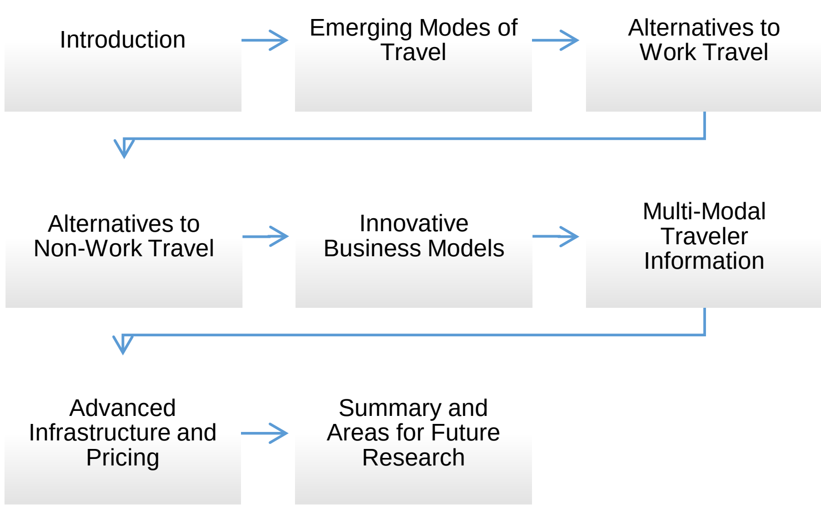
CHAPTER 4.0. TRANSFORMATIVE TECHNOLOGY AND SYSTEMS CHANGING TRAVEL BEHAVIOR TODAY

Introduction

As changing socio-demographics have influenced travel in the United States, rapidly evolving technology has similarly played a notable role in shaping travel choices. This chapter explores the technologies and systems that are currently changing travel behavior in the U.S, with a focus on the emerging technologies that have been most influential within the 21st century. These technologies include those that facilitate travel reductions (e.g., telecommuting and online shopping), as well as emerging technologies that influence new ways of travel (e.g., carsharing, bikesharing, ridesharing, ridesourcing/TNCs, and microtransit). Chapter 4 provides a review of research and the state-of-knowledge of travel behavior changes that are occurring as a result of these transformative factors. The flow of Chapter 4 is depicted in Figure 4-1.

Figure 4-1: Content Flow of Chapter 4



Emerging Modes of Travel

Apart from conventional transportation modes where users drive or take public transit, multi-modal trip chaining and innovative travel modes are becoming more common with the advancement of technology.

This section covers how emerging technologies are presenting new modes of travel and what is known about their impacts on travel behavior.

Shared Mobility

Shared mobility—the shared use of a vehicle, bicycle, or other low-speed mode—is an innovative transportation strategy that enables users to have short-term access to transportation modes on an as-needed basis. Shared mobility includes carsharing, personal vehicle sharing (or peer-to-peer carsharing), bikesharing, scooter sharing, shuttle services, microtransit, ridesharing, and on-demand ride services (or ridesourcing). Origins of several shared modes, such as carsharing, have their roots from Europe in the 1940s, but modern shared mobility began to proliferate in the U.S. after the late-1990s. The industry has since emerged from a niche urban application, and is beginning to have a transformative impact on many cities worldwide by enhancing transportation accessibility, while simultaneously reducing travel by personally-owned single occupancy vehicles (SOVs).

Shared mobility systems leverage information and communications technologies (ICT) to facilitate their operations. In the case of carsharing and bikesharing, vehicles and bicycles are typically unattended, concentrated in a network of locations where the transaction of checking out and returning a vehicle or bicycle is facilitated through automated equipment and communications. Similarly, ridesourcing or TNC services employ ICT to enable the matching of riders and drivers for tripmaking.

The benefits of shared mobility are numerous. Studies of shared mobility modes have documented the reduction of vehicle use, ownership, and vehicle miles/kilometers traveled (VMT/VKT). Cost savings and convenience are frequently cited as primary reasons for shifting to a shared mobility mode. Shared mobility modes can also extend the catchment area of public transit, bridging gaps in existing transportation networks and addressing the first- and last-mile barriers that are common to public transit. The subsequent sections review studies of these impacts in further detail.

> The benefits of shared mobility include the reduction of vehicle use, ownership, and vehicle miles/kilometers traveled (VMT/VKT).

Carsharing in the United States and Canada

Carsharing is generally described as short-term auto use. Typically, carsharing users are members within an organization and are provided access to a fleet of shared vehicles on an hourly and roundtrip basis. The vehicle fleet may be owned by the organization in a business-to-consumer model or it may be owned by its members in a peer-to-peer model. Members book a vehicle through an online reservation system and access unattended vehicles using a smartkey, smartcard, or smartphone technology. Payment is generally done electronically. In addition to roundtrip and peer-to-peer carsharing, there is one-way (or point-to-point) carsharing in which individuals can access vehicles from one location and return them to another.

The first carsharing program launched in North America in 1994, and the industry has grown rapidly since. As of July 2015, there were 22 carsharing operators in the U.S. with over 1.1 million members and over 19,000 vehicles (Shaheen and Cohen, 2015). These numbers include roundtrip and one-way carsharing numbers but not peer-to-peer carsharing due to proprietary concerns. Today, there has been burgeoning activity and the emergence of several carsharing business models to suit the needs of its members, each of which are defined and discussed in the subsequent sections.

Roundtrip Carsharing

At present, roundtrip carsharing is the predominant business model in carsharing, whereby an organization places shared vehicles throughout a network and requires members to access and return vehicles to the same location. Such carsharing systems allow members access to a vehicle fleet for a paid period of time. These systems follow a “business-to-consumer” model because the vehicles in the carsharing fleet are owned by the service provider itself, and are often branded in a special identifiable way. Examples of carsharing companies include Zipcar, the largest roundtrip carsharing operator in North America, Enterprise CarShare, and more locally based companies such as Halifax CarShare. Among the different business models, roundtrip carsharing also has the longest legacy, with many studies capturing its impact on VMT/VKT, fuel consumption, GHG emissions, and modal shifts.

Cervero conducted a series of longitudinal studies (2003, 2004, 2007) of City CarShare in San Francisco to determine short-, intermediate-, and long-term impacts on travel behavior. Nine months after joining the carsharing service, members made 7% of trips by City CarShare vehicles (an increase from 2% at the 3-month marker). More than 20% of members’ VMT were in carsharing vehicles, suggesting that access to carsharing vehicles may increase mobility and VMT, particularly among those who do not own/lease a vehicle (Cervero, 2003). At the two-year mark of City CarShare, 10% of VMT and 6.5% of trips were in carsharing vehicles. Thirty percent of members shed one or more of their own personal cars, and two-thirds chose to postpone the purchase of another vehicle (Cervero and Tsai, 2004). At the four-year mark, 5.4% of VMT and 4.9% of trips were in carsharing vehicles, and 29% of members had shed a vehicle. A longitudinal analysis of the studies found clear evidence of a net reduction of VMT and per-capita fuel consumption among City CarShare members as a whole. Moreover, carsharing members became more judicious of their travel choices, opting for alternative modes, such as public transit, walking, cycling, or even forgoing trips (Cervero et al., 2007). Martin and Shaheen (2011) conducted a large survey of 6,281 carsharing members in North America and found an annual VMT decline of 27% to 43%. The 27% reduction considered only miles that were observed to have declined before and after carsharing due to car sales, termed the “observed impact.” The 43% reduction considered the elimination of additional miles that would have been driven on vehicles that would have been acquired (or postponed vehicle purchases).

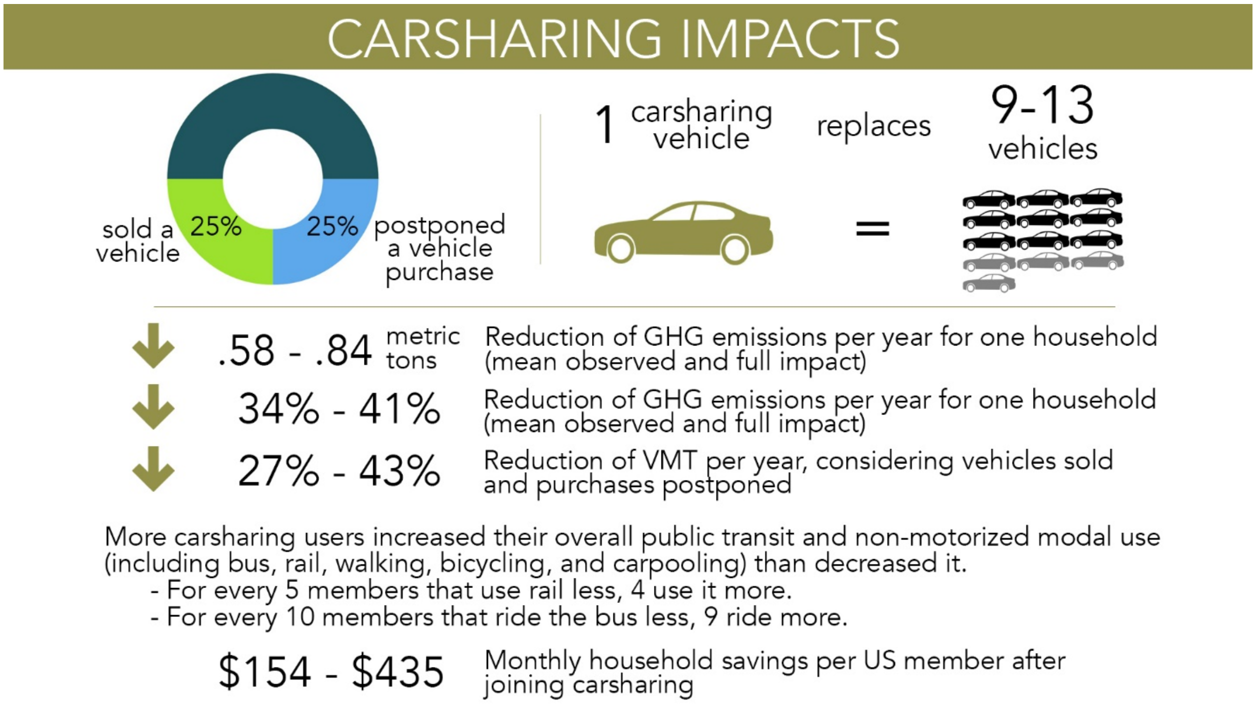
Research has shown that roundtrip carsharing reduces household vehicle ownership to different extents. An early study from Portland CarShare found that 26% of its members sold a car and 53% avoided a new purchase (Katzev, 2003). A study on PhillyCarShare found that each vehicle from its fleet removed 23 cars from the road either by direct sale or vehicle suppression (Lane, 2005). The study by Cervero et al (2007) on users of San Francisco's City CarShare revealed during the period of study that the percentage of respondents who came from zero-vehicle households increased from 42% to 63%, while those from one-vehicle households decreased from 41% to 29%. Moreover, 17% of City CarShare members surveyed stated that they had reduced vehicle ownership since joining (Cervero et. al, 2007). Martin and Shaheen (2011) found that average household vehicle holdings dropped from 0.47 to 0.24 (i.e., many one-car households were able to become carless due to carsharing). Moreover, it was estimated that North American carsharing took 90,000 to 130,000 vehicles off the road, or about 9 to 13 vehicles for each carsharing vehicle, as the whole fleet had about 10,000 vehicles at the time. Overall, these effects equate to an aggregate reduction of 1.1 billion miles driven for members of roundtrip carsharing (as of January 1, 2013). However, this is still relatively small compared to the Federal Highway Administration estimate of 2.9 trillion miles driven in the U.S. in 2012 (Shaheen and Cohen, 2013). As carsharing membership continues to grow, these vehicle reductions could continue in to grow in scale.

Energy use and GHG emissions are a growing concern among city leaders and has been studied in previous research. Martin and Shaheen (2011) found an average of 0.58 metric ton reduction of GHG emissions per year per household for the observed impact. The observed impact was defined as emissions reduction that could be "seen" with changes in behavior. When carsharing households avoided or postponed vehicles, and the miles they were not driven were also considered, the average GHG reduction per household was found to be 0.84 metric tons (Martin and Shaheen, 2011). Overall, this amounted to a 34% to 41% reduction in GHG emissions per carsharing member household (Shaheen and Chan, 2015). Chen and Kockelman (2015) examined the lifecycle inventory impacts on energy use and GHG emissions by adopters of carsharing in the U.S. It was found that average energy use and GHG emissions are reduced by over one-half (51%). This amounted to a five-percent reduction of household transportation energy use and GHG emissions. The estimated savings include avoided travel, shifts to other travel modes, lower fuel consumption, and less parking infrastructure requirements — all societal benefits of carsharing.

> There are two main models of one-way carsharing: 1) free-floating carsharing and 2) station-based carsharing.

Roundtrip carsharing has also had a notable impact on modal shift. An earlier study from Scott et al. (2000) reported a 14% increase in public transit trips, a 10% increase in bicycling trips, and a 26% increase in walking trips among members of a large carsharing organization in Portland, Oregon. More recently, a case study in Montreal, Canada found that carsharing members have a modal split with auto usage significantly lower than that of non-carsharing members (Sioui et al., 2012). Martin and Shaheen (2011) examined the impact of carsharing on public transit and non-motorized travel, and found an overall decline in public transit use. For every five members that use rail less, four members use rail more; for every ten members that ride the bus less, nine ride the bus more. They noted that this decline was not uniform across all carsharing programs, but it was driven by a minority (three of 11) organizations participating in the study. At the same time, members exhibited an increase in other modes, such as walking, bicycling, and carpooling. Shaheen and Chan (2015) produced a summary of these research findings and graphically summarized in Figure 4-30

Figure 4-2. Key Impacts of Roundtrip Carsharing



Like most carsharing organizations, roundtrip carsharing companies operate mainly in cities or urban centers. Therefore, suburbs and lower-density areas generally do not benefit as much from roundtrip carsharing. P2P carsharing and one-way carsharing may allow for the introduction of carsharing to these nascent markets, but they have yet to penetrate these markets in major ways.

One-Way Carsharing

One-way carsharing (also known as point-to-point carsharing) allows its members to pick up a vehicle at one location and drop it off at another, contrasted to roundtrip carsharing that requires the vehicle to be picked up and dropped off at the same location. This business model uses GPS technology and algorithms for vehicle distribution and rebalancing to better ensure vehicles are located near where members will access them. There are two main models of one-way carsharing: 1) free-floating carsharing and 2) station-based carsharing (Shaheen et al., 2015). Free-floating carsharing services enable shared vehicles to be picked up and dropped off anywhere within a designated operating area. In contrast, station-based systems require users to return the vehicle to any designated station. Although this model may be perceived as less flexible, station-based carsharing limits the need for members to search for a vehicle within a region. Instead, they can access vehicles at reliable and familiar locations.

One-way carsharing experienced a rapid worldwide expansion during 2012, operating in seven countries, including in the U.S. and Canada (Shaheen and Cohen, 2012). As of January 2015, 35.7% of North American fleets were one-way trip capable, and 30.8% of members had access to these fleets. In December 2014, Zipcar announced the launch of its one-way carsharing service in Boston with 200 vehicles (Shaheen and Cohen, 2015). As of September 2015, four carsharing companies offer one-way functionality (car2go, DriveNow, Zipcar, and BlueIndy) in 14 U.S. metropolitan regions.

As the one-way model is still nascent in the U.S., few studies have been conducted to understand its impacts. Future studies of one-way carsharing will continue to reveal more data on impacts to VMT/VKT, GHG emissions, vehicle ownership, and modal shifts.

Personal Vehicle Sharing

Personal vehicle sharing (PVS) is another carsharing service model characterized by short-term access to privately-owned vehicles. It is often also referred to as peer-to-peer (P2P) carsharing, although this is a distinct type of PVS. PVS companies broker transactions among car owners and renters by providing the organizational resources needed to make the exchange possible, such as an online platform, customer support, automobile insurance, and vehicle technology. Members access vehicles through a direct key transfer from the owner to the renter or through operator-installed in-vehicle technology that enables unattended access. There are four distinct models of personal vehicle sharing: 1) P2P carsharing, 2) hybrid P2P-traditional carsharing, 3) P2P marketplace, and 4) fractional ownership (Shaheen et al., 2012a).

P2P Carsharing

Peer-to-peer carsharing employs privately-owned vehicles or low-speed modes made temporarily available for shared use by an individual or members of a P2P company. While still heavily focused in urban areas and cities, P2P carsharing operations are not as geographically confined as other types of carsharing because the users provide the floating vehicle fleet. In addition, P2P carsharing appears to serve a more diverse population than traditional station-based carsharing services. In a study of P2P carsharing use in Portland, it was found that 37 percent of families in poverty live in a census block group that contains at least one P2P vehicle, but only 13 percent live in a census block that has a station-based carsharing vehicle. In parts of East Portland, P2P vehicles are the only type of carsharing vehicles available (Dill, 2014). Furthermore, Fraiberger and Sundararajan (2015) project that P2P carsharing will have more pronounced impacts on below-median income consumers than above-median income consumers. Examples of P2P carsharing operators in the U.S. include: RelayRides, Getaround, and FlightCar. Pricing and rental terms for P2P carsharing services vary, as they are typically determined by vehicle owners listing their vehicles for rent. The P2P carsharing operator generally takes a portion of the rental amount in return for facilitating the exchange and providing third-party insurance. For example, RelayRides takes 25 percent commission from the owner along with 10 percent from the renter, and Getaround takes 40 percent from the owner for its services. With FlightCar, the car owner is paid $.05 to

> There are four models of personal vehicle sharing: 1) P2P carsharing, 2) hybrid P2P-traditional carsharing, 3) P2P marketplace, and 4) fractional ownership.

$.20 per mile, with an average payment of $20 to $30. There are no parking fees at the airport, and the vehicle is washed and vacuumed when the owner picks it up upon return. There also is a flat-rate monthly program in which the driver can net a total of $250 or greater. As of May 2015, there were eight active P2P operators in North America, with two more planned to start in the near future.

Hybrid P2P-Traditional Carsharing and P2P Marketplace

Hybrid P2P-traditional carsharing is where individuals access vehicles or low-speed modes by joining an organization that maintains its own fleet, but it also includes private autos or low-speed modes throughout a network of locations. P2P marketplace enables direct exchanges between individuals via the Internet, including pricing agreements. Terms are generally decided among parties of a transaction, and disputes are subject to private resolution.

Fractional Ownership

In the fractional ownership model, individuals sublease or subscribe to a vehicle owned by a third party. These individuals have "rights" to the shared vehicle service in exchange for taking on a portion of the operating and maintenance expenses. This enables access to vehicles that individuals might otherwise be unable to afford, and it results in income sharing when the vehicle is rented to non-owners. Fractional ownership could be facilitated through a dealership or a partnership with a carsharing operator. Often, fractional ownership is used with luxury cars, which would otherwise be unaffordable for most, as well as for recreational vehicles (RVs) in recent years. This segment of the industry is currently small, and it remains to be seen whether or not fractional ownership can compete with existing carsharing models and personal vehicle ownership overall.

Fractional ownership companies in the U.S. currently include: Curvy Road, Gotham Dream Cars, and CoachShare. In December 2014, Audi launched its "Audi Unite" fractional ownership model in Stockholm, Sweden. Audi Unite offers multi-party leases with pricing based on model, yearly mileage (2,000 or 3,000 Scandinavian mile packages available), and the number of drivers ranges from two to five. For example, an Audi Unite A3 sedan can be leased among five drivers for approximately 1,800 kronors per month (~$208 USD per driver per month) for 2,000 annual Scandinavian miles (~12,000 statute miles) on a 24-month lease.

Bikesharing

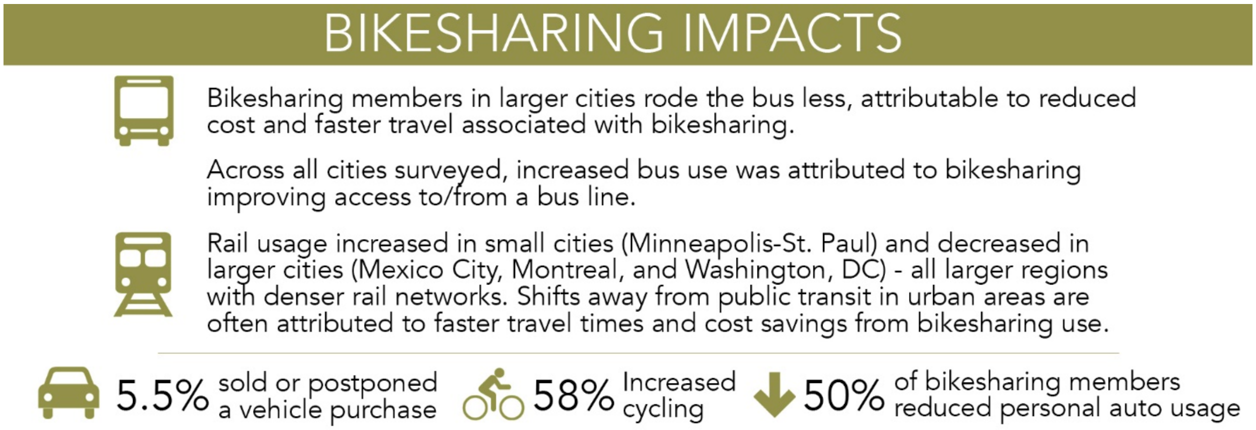
Bikesharing has emerged as one of the latest and fastest growing transportation innovations in many North American cities. Bikesharing systems allow users to access bicycles on an as-needed basis from a network of stations, which are typically concentrated in urban areas. Bikesharing stations are usually unattended and accessible at all hours, granting an on-demand mobility option. Most bikesharing operators are responsible for bicycle maintenance, storage, and parking costs. Bikesharing can also be free floating within a geo-fenced area either through a business-to-consumer (B2C) operator (e.g., Social Bicycles) or

> There are three main types of bikesharing systems: 1) public bikesharing, 2) closed campus bikesharing, and 3) peer-to-peer bikesharing.

through P2P systems enabled through third-party hardware and applications (e.g., Bitlock, Spinlister). There are three main types of bikesharing systems: 1) public bikesharing, 2) closed campus bikesharing, and 3) P2P bikesharing (Shaheen and Christensen, 2014). The majority of bikesharing systems in U.S. cities are public, with anyone able to access a bicycle for a nominal fee (and a credit/debit card on file). As of August 2015, there were 56 information technology-based public bikesharing systems in the U.S. (spread over 70 cities), with approximately 28,625 bikes and 2,986 stations (Russell Meddin, unpublished data). Closed-campus bikesharing systems are increasingly being deployed at university and office campuses, and they are only available to the particular campus community they serve. P2P bikesharing services are available in urban areas for bike owners to rent out their idle bikes for others to use and are also growing due to companies, such as Spinlister and Bitlock.

Shaheen et al. (2012b and 2014) conducted a two-part study of public bikesharing programs in North America to determine the program impacts on modal split. The results suggest that public bikesharing in larger cities takes riders off of buses, while bikesharing in smaller cities improves access/egress from bus lines. Moreover, respondents reported that rail usage decreased in larger cities due to faster travel speeds and cost savings from bikesharing. Half of all bikesharing members reported reducing their personal automobile use (Shaheen et al., 2014). A 2012 survey of 20 U.S. public bikesharing programs found the average cost for a day pass to be $7.77, and all the programs offered the first 30 minutes of riding free. Twelve programs offered monthly memberships, averaging $28.09 per month. Eighteen of the programs offered annual memberships, which cost an average of $62.46 (Shaheen et al., 2014). Aggregate-level impacts of bikesharing are summarized by Shaheen in Chan (2015) in Figure 4-3, below, based on a number of cities analyzed in North America.

Figure 4-3. Key Impacts of Public Bikesharing



On-Demand Ride Services (Ridesourcing)

One of the fastest growing transportation innovations in the United States in recent years has been transportation network companies (TNCs), which provide app-based, on-demand ride services. On-demand ride services use smartphone applications (apps) to connect drivers with passengers. The business model is built on the premise that anyone with a driver's license and a car can provide rides to customers, the requests for which are facilitated by a smartphone app. The vehicles used with these applications are owned by the drivers themselves. The TNC only operates the app and takes a percentage of the fare paid by the passenger to the driver. This is a change in the model of fleet ownership by ride services such as taxicab companies, which often own the vehicles in the fleet and lease them out to drivers.

There are various terms for this emerging transportation option, including ridesourcing (used by transportation researchers and practitioners), ride-hailing or ride-booking (now used by the Associated Press), transportation network companies (TNCs) (used by public utilities agencies and the insurance industry). It is often confused with ridesharing, which is the grouping of travelers with common origin and/or destination into the same vehicle. The popular press previously merged the two distinct travel modes, but it has since begun to use the terms ride-hailing or ride-booking. Examples of these ride services include Lyft and Uber

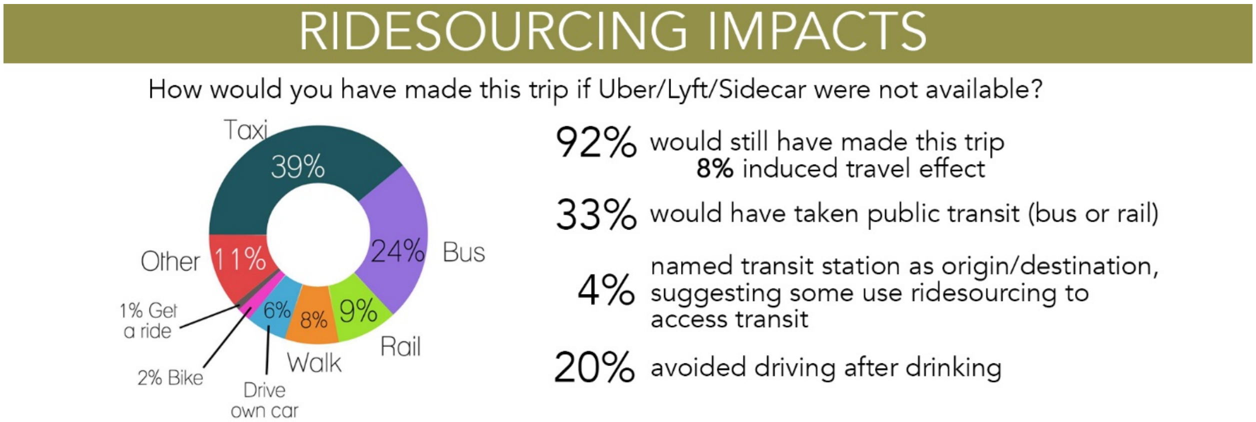
Ridesourcing services have also begun to include ridesplitting. Ridesplitting involves splitting a ridesourcing/TNC-provided ride with someone else taking a similar route. Lyft and Uber match riders with similar origins and destinations together, and they split the ride and the cost. Recent examples of ridesplitting are Lyft Line and UberPOOL. These shared services allow for dynamic changing of routes as passengers request pickups in real time. These services may enable greater environmental benefits of ridesourcing services, as ridesourcing trips are able to increase occupancies beyond the standard driver/passenger pair.

Both of the two largest TNCs today, Uber (UberX and UberXL) and Lyft, started in San Francisco, with Uber launching operations in 2010 and Lyft following in 2012. Lyft operates 65 cities in the United States, while Uber has expanded internationally to over 310 cities in 59 countries as of August 2015. Generally, TNCs operate within or near urban centers in order to ensure adequate density of origin and destination points within a short enough driving distance from each other. The recent explosion in popularity of TNCs has come with significant pushback from taxi companies, who consider themselves at a significant disadvantage as they are subjected to far greater regulation than TNCs. Further, major insurance and legislative issues pertaining to ridesharing vehicles remain.

> Ridesourcing trips tended to have shorter wait times than taxis.

Because ridesourcing is a new phenomenon, there are few studies documenting impacts to travel behavior and other transport modes. The TNCs have conducted internal studies of its users and travel activity; however, that data remains proprietary given the competitive and controversial nature of the industry. Rayle et al. (2014) conducted an exploratory study of 380 ridesourcing users in San Francisco, California during Spring 2014. They found that ridesourcing users were generally younger and more highly educated than the city average (84% had a bachelor's degree or higher). They also found that people using TNCs were slightly more likely to not own a vehicle than those that were frequent taxi users (43% versus 35%). Ridesourcing trips in the sample tended to have shorter wait times than those of taxis. For trip purpose, two-thirds were social/leisure trips, and only 16% were work-related. Almost half of the trips began somewhere other than home or work, while 40% were home-based. If ridesourcing were unavailable, 39% would have taken a taxi, 24% a bus, 9% rail, and 6% would have driven. Four percent named a public transit station as their origin or destination, suggesting that ridesourcing users can serve as a first-/last-mile mode to and from public transit. Only 10% of those surveyed had changed their vehicle ownership level since using TNCs, but there was no evidence to suggest that TNCs had an impact on their decision to either get rid of or obtain a new vehicle. Moreover, 40% of users who owned a car stated they had reduced their driving due to ridesourcing. Finally, 20% stated they used ridesourcing to return home to avoid driving after drinking. Figure 4-4 presents a summary of the findings.

Figure 4-4. Key Findings of Ridesourcing



Source: Graphic excerpted from Shaheen and Chan (2015)

Ridesourcing continues to evolve as the industry expands, and as public agencies develop regulations regarding safety, accessibility, and insurance coverage. Thus, research needs to continue to investigate its impact on travel behavior with revealed preference and activity data.

Employer Shuttles

Employer shuttle systems have become a significant share of the urban transportation network in certain metropolitan areas. They operate widely in the Silicon Valley of the San Francisco Bay Area, providing direct transport for workers between San Francisco and job centers in other areas. Understanding the impacts of these shuttles is becoming more important as organizations plan for accommodating future growth and meeting sustainability needs.

Employer shuttles are not a recent innovation; however, it is only in the past decade that they have been used more extensively. Thus, there are few studies in the literature focused strictly on them. Moreover, the employer shuttle systems in previous implementations were fundamentally different—they focused primarily on the “last-mile” problem, ferrying people between suburban workplaces and public transit stations. Also, the studies have been largely limited to the Silicon Valley (Dai and Weinzimmer, 2014), a primary location of high technology companies implementing shuttle their own services. These services are also popular in the Seattle, WA and Tysons Corner, VA areas. Dai and Weinzimmer (2014) found that employer shuttles are attractive due to time and cost savings for commuters, but they have the potential to exacerbate the job-housing imbalance by enabling commuters to live farther from their workplace.

Current studies conducted on employer shuttle systems are showing fairly positive results. A 2011 San Francisco County Transportation Authority (SFCTA) survey found that 63% of shuttle passengers would drive alone were the shuttle service not provided. This equated to a reduction of 327,000 solo vehicle trips annually due to employer shuttle systems. Moreover, these shuttles produce only 20% of the emissions that would have been produced by the vehicles they take off the road. It is important to note that the shuttles also draw approximately 20% of their demand from existing public transit. However, there remains a net reduction of vehicles on Bay Area roadways due to shuttle services (SFCTA, 2011).

Carpooling and Vanpooling (Classic Ridesharing)

Classic ridesharing—which includes carpooling and vanpooling—has always been a simple concept involving the sharing of rides with people with similar origin-destination pairings, and it can be classified under several categories: 1) acquaintance-based, 2) organization-based, and 3) *ad hoc*. Acquaintance-based ridesharing consists of carpools that are formed by people who are already acquaintances [i.e., carpools among family (“fampools”) and carpools among coworkers]. Organization-based carpools require participants to join the service either through membership or by visiting a website. *Ad hoc* ridesharing involves more unique forms of ridesharing, including casual carpooling – also known as “slugging” (Chan and Shaheen, 2012). Vanpooling is classified by the Federal Highway Administration (FHWA) as a grouping of seven to 15 persons commuting together in one van, whereas carpooling involves groups smaller than seven traveling together in one car.

Carpooling and vanpooling have the added benefit of reducing driver costs. A vanpool could cost between $100 and $300 per person per month, although this varies considerably depending on gas prices, local market conditions, and government subsidies (Martin (2015), unpublished data). Flexible carpoolers could save two-thirds the cost of commuting alone in a single-occupancy vehicle (Dorinson et al., 2009).

Automated Vehicle Technology

Automated vehicles (AVs) are vehicles that can operate themselves without needing the control of humans. NHSTA has defined five levels of automation for highway vehicles. Level 0 is simple—no automation. Level 1 is defined as function-specific automation, which includes electronic stability control or pre-charged brakes. The vehicle assists a driver in making faster or better actions. Level 2 automation consists of functions that help the driver with at least two primary control functions. These functions must be combined, such as adaptive cruise control in combination with lane centering. These vehicles are on the road today, but they require full human control of the vehicle at all times. Future automated vehicle technology generally refers to vehicles that have Level 3 or Level 4 automation capability. Level 3 automation refers to vehicles where automated driving is partially allowed, when the driver can yield control to the vehicle. Under Level 3, drivers are still required to either pay attention or retake control of the vehicle in certain circumstances, but drivers may cede full control temporarily. An example would be truck platooning, where truck drivers cede full control when driving in a platoon on a highway but retain full control during all other functions. With Level 4 automation, vehicles are entirely self-driven and drivers are no longer required to perform any functions over the course of the trip.

Automakers and technology companies have increased interest and research on AV technology. Google, in particular, has devoted considerable resources toward the research and development of AVs, and the company is already testing driverless cars on public highways. By 2020, it is estimated that several companies will have released level 3 automated vehicles. Level 4 automated vehicles (e.g., Google Self-Driving Car) may also be fully operational in several states. By 2030, it has been predicted that Level 4 automated vehicles will be readily available in a commercial context, and by 2050, increased production of automated vehicles could bring production and purchase costs of the vehicles down to levels that are affordable by the general public (Shaheen and Galczynski, 2014).

By 2030, it is predicted that level 4 automated vehicles will be readily available in a commercial context.

As automated vehicles play a greater role in the transportation system, shared autonomous vehicles (SAVs)/autonomous taxis (aTaxis) applications may emerge that work with carsharing organizations to better match demand. SAVs may be able to make carsharing more accessible, increase carsharing membership, and reduce total vehicle emissions. SAVs may also drive more efficiently, particularly if other SAVs are on the road. Predictive models suggest that a SAV can reduce GHG emissions by 5.6% when compared to a regular sedan that is replaced (Fagnant and Kockelman, 2013). Automated vehicles could easily implement ecodriving, which could save between 22% to 31% of fuel in acceleration conditions and 12% to 26% fuel in deceleration conditions (Wu, 2011).

Automated vehicles could also have positive impacts on driver safety. Drivers falling asleep at the wheel have been reported to account for 20% of accidents (Philip, 2005). Excluding drunk driving, another 8.3% of accidents in general are found to be a result of distracted driving by events, objects, or activities both inside and outside of the vehicle (Young, 2007). Automated vehicles could reduce the possibility of accidents happening for these reasons.

On-Demand Transit and Microtransit Services

Many transportation options have existed in parallel to established public transit networks including: jitneys, dollar vans, paratransit, and shuttles. While these services can target special populations, they are often inefficient and costly to the service provider. There has recently been increased attention on mobility options that can serve as alternatives to public transportation networks, such as on-demand transit and microtransit.

One well-known form of on-demand transit is paratransit, which is special transportation for persons with disabilities, typically in an ADA-accessible vehicle. Many municipal and regional transportation authorities operate paratransit services along with regular public transit. Paratransit can range from a vehicle that runs along a fixed route (with occasional brief deviations) or it can be fully responsive to demand and door-to-door service. From 2000 to 2014, growth in ridership on demand-responsive transportation in the US doubled from 110.9 million trips to 225.4 million trips. During the same period, overall transit ridership in the US increased as well, but only by 14% from 9.4 billion trips to 10.7 billion trips (APTA, 2015).

A more technology-enabled type of alternative transit service has recently emerged called microtransit, which can incorporate flexible routing, flexible scheduling, or both. These services operate much like jitneys of the past but are enhanced with information technology (Cervero, 1997). Existing microtransit operators target commuters, primarily connecting residential areas with downtown job centers. However, there are opportunities for microtransit services to either expand into the paratransit space or for paratransit to innovate along similar lines. Microtransit's use of smartphone technology avoids traditional and costly methods of booking rides, such as call centers or even booking websites. The use of advanced technology has the potential to lower operating costs for services that target special populations, such as disabled, older adults, and low-income groups.

Microtransit services typically include one or more of the following service characteristics (these are a variation of the characteristics attributed to "flexible transit services" by TCRP, 2004):

1) Route deviation (vehicles can deviate within a zone to serve demand-responsive requests);
2) Point deviation (vehicles providing demand-responsive service serve a limited number of stops without a fixed route between spots);
3) Demand-responsive connections (vehicles operate in a demand-responsive geographic zone with one or more fixed-route connections);
4) Request stops (passengers can request unscheduled stops along a predefined route);
5) Flexible-route segments (demand-responsive service is available within segments of a fixed-route); and
6) Zone route (vehicles operate along a route corridor whose alignment is often determined based on user input, with fixed departure and arrival times at one or more end points).

Microtransit services can include variations of the following two models: 1) fixed route, fixed schedule (can be similar to the operations of public transit) and 2) flexible route with on-demand scheduling (this more closely mirrors ridesplitting and paratransit services).

Fixed, Pre-Determined Routes and Fixed Schedules

An example of a fixed-route microtransit service is Chariot, which operates similar to a public transit service by running vans along predefined routes. However, customers can make requests for new "crowdsourced" routes to be created based on demand. At present, Chariot operates seven predefined routes in San Francisco and plans to continue opening new routes as user-demand grows or shifts. Fares range from $3 to $6 on select routes.

While these services are somewhat similar to vanpools, microtransit vehicles are usually larger, more flexible in vehicle type, and have employed drivers (whereas vanpool passengers often share driving responsibilities). Because of their more rigid nature (fixed routes and fixed schedules), these services mirror public transit more closely and could represent more direct competition. It is important to note, however, that Chariot currently serves about 700-1,000 people per day, whereas the 38-Geary Muni bus lines serve over 33,000 riders a day (Fehr & Peers, 2015). Thus, the impact of many microtransit services is still limited.

Flexible Routes and On-Demand Scheduling

An example of on-demand microtransit is Boston-based Bridj, a mobile application that enables customers to request a ride in select neighborhoods from 14-seater vans. After the Bridj system receives pickup requests, its algorithm sets a central passenger meeting spot based on the location of the most recent requests. Customers then walk to the meeting spot and share a ride with other passengers that have a similar route or destination as defined by the algorithm. The company has recently expanded services to include select neighborhoods in Washington D.C., and fares currently range between $3 to $6 (Stromberg, 2015).

Another service that has emerged is Via. At present, it is only operational in New York City. This service is most similar, out of the microtransit models mentioned above, to ridesplitting services—like Lyft Line and UberPOOL. Users can request rides real time and expect a shared vehicle to pick them up within minutes with other travelers going in a similar direction. However, Via is not technically door-to-door, like UberPOOL and Lyft Line, since riders must walk to corners on New York avenues so that the shared vehicles do not have to make many deviations along the route. This makes Via's service more similar to Lyft Line's "Hot Spots" and Uber's "Smart Routes." Furthermore, Via charges a flat fare of $5 to $7 (depending on booking method), similar to Lyft Line's flat $5 fare when taking advantage of its "Hot Spots" and Uber's "Smart Routes," which offer discounts starting at $1 off the price of the ride (de Looper, 2015).

There is not yet agreement on whether the growth of mobile app-based microtransit services is a long-term trend or just an offshoot of the success of services like Uber and Lyft. There is also considerable controversy over whether these services are "good" for urban transportation. Arguments in favor of these services include augmenting the capacity of shared-transportation when public transit is congested, solving the issue of first-mile/last-mile connectivity, and finally, potentially feeding more riders to public transit by providing connectivity in areas underserved by transit. Reasons against such services include pulling riders away from public transit by providing a tailored and more comfortable service, increasing congestion on the road due to the increased number of shuttle vehicles. A tailored, more expensive commute system has the potential to segregate travel modes based on income, which would be undesirable for cities seeking to create more equity on the roads (Jaffe, 2015).

Bus Rapid Transit (BRT) and Personal Rapid Transit (PRT)

BRT is a high-quality, high-capacity bus system that aims to provide service similar to that of a light rail system. BRT systems vary in their amenities, but often include the following elements: exclusive lanes for buses, large-capacity stations, pre-board fare collection, and all-door boarding. BRT systems are often four to 20 times cheaper than light rail to construct and maintain (Wright and Hook, 2007). High-capacity BRT systems, such as the TransMilenio in Bogotá, Colombia, can carry between 15,000 and 45,000 passengers per hour per direction (Hidalgo, 2012), making BRT's speed and efficiency comparable to car travel.

A case study in Brisbane, Australia suggests that BRT could play a role in taking cars off the road and reducing VMT. Tao (2013) conducted a longitudinal study from 1996 to 2006, when various BRT stations were being constructed in Brisbane. The study found that areas around BRT stations had a significantly larger decrease in car use than on the metropolitan level, suggesting that BRT can play a significant role in reducing the number of people driving. In a three-kilometer (1.9-mi) radius area around the BRT stations, the number of people driving dropped from 64.6% to 61.5%, and bus usage went up from 10.1% to 11.7%. Whereas 1,600 meters (1 mi) from the BRT stations car use dropped from 62.3% to 57.7% and bus usage increased from 11.0% to 13.1%. In an 800-meter (0.5 mile) catchment area around the BRT station, the use of cars dropped from 56.6% to 51.8% and bus usage went up from 11.0% to 13.7%. There were very small increases in the percentage of people walking and bicycling as well. In the greater Brisbane area as a whole, car usage only dropped from 70.5% to 69.6% (Tao, 2013).

> 45% of the U.S. workforce have occupations compatible with at least part-time telework.

Personal Rapid Transit (PRT), also known as podcars, involves small automated vehicles operating on a network of special guideways. It is generally sized for individuals or small groups of no more than 3 to 6 passengers. A study of the PRT system at the Heathrow airport showed high ratings for passenger satisfaction with 90% of passengers saying it was better than the bus service (Bly, 2011). The PRT system also significantly cut down on the total travel time and wait time when compared to the bus system at Heathrow airport (Bly, 2011).

Alternatives to Work Travel

The revolution of ICT has transformed the way we perform daily tasks, including our travel behavior. Mobile technology has changed the pattern of modern life at home and work (Baillie et al., 2008). New technologies have reduced the need for workers to be physically present in an office. With technological advances such as the Internet, mobile phones, personal digital assistants, and more recently, smartphones and tablets, people now have access to a wide range of services from almost anywhere. Telework's growth accelerated with personal computing in the 1990s, and as such, there is a large body of literature evaluating the impacts of telework in the U.S., which was conducted prior to the 2000s. Notable work from this era includes Pendyala et al., (1991), Mokhtarian et al. (1995) and Handy and Mokhtarian (1996), to name just a few. Much of this work focused on travel behavior changes and estimation of energy and air quality impacts. For further discussion on the impacts of telecommuting on travel and recent trends, see Chapter 2, Section 6: *Telework and Telecommuting*.

> ICT has changed the way we perform daily tasks.

Since those early days of study, telecommuting has continued to grow. Lister and Harnish (2011) report that 45% of the U.S. workforce had occupations compatible with at least part-time telework. About 2.6%

of the U.S. employee workforce (3.3 million people, excluding the self-employed or unpaid volunteers) considered home as their primary place of work (ACS, 2012). In addition, regular telecommuting grew by 61% between 2005 and 2009. Based on forecasts by Lister and Harnish (2011), the number of regular telecommuters will reach 4.9 million by 2016.

Several studies in the U.S. and France (Barron, 2007; Lewis, 2013) have asserted that a key consideration for telecommuters is reliable hardware and broadband Internet access. This is not surprising as the Internet serves as the primary conduit through which work-related information and documents are exchanged. Mobile phones, personal digital assistants (PDAs), or smartphones and tablets more recently, have increasingly become prevalent for telework. Chesley (2010) conducted an empirical study of over 2,000 employees and found that a higher frequency of computer, email, and mobile phone use led to the perception that technology improved workplace productivity. Interestingly, the study also noted that the social consequences of ICT use is also dependent on context: what type of device is being used (i.e., computer vs. a mobile phone) and the purpose of the use (i.e., work-related use vs. personal use).

Mans et al. (2012) summarized some more recent studies on telecommuting and its impacts on travel behavior. They review impacts assessed in Choo et al. (2005) and Walls and Safiro (2004), which among findings reported that telecommuting resulted in considerable reductions in VMT for the individual, but due to the small scale of telecommuting, may be on the order of 0.8% of total VMT nationally. With respect to generational differences, they noted that:

"It is not yet clear if younger generations would have a different travel behavior response to telecommuting than older generations do. This is an important field for further research. This being said, younger generations, such as Generation X and the millennials, appear to be increasingly interested in telecommuting."

They further noted that the growth of telecommuting between 2006 and 2008 appears to have been driven by the younger population, reporting a modest decline in the median age of telecommuters from 40 to 38. In another relatively recent work (also referenced by Mans et al. (2012)), Cisco (2009) studied telecommuting on worker productivity through a survey of about 2,000 employees. They found that 69% reported that they were more productive when working remotely and that 67% reported improved quality of work.

Other research has looked into the behavioral response to ICT in telework. Dal Fiore et al. (2014) explored how mobile technology might affect travel and work-life arrangements. They found that mobile technology offer workers new reasons to be mobile—technology makes them more informed, more capable of using various physical spaces and changing schedules, and even more efficient in their use of time and resources. As work becomes more digitized, there is less need for workers to physically be where work and information are located. In fact, mobile technology places other burdens on its users and can make travel less appealing. With that freedom, most choose to integrate more work into their lives. Cavazotte et al. (2014) found that while employees were concerned about how smartphones increased manager demands and impeded their lives outside of work, they requested more efficient smartphone connectivity.

A specific area of telework that has been impacted by ICT is remote teamwork and collaboration. In addition to basic telephone and email communication, companies employ software suites for a variety of collaboration needs, including:

- Video conferencing (Cisco WebEx, Google Hangouts, Skype)
- Instant messaging (Google Hangouts, Hipchat)
- Virtual Private Network (VPN) access (Cisco AnyConnect, OpenVPN)
- Collaborative calendar scheduling (Google Calendar, Microsoft Outlook)
- Screen sharing (Cisco WebEx, GoToMeeting, Join.me)
- Cloud access and file sharing (Box, Dropbox, Google Drive, Microsoft OneDrive)
- Real-time document collaboration tools (Google Docs, Microsoft Office 365).

Boell et al. (2014) explored the attitudes of a team of employees engaged in remote collaboration and found mixed opinions. Little research has been done to understand the impact of ICT on collaborative work (Shih et al., 2013). Overall, telecommuting, and its impact on travel behavior has been the subject of considerable research during the past several decades. While a topic for future evaluation, interest in telecommuting appears to have waned somewhat, despite the fact that it has been growing in terms of modal share over the last decade (See Chapter 2). Continued research is needed to better assess the short- and long-term benefits and drawbacks of remote collaboration through ICT, as well as the impact of expanded telework applications and supportive policies.

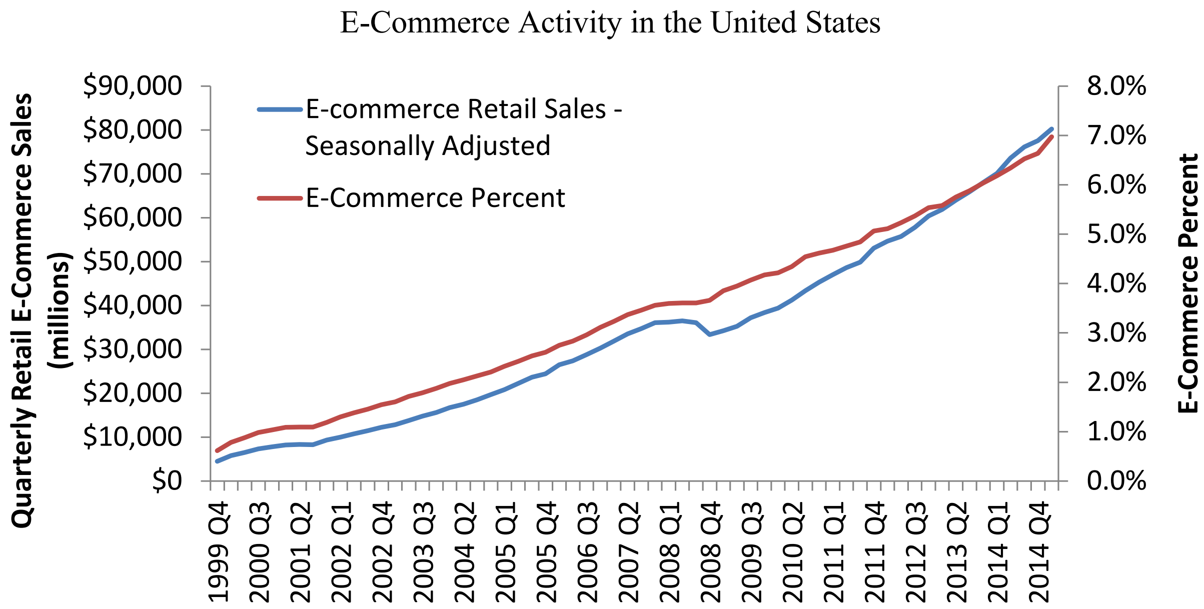
Alternatives to Non-Work Travel

The same technologies that have ushered in a growth in telework have brought changes in non-work travel. Non-work travel has been most prominently influenced by e-commerce, which has facilitated the purchase of tangible and intangible goods and services online since the 1990s. While most e-commerce applications have fallen under the realm of shopping, advances in technology have begun to introduce the possibility of displacing other types of non-work travel, such as medical trips. These non-discretionary, non-work trips require the secure transmission of data, but they may open up new industries and efficiencies in the delivery of healthcare and other services.

Online Shopping (E-Commerce)

Online shopping allows customers to get information, compare, and buy products over the Internet. It has some advantages over physical shopping trips because a wider variety of information on products and prices are available to the consumer, without the need to travel. Online shopping is growing in terms of overall activity and percent of total retail activity. The U.S. Census reported quarterly retail sales for the first quarter of 2015 were $80.26 billion; this was 7% of all retail sales. This share is currently at an all-time high and shows the increasing role that e-commerce is playing in overall retail activity. Figure 4-5 shows that e-commerce activity is exhibiting a nearly continuous upward trend in the growth of retail sales (U.S. Census, 2015).

Figure 4-5 Trend in E-Commerce Activity within the U.S.



An early study of the Internet's effect on travel behavior found that Americans are generally spending more time at home, and heavy Internet-users tend to travel fewer miles (Contrino and McGuckin, 2006). While this result may seem intuitive, research has more broadly explored whether e-commerce increases, reduces, or has no net effect on personal travel.

In Europe, Weltevreden (2007) used data from a sample of 3,200 Internet users in the Netherlands and concluded that e-shopping is unlikely to have a significant effect on center city shopping in the short run. He surmised that in the long-run trip substitution could occur. Weltevreden and Rietbergen (2007) further studied the same data and reported that 20% of online buyers made fewer trips to city center stores. E-commerce was far more novel at the beginning of the 21st century, and earlier work tended to find that online shopping reduced travel through trip substitution. Most early studies report a substitution or neutral effect, but some reporting a complementary effect starting to appear as early as 2003 (see Cubukcu (2001), Dixon and Martson (2002), Mokhtarian and Salomon (2002), Sim and Koi (2002), Tonn and Hemrick (2004), Ferrell (2005)). Weltevreden (2007) also presents a summary of the literature studying the substitution effects e-shopping on physical shopping. The research summarized by Weltevreden (2007) is reproduced in Table 4-1.

Table 4-1 Previous Studies Evaluating the Impact of e-shopping on Physical Shopping (Reproduced from Weltvreden, 2007)

Reference	Sample (year, method)	Dependent variable(s)	Effect(s)
Sim and Koi (2002)	175 Singapore shoppers (NA; D)	Frequency of in-store shopping	S, N (mainly N)
Bhat et al. (2003)	255 German residents of Karlsruhe and Halle (1999; HM)	Inter-shopping duration for non-maintenance goods	S, E (mainly S)
Corpuz and Peachman (2003)	1487 Australian Internet users residing in the Sidney Metropolitan Region (2000-2001; D)	Number of shopping trips	S
Ferrell (2004)	14,563 US households in the San Francisco Bay Area (2000; R)	Shopping travel distances and shopping travel frequencies (trips)	E (trips), M (distances)
Hassenpflug and Tegeder (2004)	957 German shoppers in Hannover and Leipzig (2002; D)	Shopping at various urban retail locations	S, E (mainly E)
Tonn and Hemrick (2004)	118 Internet users in the Knoxville, Tennessee, metropolitan region (2001; D and R)	Trips to five types of stores (i.e. books, groceries, clothing, music, and other)	S, E (mainly S)
Esser and Kurte (2005)	1590 German households in Cologne and surrounding cities (2003; D)	Number of trips according to transport mode	S, E (mainly S)
Farag et al. (2005)	826 Internet users residing in four Dutch municipalities (2003; PA)	Frequency of in-store shopping	E
Ferrell (2005)	18,026 US residents in the San Francisco Bay Area (2000; SEM)	Shopping travel time, shopping travel distances, and shopping travel frequencies	S (frequency), M (time and distance)

Reference	Sample (year, method)	Dependent variable(s)	Effect(s)
Schellenberg (2005)	German high school students (N ¼ 1174) and their parents (N ¼ 881) in the Heidelberg and Necker-Odenwald-Kreis region, and 625 German Internet users (2001/2002; D)	Purchases in the city centre and in large-scale peripheral retail locations	S
Krizek et al. (2005)	692 US residents in Seattle, Kansas City, and Pittsburg (NA; D)	(Willingness to) substitute a shopping trip	S
Farag et al. (2006)	634 Dutch Internet users residing in three communities in the municipality of Utrecht (2003; R)	Number and duration of daily and non-daily in-store shopping trips	M (duration), E (number)
Farag et al. (2007)	826 Internet users residing in four Dutch municipalities (2003; SEM)	Frequency of in-store shopping and duration of in-store shopping trips	M (duration), E (frequency)

Key: D = descriptive, R = regression, HM = hazard modeling, PA = path analysis, SEM = structural equation modeling, NA = not available, S = substitution, E = enhancement (complementary), M = modification, N = neutrality.

While studies leading up to 2007 seem to identify mostly a substitution effect, more recent work appears to uncover more complementary effects of e-shopping. For example, Cao et al. (2012) found that increased e-shopping was correlated with increase in-store shopping. Through a survey of over 500 adults in Minneapolis-St. Paul, they found that there was a complementary effect on in-store shopping. They drew their conclusions through the application of a structural equations model to investigate the interactions between online purchases, in-store shopping, and product information searching. Their analysis determined that consumers who engage in more online searching and online buying, also engage in more in-store shopping. They concluded that promoting e-shopping to reduce shopping trips is not likely to have a substantial impact. Others have also reached this conclusion more recently. An analysis completed by Zhou and Wang (2014) evaluated the connection between online shopping and travel using the 2009 NHTS and a structural equation model. Their study found that online shopping encourages shopping trips. Calderwood and Freathy (2014) studied the effects of e-commerce on travel behavior within island communities in Scotland and found only modest impacts on consumer travel patterns. Finally, Hiselius et al. (2015) looked at the association between online shopping and physical store shopping through a web survey of consumers in Sweden. They found frequent online shoppers made as many car trips as others. They also found that the time saved from online shopping was spent on both additional shopping trips and other errands. They concluded that online shopping may change travel behavior, but it is not a good measure for reductions in vehicle mileage.

As e-shopping has become more commonplace and ingrained in everyday life, it may simply be an augmentation of existing shopping activity for specialized products. That is, today e-shopping may be allowing consumers to buy specific products that would otherwise not be available at nearby physical stores. The economy may have also since adapted in ways that eliminate such stores from existence. Anecdotally, this can be seen in the bankruptcies of some major retail chains such as RadioShack, Blockbuster Video, Circuit City, and Borders bookstore, while surviving competitors continue to struggle today. The products offered in these major chains, electronics, books, and music, have been shifted considerably to the online market.

Today, the economy has restructured in the presence of e-shopping. Recent research suggests that overall the effect on travel is limited. It may be that there is an effect of e-shopping on the margin in the form of forgone trips to buy electronics, books, and music. But the elimination of these unmanifested trips is small (such products are generally not bought on a weekly basis). Thus, the changes they have brought are imperceptible in the data today and possibly have been replaced by other trips. E-shopping may still have the potential to reduce personal trips, but technology and services may have to change to reduce trips that are more frequently needed, such as the trip to the grocery store or general needs stores, such as Target. Replacement of these trips, even through online shopping services operated by the stores themselves, appear to have had limited success.

> The changes that e-shopping have brought to travel behavior may be imperceptible in data and possibly have been replaced by other trips.

Telemedicine

While the Internet has had the most impact on how we engage in commerce and collect information, other applications are on the horizon that may influence travel. Telemedicine is one emerging and specialized area that may alter non-work travel, particularly for non-discretionary trips. According to the American Telemedicine Association (2015), telemedicine is the exchange medical information via electronic communications to improve a patient's health status. Telemedicine is more advanced than health websites that present people with extensive information on afflicting ailments. Such information, which includes symptoms, causes, tests, doctor's visit expectations, treatment options, and prevention methods, offer the public an extensive knowledge base that was not available just two decades ago. While this provision for patient research is helpful, such resources do not fulfill the vision of telemedicine.

Telemedicine is more defined by a two-way exchange of information, which connects the health care system with the patient. This includes video conferencing of doctor visits with patients, transmission of diagnostic images, remote monitoring of patient vital signs, continued medical education, nursing call centers, and other applications. In general, telemedicine does involve some clinical service with the patient. Some of these

> Telemedicine connects the health care system with the patient through a two-way exchange of information.

applications, such as nursing call centers, the electronic transmission of images (e.g., MRI, CT scans), are in widespread application today. Other applications, such as video conferencing with doctors are less common, but also in use.

Telemedicine in its current forms does appear to eliminate the need to make some of these trips. A study on the economic effects of telemedicine in rural communities found that patients who took advantage of telemedicine saved money (Whitacre, 2011). The majority of these savings stemmed from the elimination of transportation costs. In one instance, telemedicine prevented a 130-mile trip to the hospital (260 miles roundtrip). From a transportation perspective, such avoided trips are certainly positive. There is a sizable and growing body of literature exploring telemedicine applications. However, most of the research is focused on the function of specific technologies and their effectiveness on patient care. Research on the impacts on travel is far more limited. Call et al. (2015) evaluated attitudes toward telemedicine in urban and rural communities through a 3,512 respondent statewide survey in Montana. They concluded:

"From the patient's perspective, the advantages of reduced travel and convenience are recognized, but questions remain about the equivalence to physician visits. Many people are averse to telemedicine, indicating a perceived incompatibility with patient needs. Only 1.7% of the respondents reported using telemedicine in the previous year; about half were veterans. Hence, few have used telemedicine, and key innovation adoption criteria—trialability and observability—are low. Increased attention to public awareness in the adoption process is needed to increase willingness to embrace telemedicine as a convenient way to obtain quality healthcare services."

Thus the impacts of telemedicine are still under development with the technologies. While video conferencing and other enabling functions are in mature applications, their incorporation into widespread medical use is still limited. The travel implications of these technologies, as well as their scale of impact on travel, is a subject for future research.

Innovative Business Models

Innovative business models in transportation are models that change how we interact with existing products or transportation services. Many of the systems and services detailed in earlier sections would fall into the category of "innovative" business models at the time of their introduction. This section focuses on new and innovative business models of the same kind that are on-the-horizon, under development, and thus less studied.

Many of the current innovative business models exist in the form of Internet-based apps that provide basic services that reduce travel. One example of an app representing an innovative business model is Luxe, which is a valet parking service that picks up a traveler's car anywhere within a service area and parks it at a Luxe-affiliated parking lot. This service will return a traveler's car anywhere within a service area and even provide car wash and fuel-up services for a cost. Because the application is so new, there is little research available on its potential impacts on traveler behavior. However, Luxe, and services like it have the potential to reduce the number of cars circling crowded city-blocks looking for parking. This could potentially reduce VMT and ease congestion. On the other hand, Luxe may lead to cars being parked in lots further away from the traveler's destination, increasing average VMT (Buhr, 2014).

Another innovative business model that has emerged is on-demand goods delivery. These have also been called "courier network services" as well as "flexible goods delivery." They provided for-hire delivery services for monetary compensation using an online application or platform (such as a website or smartphone app) to connect couriers using their personal vehicles, bicycles, or scooters with freight (e.g., packages, food). Although the business models in this realm are evolving, two general models appear to have emerged: 1) P2P delivery services and 2) paired on-demand passenger ride and courier services.

In P2P courier network services, anyone who signs up can use their private vehicle or bike to conduct a delivery. Within P2P delivery services, there are a variety of business models. Postmates couriers, for example, operate on bikes, scooters, or cars. They deliver groceries, takeout, or goods from any restaurant or store in a city. Instacart is similar to Postmates, but is limited to grocery delivery and charges a delivery fee of between $4 and $10 depending on the time given to complete the delivery. It has begun to allow some of its couriers to be classified as part-time employees. DoorDash is a service where one can be paid a flat delivery fee of $7 in return for going to a restaurant and delivering to the requester's home or office. Roadie is another courier service, but it is used more for inter-city goods movement rather than same-day intra city deliveries. Finally, Shipbird is a shipping service that connects everyday commuters with individuals seeking couriers. Couriers provide the Shipbird app with their availability, commuting route, and the distance they are willing to deviate from their commute route in order to complete a delivery. The algorithm then matches these couriers with the requested delivery jobs. P2P delivery services make use of existing personal vehicles to get items delivered. The proliferation of these services—where couriers use their personal travel modes—could reduce the amount of shipments on traditional carriers. The impacts on overall travel is unclear, and could result in a VMT increase or decrease.

The second CNS model that has emerged is one in which for-hire ride services (e.g., TNCs or pedicabs) also conduct package deliveries. Deliveries via these modes can either be made in separate trips or in mixed-purpose trips (e.g., for-hire drivers can transport packages and passengers in the same trip). Uber has also entered the food and goods delivery services market with UberEATS (food) and UberRUSH (bike messenger delivery service). In 2014, Uber piloted a courier service in New York City called UberRUSH, where bike messengers would pick up an item from the requester and deliver it somewhere within a coverage area within the same day. This is now being expanded to merchant delivery, where items are picked up from stores and delivered either to the requester or to a third party (Cuthbertson, 2015). For one day in June 2015, Lyft ran a promotion with Starbucks where they delivered free iced coffee. Thus, the major ridesourcing/TNC operators have in some form tried expanding their ride services to include package/item delivery, food delivery, or both.

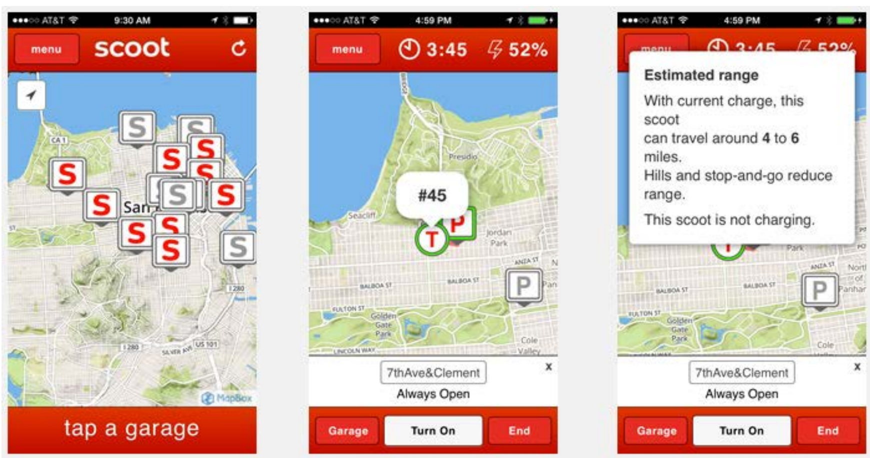
As mentioned earlier, various innovative privately-run transit services have emerged, called microtransit. Examples are Chariot, Bridj (shown below), and Via. These services, broadly speaking, use SUVs, vans, and buses to pick up and drop off customers based on demand.

Figure 4-6. Picture of Bridj Shuttle

Source: bridj.com

Another innovation in the urban mobility world is Scoot, touted as the “Zipcar for scooters” by TechCrunch (Perez, 2012). The service provides a fleet of electric scooters for use by members in an urban area for a fee. Thus, the service is more similar to a bikesharing system and has greater potential for use as a means of commuting than any roundtrip service does.

Figure 4-7 Screenshots of the Scoot Mobile Application



Spinlister is another innovative mobility mobile application. Branded as the “Airbnb for bikes,” the service allows individuals or bike rental shops to rent out their idle bicycles to users who temporarily need them for use. The application has also expanded to allow the sharing of sports equipment. The app has potential for affecting urban mobility in that it allows individuals access to bikes without them having to pay the full cost of owning a bike. While urban bikesharing systems are similar, peer-to-peer services may allow sharing to occur in lower density areas (neighborhoods, rural areas, etc.). Though the California-based company was founded in 2011, it has faced funding issues and even shut down at one point. However, it has since restarted operations and now has bikes and sport equipment are available for rent across the U.S., Europe, and even South America, Africa, and Asia (Kamenetz, 2013). Table 4-2 presents a summary of the innovative business models discussed in this section.

Table 4-2 Summary of Services Employing New Business Models

Mobile App Name	Functions
PostMates	On-demand delivery service for groceries, take-out, and other goods.
Luxe	Valet parking service
Bridj	A pop-up transit system where minibuses and vans pick up and drop off users based on origin-destination demand. Similar to Lyft Line and UberPOOL.
DoorDash	On-demand delivery service for restaurants
Roadie	P2P delivery service for packaged goods
Shipbird	P2P delivery service for packaged goods
Sidecar Deliveries	On-demand delivery service for food, groceries, packages, and other goods
UberEATS and UberRUSH	UberEATS is an on-demand meal delivery service. UberRUSH is a courier service, either on bike or in the courier's personal vehicle.
Chariot	A smartphone-enabled transportation service in San Francisco in which 15-seater vans run along fixed routes and can be located in real time with their smartphone app. New routes are "crowdsourced" based on demand.
Bridj	A smartphone-enabled transportation service that enables customers to request a ride to and from select neighborhoods in 14-seater vans. After receiving pickup requests, their algorithms determine a central optimal meeting spot for passengers.
Via	A smartphone-enabled transportation service that operates van rides to passengers requesting pickups in real time based on similar origins and destinations. Via's model is similar to ridesplitting but is not always door-to-door, as it often requires passengers to walk to corners on avenues in New York City to keep the vehicle moving directly north or south.
Scoot	One-way electric scooter sharing service
Spinlister	Peer-to-peer bike rental service

Innovative business models such as those listed Table 4-2 are generally not the subject of extensive study. They represent new ideas that are under development, with limited markets. Their status as innovative is naturally temporary. Some of the models will fail to become competitive and fail, others may become acquired and integrated into the services of a larger company, and yet others may become wildly successful, and thus generate a need for deeper evaluation. This can happen very quickly. It was only in the summer of 2012 that the start of Lyft was publicly announced as a beta pilot service of

In the summer of 2012, the start of Lyft was publicly announced as a beta pilot service of Zimride. In 2015, it was raising venture capital at valuations of $2.5 billion.

Zimride at a panel session on shared mobility on the top floor of the TransAmerica building in San Francisco. In early 2015, it was raising venture capital at valuations of $2.5 billion (Etherington, 2015).

Multi-Modal Traveler Information

Transit Agency Initiatives

Transit providers and public agencies are increasingly making their real-time data public. The Transit Cooperative Research Program (TCRP) study of transit data and apps found that 16% of American Public Transit Association (APTA) member agencies (45 of 276) provide some information on mobile devices (Schweiger, 2011). With these data, tools have been developed so users can make more informed decisions. Decisions range from changing driving routes to changing departure times and travel modes. Today, multi-modal trip advising and planning apps have become more popular for finding travel information. As people become more dependent on their phones for trip planning, apps are starting to offer incentives to reduce special and temporal saturations of transportation networks.

Today, multi-modal trip advising and planning apps have become more popular for finding travel information.

Zhang et al., (2008), studied the effects of an early application at the University of Maryland, which made real-time information of its campus shuttle service publicly available to determine the effects of real-time information on travel behavior and user experience. Fixed-effect and random-effects-ordered models were created to determine the causal relationships between the traveler information and the use of the real-time information system. Although users felt the service was safer and more reliable, there was no significant increase in ridership. The authors note that this may have happened because the system had not had enough time to show ridership impacts or that the research population—students of the University of Maryland—have inelastic travel behaviors (Zhang et al., 2008). Gooze et al. (2013) studied a real-time information system for transit riders in the Greater Seattle region. The authors explored the user experience and effects on transit ridership through surveying people before and after the implementation of the real-time transit information tool, which was called OneBusAway. The results showed positive shifts in user satisfaction, transit safety, and ridership. They also noted that negative impacts on ridership could occur when users experienced inaccuracies in the data, but this effect was limited to less than 15% of the sample (Gooze et al., 2013).

The impact of a real-time bus information system on public transit users in Chicago was studied between 2002 and 2010. The Chicago Transit Authority gradually implemented their real-time bus information system—the CTA Bus Tracker—between August 2006 and May 2009. By implementing the system one route at a time, they were able to compare the isolated effects of real-time information on each line. The study also controlled for the effects of transit fare, transit service, unemployment levels, gas prices, weather, and socioeconomic characteristics. A linear mixed-effects model, which has both fixed effects and random effects, was created to determine the relationship between variables. The study found that the real-time information led to a modest increase in ridership. Overall, there was an average increase of 126 trips in weekday ridership on routes with real-time information. Routes where the CTA Bus Tracker was implemented later during the study period were more likely to experience an increase in ridership (Tang and Thakuriah, 2012).

A similar study was conducted in New York City beginning in 2011. New York City Transit, under the Metropolitan Transit Authority, started providing real-time ridership information in 2011 on a per-borough basis through the Bus Time system. This allowed them to isolate the effects of the user information on ridership. Bus Time provided real-time information though a desktop website, a mobile website, and text messaging. Through random-effects and fixed-effects regression models, the authors looked at the causal relations of Bus Time while simultaneously controlling for transit fare, public transit service, weather, socioeconomic conditions, etc. They found that real-time information was on average responsible for an increase of 118 unlinked trips per route, which corresponds to approximately 1.7% of the weekday route-level ridership. These trips tended to be concentrated on the busiest routes. On the largest quarter of the routes, those with the highest ridership, the authors found that ridership increased by 340 trips per workday, or 2.3%. The authors speculated that the higher increase in the larger routes was due to choice trips (e.g., trips in which the traveler has a mode choice). That is, if a person decided to take a trip, real-time information systems would show shorter wait times for larger routes than smaller routes. Trips that would require routes with less frequent service might be completed through a different mode (Brakewood et al., 2015).

More recently, a study was conducted with public transit users in Tampa, Florida in 2012. The Hillsborough Area Regional Transit has 27 local and 12 express bus routes. They started gathering real-time location information in 2007, but they only considered releasing the data to the riders after 2012 through OneBusAway. A behavioral study was conducted with users of the system. The analysis found that those who had access to real-time information saved an average of two minutes at bus stops. There was a considerable increase in the satisfaction and perception of safety and a decrease in anxiety and frustration. Although the study was limited to people who were already users—which meant it did not look at the change in weekday trips per route—39% of those using OneBusAway reported taking the bus more frequently (Breakwood et al. 2014).

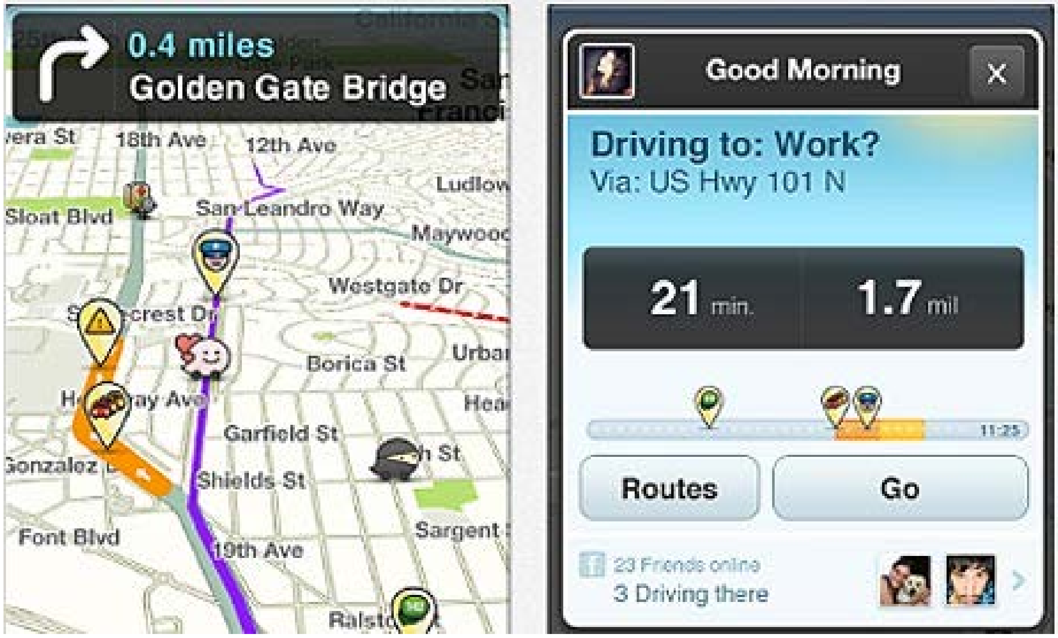
Mobile App Initiatives

As smartphones have become more widely available, mobile applications have been emerging to provide real-time trip advice across a whole host of modes. The mobile app space is one that is undergoing rapid evolution and development. These applications, which are very new, have gone beyond using just public transit as a mobility option, and have been able to combine bicycling, walking, taxi and on-demand ride services, and carsharing into route-planning algorithms.

The mobile app space is one that is undergoing rapid evolution and development.

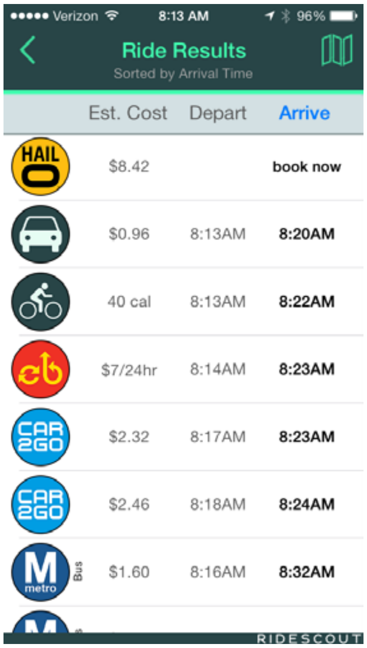
Waze is one of the earlier applications that appeared after the success of Google Maps. It built off of the route planning guide of Google Maps by integrating real-time information, eventually leading to its acquisition by Google. The app gives users turn-by-turn routing for automobiles based on information from other mobile users and user-reported events, such as accidents.

Figure 4-8 Screenshots of Waze Mobile App



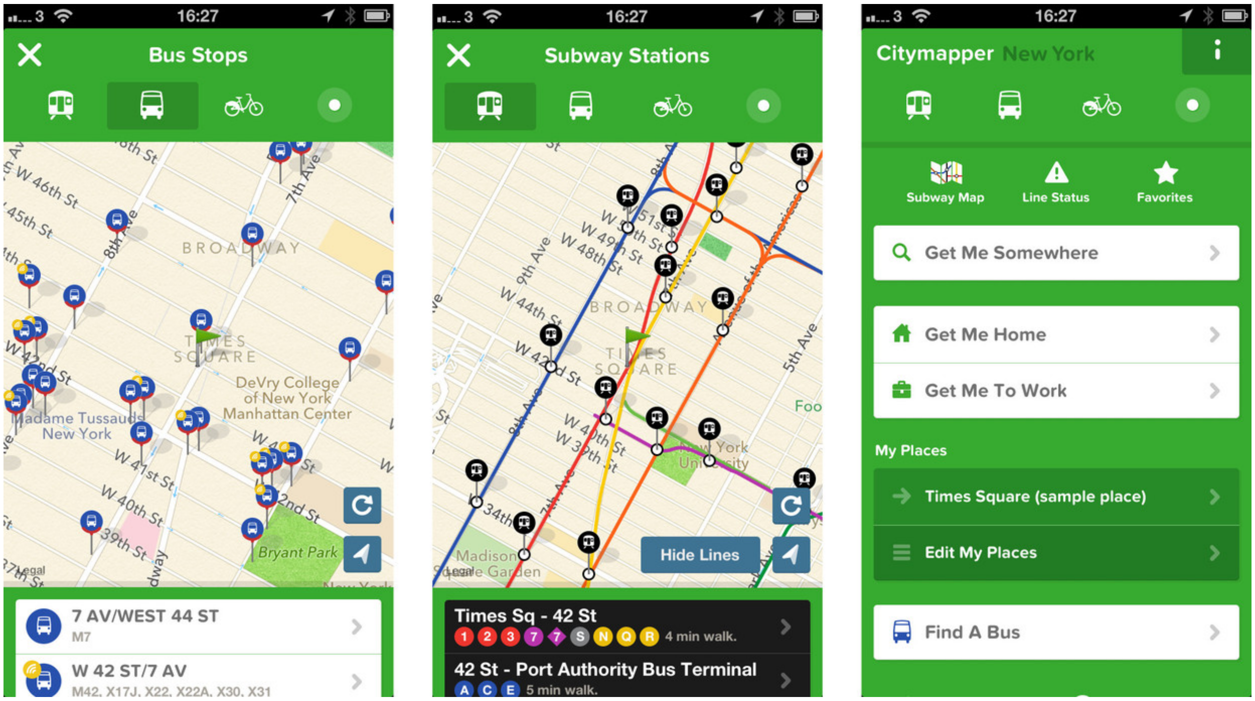
While a number of multi-modal apps currently exist on the market, some have become quite comprehensive in coverage with consumer-ready presentation. *RideScout* started in November 2013, and it is now available on desktop and for Android and iPhone. One of the many features contained within the RideScout app is calendar functionality, which allows the user to sync their personal calendars to find rides and events. Covering many major cities throughout the U.S., the app provides route options that will list different modes, approximate cost, calories burned, departure and arrival times, and trip duration.

Figure 4-9 Screenshot of RideScout Mobile App



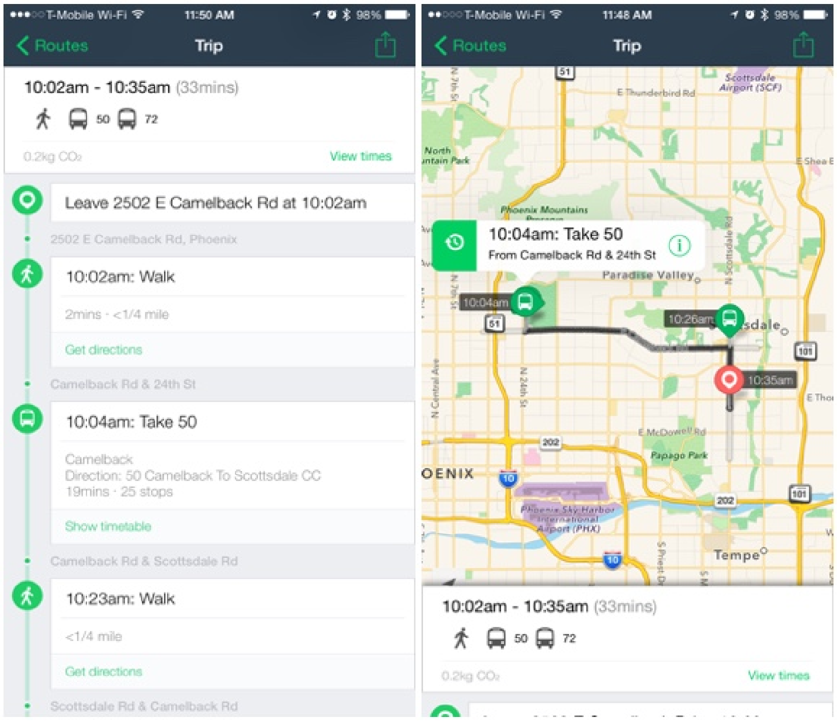
Another trip planner is *Citymapper*, which is available for desktop, Android, and iPhone. It consolidates real-time information for practically all modes in the cities it covers. As of June 2015, it was available in London, Washington DC, San Francisco, México DF, Philadelphia, Vancouver, New York, Madrid, Chicago, Manchester, São Paulo, Montreal, Paris, Boston, Milan, Hamburg, Singapore, Berlin, Barcelona, Rome, Los Angeles, and Toronto. The app allows the user to set arrival and departure times and also gives suggestions based on travel time, cost, mode choices, and calories burned. The app integrates public transit, ridesharing, carsharing, auto, bikesharing, etc.

Figure 4-10 Screenshots of Citymapper Mobile App



TripGo is a trip advisor available for Android and iPhone. The app allows the user to set their relative priorities between saving money, saving time, the environment, and convenience. It then uses utility theory to make route suggestions. Suggestions tell the user arrival time, trip duration, approximate cost, and carbon dioxide emissions. The app also allows the user to select what modes he or she is willing to take. The app integrates public transit, ridesharing, carsharing, auto, bikesharing, etc. *TripGo* also allows users to create agendas for their days. The app then creates routes and schedules to make sure the user arrives on time.

Figure 4-11 Screenshots of TripGo Mobile App

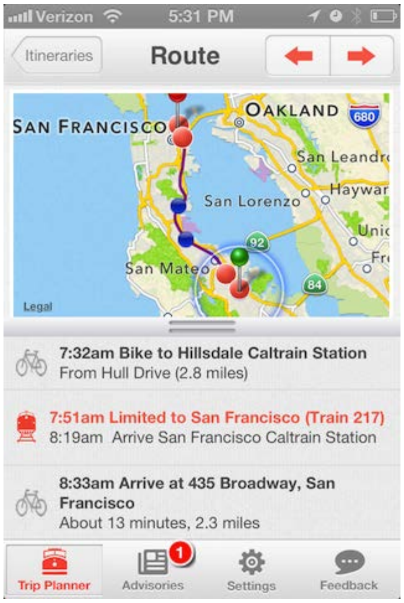


Certain applications have also developed incentive systems to reduce congestion. *Metropia*, which is available for desktop and on Android and iPhone, currently works in Austin, TX and Tucson, AZ. *Metropia* essentially provides routes for commuting, but then offers incentives for people to take alternative routes and depart at different times to reduce saturating certain routes of the network. Awards include online music, gift cards to local and online shops, etc. The app also tracks how many pounds of carbon dioxide the user saves and, through a partnership with American Forests, they plant trees based on your savings. This app is an example of gamification in practice, where positive behaviors are encouraged through rewards and points. A Metropia pilot study on its users in Los Angeles found that after six weeks of use, 86 percent of commuters reported saving time, and over 60 percent of users changed their regular departure time. Users who changed their departure time and route experienced between a 20 and 30 percent reduction in commute times (Hu et al., 2014).

> 74% of Metropia users report saving time, and 65% of users are willing to change their regular departure time. Users experience, on average, 20% reduction in travel times.

Nimbler is another trip-planning app that provides turn-by-turn directions, taking into account travel by bike, train, bus, and walking. Currently operational in San Francisco, Portland, and Washington D.C., the app also takes into account real-time traffic and public transit delays when providing route options. For bicyclists, the app also allows users to set preferences related to the fastest, safest, or flattest route (Anderson, 2013). Figure 4-12 shows a screenshot of the application below.

Figure 4-12 Screenshot of Nimbler



Similar to Apple's Siri and Microsoft's Cortana, Google Now is an intelligent personal assistant that can help with a whole host of functions, including planning public transit or traffic trips. It uses Google's traffic and transit real-time information and integrates it with the user's daily life (for example, it will provide traffic route options at the time the user usually gets done with the working day). Further, it has pushed other innovations such as setting an alarm when a user is reaching his or her transit stop so as to allow the user to nap on the morning or evening commute (Blattberg, 2014). In addition, apps have also been developed to help identify parking spaces so as to reduce the congestion caused from circling in search of parking. One such app is the ParkWhiz app, which allows drivers to search for available parking, view pricing, and make reservations at over 2,000 parking lots across the United States. Additionally, ParkWhiz customers are offered a discount for booking parking in advance.

Figure 4-13 Screenshots of ParkWhiz Mobile App

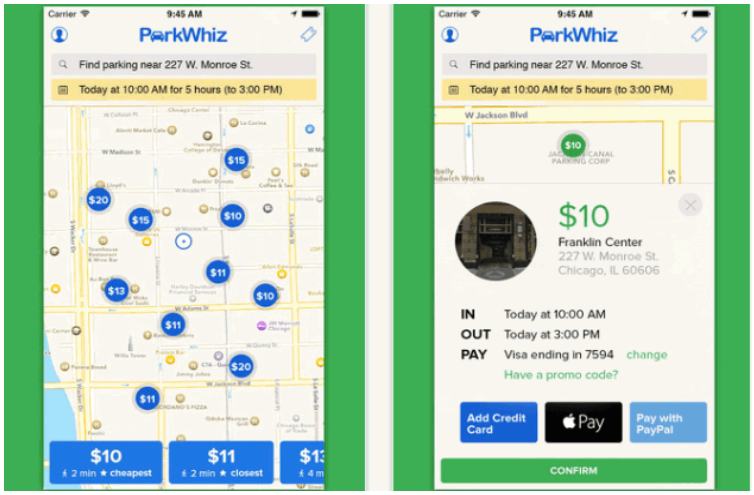


Table 4-3 Summary of Trip Planning Assistance Mobile Apps

Mobile App Name	Year Launched	Functions
Waze	2009	Provides turn-by-turn route guidance, with real-time traffic and accident information
RideScout	2013	Provides route options that list different modes, approximate cost, calories burnt, departure and arrival times, and trip duration
Citymapper	2011	Similar to RideScout, this app integrates transit, ride sharing, car sharing, auto, bike sharing in route planning options
TripGo	2012	The app allows the user to set their relative priorities between saving money, saving time, the environment, and convenience. Includes CO_2 calculations and integrates with your calendar.
Metropia	2014	Offers incentives for people to take alternative routes and depart at different times to reduce saturating certain routes of the network
Nimbler	2012	Nimbler provides turn-by-turn directions, taking into account travel by bike, train, bus, and walking. The app accounts for real-time traffic and public transit delays when evaluating route options.
Google Now	2014	Helps with planning public transit or traffic trips, using Google's traffic and transit real-time information and integrates it with the user's daily life.
ParkWhiz	2006	Allows drivers to search for available parking, view pricing, and make reservations at over 2,000 parking lots across the United States

Research is beginning to emerge on the impact of these and similar apps on travel behavior. Chen and Jovanis (2014) conducted a study on the effectiveness of turn-by-turn advice. They used a travel simulation program on a desktop computer to understand what affects a driver's likelihood to accept real-time advice. The mixed model created to understand compliance found that, while "freeway advice, turning advice, congestion occurrence, incident occurrence" played a large role, "subjects' spatial experience, temporal experience, and education level" also affected their likelihood to comply (Chen and Jovanis, 2014). The authors concluded that drivers will not always comply with the instructions given by trip advisors, given their own experience and education.

More recently, multi-modal models have been developed to make travel more efficient. Overall, an Advanced Traveler Advisory Tool (ATAT) is used to advise and guide users on multimodal trips with both path and mode choices. While trip planners tend make decisions based on real-time route information, trip advisors also allow the user to tailor the advice to their preferences.
According to Nuzzolo et al. (2014), there are three major types of trip planners and advisors:

1. *Rule-based:* Refers to a selective approach in which filters reduce the choice set of all feasible paths by removing unacceptable paths (e.g. those exceeding a maximum walk time or distance, number of changes, transfer time) – such rules can be defined by the transport agency and/or by the user.

2. *Weighted time-based:* Refers to paths individualized through a function of weighted time components (such as access, waiting, transfer on-board, and so on), with weights that can be defined by the transport agency and/or by the user;

3. *Utility-based:* Refers to the path "cost" on the basis of the utility theory, with a utility function of path attributes associated to each alternative. The parameters, which should be calibrated, can be average values applied to all users or can be individual parameters tailored on the basis of personal user preferences (personal traveler advisory tools).

Since this type of technology is fairly new and evolving very rapidly, formal studies are limited on the effects of these apps. However, it is believed that "[almost] all movement in a major city now begins with a phone" (Goldwyn, 2014). People depend on technology to get around in major cities where multi-modal apps provide an easily navigable approach toward the various choices in routing.

Early applications of multi-modal traveler information were, in fact, singular to public transit or driving. Their focus was mainly travel time prediction, and where appropriate, routing information. Many of the apps under development today, including and beyond those discussed in this section, are part of an evolution of these applications. Building on information derived from first generation single mode applications, multi-modal applications are beginning to integrate real-time information from a number of different sources. The multi-modality of these applications has benefited from the simultaneous expansion of shared mobility services that are heavily dependent on reliable information on the location and availability of system assets. As these applications continue to develop, their integration with the broader array of real-time transportation information and mobile payment systems will undoubtedly improve.

Research is beginning to evaluate the impacts of these improved applications of multi-modal information as this nascent market continues to evolve.

Advanced Infrastructure and Pricing

Traffic engineers and planners have shifted their focus to managing transportation demand in existing infrastructure rather than increasing capacity through costly roadway and public transit expansion. The following sections discuss recent developments in active demand management (ADM), tolls and pricing, and parking pricing.

Active Demand Management (ADM)

Active demand management (ADM) employs technology to manage demand in real-time through the redistribution of passenger travel to alternative routes, alternative modes, or nonpeak travel times. FHWA (2015) has noted the following as ADM strategies:

- *Dynamic transit fare reduction.* As congestion within a corridor increases, the corridor's public transit system fare decreases in real time. This pricing information is disseminated to travelers to encourage some to switch modes from driving to public transit before entering the congested corridor.
- *Dynamic high-occupancy vehicle (HOV) / managed lanes*. A typical HOV lane remains static or changes its requirements based on time of day (i.e., peak travel vs. non-peak travel). Dynamic HOV/managed lanes dynamically change the conditions for driving in the lane. Minimum occupancy requirements, hours of operation, and/or exemptions change depending on real-time traffic conditions in the general purpose lanes.
- *Peak period shoulder lanes*. This strategy uses shoulder lanes normally reserved for emergencies as a normal travel lane, managed lane, or public transit lane during peak periods to accommodate increased travel demand. An example is the northbound I-495 shoulder lane in Virginia opened in July 2015 and the eastbound I-70 peak period shoulder lane in Colorado opening in late-2015.
- *Dynamic pricing.* Dynamic pricing (also known as variable tolling) is currently the predominant ADM strategy employed. The price of the toll changes based on congestion levels.
- *Dynamic ridesharing*. This strategy employs GPS-enabled smartphone apps to match riders with drivers going the same way. This is done in real-time to reduce single-occupancy vehicles and mitigate traffic congestion.
- *Dynamic routing*. Dynamic routing monitors real-time congestion on roadways and disseminates travel time information to travelers and suggests alternate routes to better use the existing roadway capacity. Currently, research in dynamic vehicle routing has focused on modeling for logistics management (Pillac et al., 2013) rather than passenger travel.

- *Dynamic transit capacity assignment*. This strategy adapts public transit vehicle schedules to accommodate demand in real-time, moving assets to areas and times when demand is high. Several academic papers have been published modeling stochastic public transit assignment (Nuzzulo et al., 2012; Szeto et al., 2013; Hamdouch et al., 2011), but real-world applications are not widespread today.

- *Flexible transit*. Flexible transit includes new systems that take input from riders on origins and destinations and dynamically form routes that collectively move riders to the destinations on dynamic routes using mid-size shuttle buses.

- *Transit transfer connection protection*. This strategy improves transfer reliability between a high-frequency public transit service (e.g., metro rail) and a low-frequency service (e.g., feeder bus). The lower-frequency service is held at the transfer point if the higher-frequency service is running late.

- *Predictive traveler information*. Similar to Advanced Traveler Information Systems (ATIS), predictive traveler information employs real-time and historical data on traffic conditions and disseminates information to travelers to influence their travel behavior.

These ADM strategies have been highlighted by the FHWA as leading strategies to enable more fluid daily travel choices in support of existing transportation modes. ADM implementations comprise the enhancement of existing facilities and infrastructure through the use of information and pricing. Among the most common ADM strategies in place today are dynamic pricing of express lanes. These and other common applications of ADM are discussed in more detail in the following sections.

Tolls/Pricing

> Tolling affects drivers differently but three studies have shown a consistent pattern: tolls have a stronger impact than travel mode in changing the number of traveler trips, trip timing, and route choice.

Tolls help generate revenue and when strategically implemented can diverge traffic and ease congestion during peak hours or at heavily occupied roadways. A survey conducted on the SR-520 Bridge in Seattle recorded an overall increase in traveler satisfaction when a toll was added to the corridor (Peirce et. al., 2014). The corridor experienced a 43% reduction in recorded trips, and one-fourth of former SR-520 drivers diverted to a nearby toll-free alternative, I-90. However, the effects of tolling extend beyond simply diverting traffic volumes from one location to another. Tolls can also affect the distribution of vehicles across different lanes on a single highway. When a federally-sponsored variable tolling program was put into effect on the I-85 corridor northeast of Atlanta, there was an increase in vehicles using the Express Lanes, even though travel declined in the general purpose lanes (Petrella et. al., 2014). This was because the HOV-2 lane was converted to a HOT-3 lane, meaning that single or double occupancy vehicles could pay to use the lane, while vehicles with three or more occupants could freely use the HOT lane. Express Lane users were more satisfied with how tolling affected travel time, travel speed, and reliability of their commute, whereas general purpose lane users expressed dissatisfaction, especially regarding peak hour travel time.

A similar study on a conversion of an HOV lane into an HOT lane revealed further impacts on travel behavior. The model showed that drivers were insensitive to price and, in turn, generated more than 10% in revenue through toll use (Burris et. al., 2009). Tolling affects drivers differently depending on the characteristics of the traveler, yet the results from the three studies above convey a consistent pattern where tolls have a stronger impact in changing the number of traveler trips, trip timing, and route choice rather than travel mode.

Parking Pricing

Parking pricing is increasingly used as a policy instrument to influence traveler behavior. Parking pricing can have a dramatic impact on discouraging single-occupant vehicles (SOVs), reducing VMT and promoting carpooling and public transit use. Market-rate parking pricing does not guarantee a reduction in vehicle travel, though, as there is a possibility that drivers may choose to park elsewhere or even change their destination (possibly farther away) because of increased parking fees. Ng (2014) found that increases in parking pricing more likely affect parking location than transportation mode.

Nevertheless, parking pricing policies can be effective in increasing average vehicle occupancy and promoting carpooling. In 18 case studies on the effects of parking pricing increases, SOV travel decreased by an average of 21% (TCRP, 2005). This reduction in SOV travel leads to an increase in carpooling and public transit use. However, the potential reduction in SOV travel appears to depend heavily on the quality of transit options in the area. SOV work trip reduction was 10% in places where transit was considered “poor,” but it was 36% where public transit was considered “best” (TCRP, 2005). Other underlying factors influence how travelers respond to changes in parking pricing. The most prominent factor is income. Not surprisingly, high-income travelers will more readily sacrifice money, whereas lower-income travelers will be more reluctant to sacrifice money for a quicker commute.

Usage-Based Insurance

Traditionally, insurance premiums have been mostly dictated by general information of the driver, such as age, gender, location, driving record, and more recently, education, occupation, and credit score (Karapiperis et al, 2015). A study from the Brookings Institute dubs current auto insurance policies as “inefficient” and “inequitable” (Bordoff and Noel, 2008). Drivers with similar demographic, geographic, and economic characteristics pay around the same premiums, even if one drives 7,000 miles a year and the other drives 70,000. This pricing structure implicitly encourages more driving. Usage-based insurance (UBI), also known as pay as you drive (PAYD) and pay how you drive (PHYD), enables insurers to use extensive driving data to more accurately calculate insurance premiums. Vehicle telematics—devices that can wirelessly communicate relevant driving behavior to insurance companies—have enabled the rise of UBI. Previously overlooked factors, such as location, number of trips, mileage, and driver behavior, can now be transmitted to insurance companies using telematics (Karapiperis et al, 2015). Drivers and insurers both benefit from more accurate insurance premiums and more driving data to more efficiently settle claims. Moreover, UBI has the potential to

> Society as a whole may benefit from UBI due to enhanced road safety, reduced congestion, and lower emissions.

promote positive changes in traveler behavior by giving a financial incentive to reduce the frequency and length of driving trips. However, such data may also permit the same factors to have a negative influence, such as adjusting rates based on where a person drives. Overall, UBI opens a number of new avenues for insurance-based pricing that may ultimately save consumers money.

Society as a whole may benefit from UBI due to enhanced road safety, reduced congestion, and lower emissions (Karapiperis et al, 2015). For example, drivers may positively modify their driving behavior. Previous work has suggested that directly linking insurance costs to miles driven would result in an 8% reduction in VMT and an 8% decline in gasoline consumption (Bordoff and Noel, 2008). Travelers would also be incentivized to rely more on environmentally-friendly public transit and ridesharing services. UBI also makes strides in unraveling the "inequitable" nature of car insurance. Current factors that influence premiums like marital status, occupation, education, credit score, and homeownership are valid predictors of risk but penalize the young, the elderly, and the poor (Karapiperis et al, 2015). As a result, many lower-income drivers remain uninsured; nationwide 12.6% of drivers are uninsured but in states with a higher proportion of lower-income drivers that percentage jumps to as high as 26% (Karapiperis et al, 2015). UBI would enable lower-income drivers to buy insurance, benefiting themselves and other drivers. A 2003 study found that UBI would decrease driving nationally by 10% (Bordoff and Noel, 2008). Further study on traveler response to UBI is needed, but consumers, insurers, and society may on balance benefit from a wider deployment of UBI.

Dynamic Management

Real-Time Traffic Management

Dynamic traffic management, with the aid of more advanced data collecting technologies, provides traffic engineers and planners the opportunity to more efficiently operate traffic. Four major elements of management systems are traveler information, traffic signal timing, traffic incident management, and work zones (Paniati, 2004). In order for this information to be useful, data must be collected in real-time so operators can make decisions regarding current traffic conditions. This information can be relayed back to drivers through the use of display signs, the Internet, or other communication channels that allow the drivers to respond accordingly. As traffic information becomes more accessible to the public through the advancement of smartphones and other communication devices, drivers can begin to more rapidly evolve their travel behaviors (speed, lane, route) in response to changing traffic conditions.

Dynamic management systems have proven to be effective in cities, such as Dallas, Seattle, Minneapolis, and others. In Maryland, the implementation of dynamic dispatch for roadside incidents yielded close to a 3% decrease in response time compared to static dispatch, and in the context of large-scale highway systems, this can be quite significant in reducing delay time due to traffic incidents (Kim et al., 2015).

Advanced Traveler Information Systems (ATIS)

Advanced traveler information systems (ATIS) aim to alleviate congestion by providing drivers with real-time information about closures and approximate driving time. This information allows drivers to make more informed choices on travel mode, route, and departure time. The advent of wireless technology has allowed real-time signs to replace generic static road signs. Real-time information is inherently more useful as static signs are generally based on long-term trends and do not account for real-time events. ATIS encapsulates pre-trip, post-trip, and en-route information provided to drivers.

A study conducted in Fresno, California showed that the possible time savings from ATIS are largely dependent on the preconceived perceptions people have of system costs—they can vary anywhere from a 17% reduction in total travel time to a 1% reduction in total travel time. In rare cases, when users perceive system costs as higher than they actually are, total travel time can actually increase with the implementation of ATIS (Rouhani and Gao, 2014). ATIS can efficiently change a user's travel behavior especially when fuel costs are high or users have a poor perception of fuel costs. Another study showed that emissions and energy consumption along ATIS routes could be reduced by up to two percent (Fontes, 2014). The results from implementing ATIS also depend on the level of demand and flows resulting from the demand. During peak hours, ATIS generally has a higher impact on the central business district than the whole system and then the situation flips for off-peak hours. One study showed that although most drivers were hesitant to switch from habitual routes, 40% of respondents had changed their habitual routes because of ATIS (Balakrishna et al., 2013). Travelers may opt to change destinations when possible (e.g., shopping destinations) or even cancel trips. As expected, noncommuting drivers changed their destination more than commuters, given their greater flexibility (Balakrishna et al., 2013). Reduced anxiety of drivers is another crucial benefit of ATIS, increasing driver satisfaction. While it is difficult to quantify the precise effects of ATIS, rapid adoption of GPS services will prove crucial in providing more traveler data. With more robust data, ATIS can be further enhanced, as its initial benefits are encouraging.

Summary and Areas for Further Research

Notable advances in wireless and communication technologies are changing travel behavior and driving innovation today. From shared mobility services to automated vehicles, telework and e-commerce, new business models, and ADM strategies, a common thread though all of these cutting edge technologies is better provision and use of information to achieve enhanced mobility or engineering goals. Research describing how these technologies influence travel behavior is at different stages of maturity.

The emergence of the shared mobility industry is one of the pioneering events that has begun to alter the American's relationship with the personal automobile. The advent of carsharing, bikesharing, and ridesourcing through TNCs have transformed how urban populations access mobility. The earliest among these modes is carsharing, which began in North America in the late-1990s, and has since spread across the continent and world. Carsharing was originally established as a neighborhood roundtrip service, where trips with operator-supplied vehicles started and ended in the same place. But after about 10 years of operation in the U.S, carsharing began to evolve into new forms. One-way carsharing allows people to drive and drop off vehicles at different network locations or anywhere within a pre-define region. Peer-to-peer carsharing opens the prospect for vehicle owners to share the vehicles they own, potentially leveraging access to millions of private vehicles across the country. Roundtrip carsharing has been well studied, and a large body of research has found that it reduces vehicle ownership, driving, and GHG emissions. Evaluation of the newer models of carsharing is currently a subject of active study.

Bikesharing is another mode that has become well established in the U.S. during the present decade. Bikesharing has been found to reduce driving as well as to reduce public transit use in large cities and the urban core. The impact of bikesharing has been found to vary across regions both within and across cities. Bikesharing appears to increase public transit use less in transit-intensive cities, and it exhibits a relatively greater contribution to increasing public transit use on the urban periphery of large cities. The growth of ridesourcing/TNCs has been the most explosive of all. As a result of ridesourcing/TNC success, the taxi industry has begun to evolve, embracing IT applications and addressing other challenges to improve its competitiveness. In August 2014, ridesplitting services emerged in the San Francisco Bay Area and have since spread to Los Angeles, New York City, and Austin, TX. Nonetheless, considerable controversy remains surrounding the broader industry of ridesourcing/TNCs.

The growth of shared mobility has provided new options for urban residents to access transportation. At the same time, shared mobility has yet to effectively reach the suburban and rural environments to a significant degree. Research on shared mobility is now an active area, and new insights pertaining to its impacts continue to emerge.

While shared mobility is a big part of the transformative technologies changing travel behavior, there exist a number of newer and older technologies that are also impactful. Telecommuting and e-commerce/e-shopping applications have existed in the North America for longer than the earliest shared mobility applications. Telecommuting grew significantly in the 1990s and was heavily studied during that decade. Technologies facilitating telecommuting have continued to advance, but research activity in this area has recently focused less on travel behavior impacts and more on how telecommuting has affected worker productivity and perceived quality of life. Research on the impact of e-commerce/e-shopping has also shifted since the concept first emerged at the beginning of the 21st century. Early studies found e-commerce to substitute for shopping travel, while studies in the 2010s have continually found no association with shopping travel or a complementary relationship. It is speculated that the reason for this shift is the result of changes in the economy that have adapted to the presence of e-commerce. Industries experiencing the brunt of the substitution effects have shrunk; thus, trip substitution is no longer as observable as it once was.

On the horizon in e-commerce are emerging applications in telemedicine. Research on the impacts of telemedicine on travel behavior is limited due to the relatively young field of application. Studies of telemedicine have been more focused on their ability to replace actual visits and patient satisfaction and comfort with these emerging technologies. It is likely that research in this area will continue to grow, but large-scale evaluations will have to await the wider deployment of telemedicine technologies as they become more commonplace.

New and innovative business models are evolving in several areas of transportation services ranging from parking, public transit, food and package deliver, and shared mobility. These new business models have not yet been the subject of in-depth evaluation given the nature of their early stage development. But the tracking of these services shows that there is active innovation in this space, which continues to leverage the mobile computing and communications capabilities of smartphones. In addition, multimodal traveler information systems have also grown and further developed since the early applications of real-time traveler information systems. Early systems provided information to users of public transit, and research has shown some modest ridership improvements as a result. Advances in these applications now span information from multiple modes, leveraging connections to shared mobility services, walking, bicycling, and public transit systems across the country.

Active demand management systems span a wide array of systems and strategies that use pricing and information to affect travel behavior within regions and corridors. The most common systems that have been deployed include HOT lanes, dynamic lane use, and predictive traveler information. In addition, usage-based insurance appears on the horizon as a form of dynamic pricing for insurance. Continued evaluation of these other systems is needed to better understand impacts and improve future deployments.

One area that is relatively open is research focusing on the impact of AVs on travel behavior and linkages to shared mobility. The advent of AVs and the changes they will engender on society are currently poorly understood. How AVs will exactly influence freight and passenger travel is a subject of speculation since applications are still under development. The body of research bringing these vehicles to fruition is developing, but impacts related to policy, behavior, and shared mobility applications are a subject of considerable debate and in need of further research.

The early 21st century has been an exceptionally transformative time in mobility, with many new applications emerging that will both enhance our experience with the automobile and simultaneously limit our need of it. With numerous new innovations on the horizon, the pace of transportation change is likely to accelerate. This continued evolution will need continued evaluation research, as shared mobility, AV applications, innovative business models, IT, and infrastructure converge to form new and advanced applications for mobility and improve transportation sustainability.

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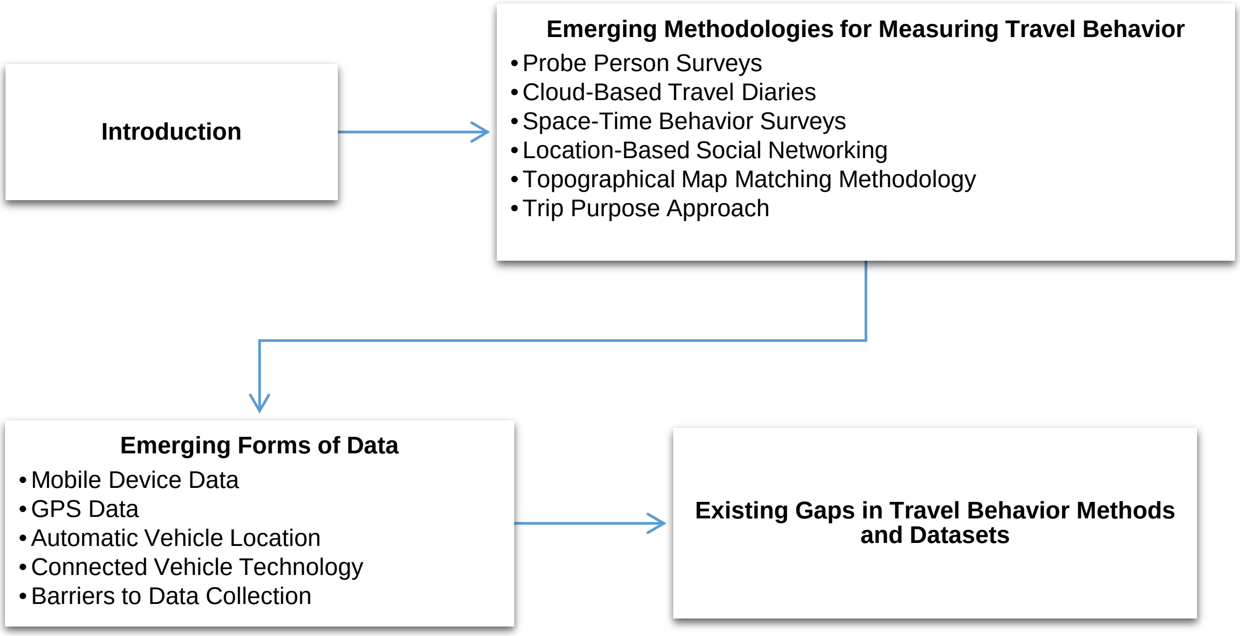
CHAPTER 5.0. EMERGING METHODOLOGIES AND DATA FOR MEASURING TRAVEL BEHAVIOR

Introduction

Technology has transformed dramatically during the 21st century, leading to new approaches for data collection and new methodologies for evaluating travel. This chapter reviews the existing research on emerging methods for measuring travel behavior, and discusses approaches that could be used with new forms of data to generate metrics similar to or in addition to those approaches discussed in Chapter 2. The topics discussed in this chapter have been largely influenced by the possibilities opened up by new data collection methods from rapidly proliferating technologies. For example, new data sources are emerging from mobile devices (including smartphones and tablets), in-vehicle sensors, advanced GPS technologies as well as other information and communication technologies. The content flow of Chapter 5 is depicted in Figure 5-1.

Figure 5-1: Content Flow of Chapter 5



Emerging Methodologies for Measuring Travel Behavior

There is a need for building methodologies that are not only mathematically robust but also capture the subjectivity of human behavior. Several other inefficiencies in existing methodologies arise from an inadequate sample size, long time required to collect trip data, self reporting which contribute to subsequent measurement error, and so on. The real challenge is to be able to collect observational data while also still being able to capture the detailed trip characteristics.

Several new methodologies have emerged in the past five years that heavily leverage the new advances in smartphone and GPS technologies. New estimation procedures (e.g., activity-based modeling) have also emerged; these are statistically sound and may perform a much more efficient forecasting than traditional choice-based estimation models. Some of these methodologies are discussed in the following sections.

Probe Person Surveys

As previously mentioned, conventional data collection methods for travel surveys are mostly comprised of telephone interviews, personal interviews, travel diaries, mail-back or web-based questionnaires, traffic counting on cross sections or intersections, and analyses of transport schedule inquires. One major caveat of these methods is that large-scale data collected through these methods comes at a very high cost. Therefore, the frequency at which this data is updated is usually 5 to 10 years. Another issue that has been highlighted in recent research is the trip-misreporting problem (Jin et al., 2013), which leads to inaccurate data that can harm the whole dataset and its interpretations. But this is just one of a number of limitations of travel surveys.

An example of one of several approaches aimed at mitigating these weaknesses is the probe person (PP) survey. This survey approaches attempts to resolve some of these methodological issues by applying a more holistic approach to people’s travel habits. Probe person surveys have been used in Japan to understand travel behavior by collecting stated preference data through Internet web diaries supplemented with actual travel choices through GPS-assisted mobile phones (Hato et al., 2014). Research on this approach found that by using GPS and accelerometer data, transportation mode could be predicted better, and the algorithm can be designed as well as applied in an economic manner in large-scale urban transportation projects. Embedded sensors on smartphones are used to detect the individual’s mobility behavior. Supervised learning algorithms, like Support Vector Machines (SVM) and Adaptive Boosting (AdaBoost), are also applied to make the device learn about the individual’s mobility patterns.

Cloud-Based Travel Diaries

With the proliferation of the Internet, travel diaries are moving from paper-based surveys to web-based platforms. An example is “Quantified Traveler” (QT), a computational feedback program that uses the “cloud” (i.e., software and services that run from the Internet rather than an offline personal computer) to collect information from web travel diaries. It uses an app on a smartphone or mobile device to collect travel data; a server in the cloud processes this data into travel diaries; and then provides a personalized carbon, exercise, time, and cost footprint.

Jariyasurant et al. (2015) uses this concept in one of the most important aspects of travel behavior research: changing people's choice of transport modes. The traditional methods for changing any travel behavior involves travel feedback programs, which are time-consuming, expensive, and prone to subjectivity. Using machine learning techniques and new advances in data analytics, the quantified traveler app forms daily travel logs for the users and provides them with alternative choices at the end of the day to help them understand how to optimize their travel behavior. The cloud-based travel diary system is much more efficient than traditional feedback campaigns because it provides personalized information that is specific to each individual's original behavior. Multi-week activity travel diaries were also collected in the cloud using GPS technologies in the Netherlands, resulting in rich and accurate datasets (Feng et al., 2014).

Space-Time Behavior Surveys

Traditional data collection methods in a travel behavior study include: 1) two stage surveys consisting of a telephonic interview and travel diary; and 2) web-based surveys, where respondents answer similar questions using a questionnaire on a website platform. Web-based surveys are very popular because they can easily reach a widely dispersed population. However, since both these methods often rely on respondents' self-assessment and stated preferences, biases may be introduced. Thus, researchers often supplement these travel surveys with other data sources that record physical movement over space and time. This mixed-mode method has been used to create enhanced data sets and involves both traditional data generation methods and new approaches using GPS and GIS technologies (Bricka et al., 2014, Reinau et al., 2013). Advanced technologies in location position are combined with the latest technologies in mobile communication to provide rich data for dot data analysis (Asakura et al., 2010).

The space-time behavior survey approach has been gaining interest from government and scholars recently for travel planning purposes. It refers to a method of survey where real-time location data points are collected from users, providing an accurate time stamped trip map for every user. The development of space-time behavior research has promoted urban planning and policy in western countries, and has grown into an influential approach in urban geography and transportation planning. Researchers in other countries have also experimented with innovative approaches to understand travel behavior. In China, smart travel planning has been gaining interest as a way to solve its growing dense urban transportation problems. Over the last two decades, significant research on space-time behavior has been advanced in China using disaggregate survey data. The focus of the approach has been to decipher the dynamic interactions that occur between individual life experiences at the micro level with urban social and spatial transformations at the macro level. A 2014 study in Beijing recruited over 700 respondents through a multi-stage cluster sampling procedure and integrated GPS tracking with web-based activity travel diaries to collect data with high spatial and temporal resolution. The data showed that on average respondents participated in 8.19 activities and 2.66 trips per person per day (Chai et al., 2014). This sort of behavior data is immensely useful for planning agencies who are motivated to regulate their policies in dense urban environments to provide benefits to the populace with minimum burden on the individual.

Location-Based Social Networking (LBSN)

Online social networking (e.g., Facebook, Twitter, Foursquare, Instagram) has opened up a new avenue to track travel behavior. "Check-ins" on these social networking sites can provide a dynamic (time-dependent) Origin/Destination (O/D) travel demand monitoring system, called venue-side location-based social network (VS-LBSN) data. Data collected through these sources can be used to develop dynamic travel demand data in a temporal and spatial resolution in order to create dynamic O/D demand estimation for an urban transportation network. The O/D matrix describes the number of trip exchanges between the origins and destinations in a transportation network during a specified time period, which is a crucial input in prevailing transportation planning. With the recent development in Active Traffic and Demand Management (ATDM) technologies in the United States, the practical needs for collecting dynamic demand information, such as the dynamic O/D matrix, have increased significantly (Yang et al., 2014).

Topological Map Matching Methodology

Spatial mismatches or map matching problems are very common in transportation research. This occurs mainly when the centerline of a roadway is incorrectly interpreted in the GPS data of complex road networks. This is a recurrent problem in overpasses and underpasses; converging and diverging roadways, such as ramps and divided highways; or when roads are close together. As a consequence of the map-matching problem, any subsequent computation, evaluation, analysis, planning, and decision-making may be impacted negatively and will result in spatial ambiguity.

A study was recently conducted in Chile to address this problem. Blazquez et al. (2014) uses a decision rule-based algorithm, taking into account the fact that decision-making must be performed simultaneously with the movement of vehicles, individuals, or objects. This is used along with real-time spatial data to fix erroneous map matching in complex road systems. The robustness of this methodology was verified using actual taxi GPS data collected in the urban area of Harbin, China (Yang et al., 2013).

Trip Purpose Approach

Identifying the trip purpose accurately has been of paramount importance to travel demand modelers and forecasters since the last decade. Recent trends in travel behavior research have shifted to an activity-based approach, which is motivated by the rationale that a person's travel is a combination of his/her lifestyle and activities surrounding it (Wolf et al., 2014). The activity-based approach to travel demand analysis views travel as a derived demand; derived from the need to pursue activities distributed in space. The approach adopts a holistic framework that recognizes the complex interactions in activity and travel behavior. The primary emphasis of this approach is on activity participation, and therefore it focuses on day-long sequences or patterns of activity behavior. This can be very beneficial to address congestion management issues by examining how people modify their activity participations on a daily level. The trip purpose approach has also been used on walking trips to analyze the interaction of a trip purpose with trip distance, trip duration, time of the day, etc. (Hatamzadeh et al., 2014).

Emerging Forms of Data for Measuring Travel Behavior

Technology today has enabled devices that can measure or record travel behavior and revealed preferences accurately and in real-time. While traditional intercept and telephone surveys remain important data collection instruments, real-time data may more accurately reflect travelers' revealed preferences and travel choices on a timely basis. Moreover, research has observed a small variability in the predictability of travel patterns (Song et al., 2010; Sagl et al., 2012; Qian et al., 2013). Recent forms of data for measuring travel behavior include the following: mobile device data, GPS data, automatic vehicle location (AVL) systems, as well as connected vehicle (CV) applications. The following sections describe these datasets.

Note there are other data sources including: National Performance Management Research Data Set (NPMRDS), which is a dataset of GPS trace data used by states and MPOs; the American Time Use Survey (ATUS) dataset; and ridesourcing app data (e.g., Lyft, Sidecar, Uber). See Task 3, for more details on these data sources.

Mobile Device Data

Mobile device data from cellular phones, smartphones, tablets, and other mobile devices are emerging forms of data applicable for travel behavior studies. Mobile device data has the ability to capture large amounts of real-time data from the general public (Calabrese et al., 2015; Steenbruggen et al., 2015). Telecommunications companies collect this georeferenced data through their cellular networks, locating the general location of a mobile device on their cellular network (i.e., not necessarily their data network) (Steenbruggen et al., 2013). When accessible and used appropriately, this data can yield new insights on personal travel behavior. It can allow researchers to better understand people's movements and to improve the responsiveness of policy when compared to infrequently updated travel surveys. Although not all travelers own smartphones, a small penetration rate of mobile technology can prove effective in obtaining travel data. Herrera et al. (2010) found that a mobile phone penetration rate of two to three percent is enough to accurately measure vehicle speeds in traffic flow.

Among the different forms of data available, mobile device data may also be the cheapest to procure. It is often already collected for cellular and data network management by telecommunication companies. Mobile device data has a lower collection cost, larger sample size, higher update frequency, and generally covers more space and time in comparison to traditional survey data (Steenbruggen et al., 2013). Although this data cannot be used to study individual or household mobility choices, the data can be aggregated over a long period of time to identify variance in mobility patterns within an urban area (Calabrese, 2013). Yuan and Raubal (2012) extracted urban mobility patterns from a major mobile phone operator's data in northeast China. Using a dynamic time warping algorithm, they determined mobility patterns for modeling and visualizations. Similarly, Phithakkitnukoon et al. (2010) used mobile phone data to develop activity-aware maps to visualize travel activity patterns. Sagl et al. (2014) used cross-dimensional clustering technology to analyze self-organizing maps (SOMs) of aggregate human activity. There are several companies that already aggregate traffic data from mobile devices. AirSage is one such company that aggregates traffic data from over 100 million mobile devices on various U.S. cellular networks, analyzing over 15 billion real-time cellular data points each day.

The acquisition and use of such data comes with a variety of challenges. Most importantly, mobile device data can contain personally identifiable information (PII), raising privacy concerns. Furthermore, even without containing explicit PII, such data can be so precise, by providing the likely GPS location of a home, that it contains implicit PII. Hence, such data needs to be manipulated to remove PII or requires robust protections from privacy breaches and confidentiality (Shklovski et al., 2014). Companies partner with telecommunication companies and other partners to remove customer proprietary network information (CPNI) and other PII (AirSage, undated). Street Light Data, another company that aggregates mobile data, anonymizes and de-identifies their datasets. In today's environment of increasing cyber espionage, providing this necessary protection has proven to be increasingly difficult.

Another challenge for conducting research is data availability, as most data provided by these emerging technologies is created and stored by industry and may not be accessible in all cases. Finally, while the data is exceptional in terms of time and space resolution, it requires additional information for full interpretation. For example, smartphones generally do not know if a person is riding in a car or on a public bus. The data may present challenges in distinguishing travel by automobile, bicycle, or walking. Thus, traditional in-person survey and interview data remain valuable survey instruments. The benefits of mobile device data, however, are numerous. The ease of collection is frequently cited as a primary reason for using mobile device data instead of surveys in some respects (AirSage, undated).

GPS Data

Global positioning systems (GPS) data are becoming a prevalent data source in travel behavior studies, partially because of the widespread usage and the wide range of applications which utilize GPS. Researchers have increasingly been utilizing GPS data since the late 1990s to correct misreporting from travel diaries and improve data accuracy (Shen and Stopher, 2014). While mobile device data is collected from most cellular phones, GPS data is limited to smartphones, tablets, and navigation systems connected to telecommunication companies' data networks or Wi-Fi networks. Moreover, location service systems, such as automatic vehicle location (discussed in Section 5.3.3), make extensive use of GPS technology.

GPS data has been used to generate prompted recall (PR) surveys, which ask respondents to recall their actual travel from GPS-generated maps and make necessary changes to improve data accuracy (Giaimo et al., 2010; Greaves et al., 2010).

GPS is a powerful strategy for monitoring vehicle location and network-level traffic patterns due to its precision. Pang et al. (2013) monitored a network of GPS-equipped taxis in Beijing on the road nearly 24 hours a day, and used them as sensors to study traffic patterns throughout the city. Similar methods could be tested in U.S. cities with either extensive taxi networks or a high volume of vehicles fitted with GPS. It is important to note that GPS data remains limited to vehicles and mobile devices actively collecting GPS data (i.e., smartphones and tablets typically are not constantly collecting GPS data due to high data and battery usage). Thus, a challenge in using GPS data is that the dataset may be incomplete. GPS data can be supplemented with mobile device data, which is collected by cellular networks more frequently than GPS data.

Automatic Vehicle Location

Another possible avenue for data collection is automatic vehicle location (AVL) systems. Typically used for transit operator and fleet management, AVL allows the geographic position of a vehicle to be automatically determined and then transmitted or communicated to a vehicle traffic system. Before AVL, transit operators manually collected data at termini, often leading to a limited understanding of the system. With the advent of AVL, operators can obtain continuous and automated point-to-point data to accurately assess the system (Ma et al., 2014). AVL systems can collect more than geographic location, including vehicle speed, whether the doors are open/closed, and whether the keys are still in the ignition. Such data can then be used to form a holistic view of vehicle travel. These systems often use a combination of GPS and geographic information systems (GIS) to determine the geographic location. Thus, they depend on GPS satellites, receivers on the vehicle, radio systems, and PC-based tracking software. The information is likely already being collected and stored where these systems are implemented; consequently, there are minimal technical barriers to collecting the data and using it for traffic behavior studies. Naturally, there remain some institutional barriers to data sharing that must be overcome to engage in research or analysis for planning purposes.

Connected Vehicle (CV) Technology

The USDOT's Intelligent Transportation Systems Joint Program Office (ITS JPO) defines connected vehicle (CV) technology as an interoperable network of wireless communications among vehicles, infrastructures, and personal communication devices (ITS JPO, 2015). CV technology is categorized into vehicle-to-vehicle (V2V) applications and vehicle-to-infrastructure (V2I) applications. V2V applications are systems in which vehicles communicate with each other via dedicated short-range communications (DSRC). Examples of V2V applications include: blind-spot warning, lane-change warning, and forward collision warning.

V2I applications are similar, but involve vehicles communicating with some sort of roadway infrastructure (e.g., traffic signals). Examples of V2I applications include: stop sign violation warning, railroad crossing violation warning, and reduced speed zone warning. Once implemented, these systems could record and communicate travel time and starting location of congestion, speed, time, and location. V2V and V2I applications have become more prolific overseas and are now beginning to appear in the United States. For example, services in Spain can give (in addition to what's mentioned in the systems mentioned above) ambient temperature, humidity, light, windshield wiper status, fog light status, fuel consumption, emissions, globally averaged traffic load, and average road speed for a travel time segment (Llorca et al., 2010).

With success abroad, the USDOT is interested in promoting CV technology on U.S. roadways. The DSRC wireless band could enable these applications, potentially improving traffic mobility and safety. This technology could help drivers to make more informed route choices by providing information that would allow them to avoid congestion and accident-prone situations (Maitipe et al., 2012). Moreover, the data provided by these services could also be used for traffic behavior research. Some companies, such as INRIX, AirSage, and Street Light Data, aggregate this dynamically collected data and sell it to different individuals or research organizations for travel and marketing analyses.

Barriers to Data Collection

Despite the emerging technologies described above that hold promise for more accurate real-time data sources on travel behavior, there remain several barriers to using these data sources for widespread research. One challenge is converting the data to a usable format suitable for research. This can be both difficult and time consuming, and requires consideration of explicit and implicit PII, which needs to be removed or have robust protection from privacy leaks. Thus, the data often needs to be anonymized and aggregated (Calabrese et al., 2013).

Other barriers are related to the nature of data collection. Because the data is dependent on mobile phone users, data samples obtained may not be representative of the population. However, as cellular phone and mobile device penetration continues to increase, sampling will become more representative of the general population (Calabrese et al., 2013).

Existing Gaps in Travel Behavior Methods and Datasets

While methodologies and datasets have evolved to better understand travel behavior in the 21st century, gaps in understanding remain. One existing gap noted in the literature relates to understanding the impact of travel behavior on local land-use development. A Caltrans study (Houston and Boarnet, 2013) noted that travel behavior studies often are based on average effects on a regional scale, leaving a knowledge gap regarding how to apply this information to local land-use development. In the case of California's Senate Bill (SB) 375, which requires that metropolitan planning organizations (MPOs) consider land-use and transportation planning to reduce greenhouse gases, such local travel behavior data is critical. Houston and Boarnet developed a methodology of collecting data via one-day travel diary surveys from local neighborhoods, supplemented with results from the California Household Travel Survey. They concluded there is a need for more localized data collection to inform trip generation models.

On the other hand, the literature also points to a lack of up-to-date multimodal and inter-regional passenger travel data hampering analysis for long-distance infrastructure investment needs (Zhang et al., 2012). Zhang et al. agree that supplementing traditional survey instruments with emerging data sources (e.g., mobile device data, GPS data) holds promise for collecting long-distance passenger travel data. They suggest the following for closing the existing gaps in methods and data sources:

1) Further testing of these emerging technologies with a focus on capturing long-distance travel data.
2) Exploring recall surveys when a long-distance trip is taken.
3) Developing more methods with new technologies to identity long-distance trips and survey the travelers.

4) Researching transferability of long-distance models developed abroad.

While there remain gaps in traditional survey datasets, mobile device data also has not been comprehensively captured or linked to traditional surveys. Reinau et al. (2015) assert that while mobile device and GPS data allow for more complex activity-based traffic models, they lack qualitative understanding of people's travel experiences. They developed a theoretical "SMS—GPS-Trip" method to combine travel diaries with travel data from GPS and short message service (SMS) location metadata. Yet a gap remains in testing this methodology. Mavoa et al. (2011) noted that linking GPS and written travel diary data generally must be done manually, which is time-consuming and impractical for very large datasets. Moreover, there may be an underreporting of trips in travel diaries. Thus, they developed a sequence aligning method to link GPS and travel diary data and compared the results to manual matching. Sequence aligning was able to match almost 62% of trips, but it may not be accurate enough for trip generation modeling.

Summary

As methodologies and datasets evolve to adapt to changing technology, they hold promise for understanding travel behavior. A major step forward has been the harnessing of real-time data to observe and analyze revealed travel choices. Gaps remain in translating metropolitan/statewide surveys for local-level transportation planning, or keeping the data updated for long-term infrastructure planning. Moreover, emerging datasets such as real-time GPS data are often cumbersome to manage and analyze. Future research can leverage these datasets, but will need to overcome institutional and technological barriers, such as data sharing, data accuracy, cyber security, and privacy.

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CHAPTER 6.0. CONCLUSION

Travel behavior in the United States is currently in a state of rapid evolution; especially in the last few years. After decades of growing reliance on the personal automobile for all travel, and declining use of public transit, walking, and bicycling, the early 21st century has witnessed a shift in behavior, particularly in urban regions. From 2005 to 2013, the mode shares of walking and bicycling have increased within all geographic regions of the country, while the mode share of public transit similarly increased in most regions of the country. Telework also made considerable gains across the country as more Americans spend a greater proportion of the week working at home. At the same time, the mode share of driving alone has declined modestly. There have been more significant declines in traditional carpooling.

VMT recently experienced a seven-year stagnation in growth, the longest in U.S. history. The average vehicle miles of travel (VMT) per person peaked in 2005. Measurements of person miles of travel (PMT), primarily through the National Household Travel Survey (NHTS), point to a reduced reliance on the personal automobile. Despite continued increases in VMT until 2006, household travel demand has experienced a plateau for over two decades, partially due to reduced travel among younger Millennials. It is possible that the broader trends in travel behavior are beginning to have large enough effects to influence big measurements of travel activity, such as national VMT and PMT. Americans are still highly dependent on the personal automobile; and current economic and oil price conditions are ideal for a return to this dependence. But they are also beginning to travel in ways that utilize other modes more often.

Vehicle ownership rates have been stagnating recently, while at the same time new vehicles are becoming more fuel-efficient. From the early 1980s to about 2005, the average fuel economy of the U.S. gasoline and diesel fleet was stuck between 20 and 22 mpg. It even declined rather steadily through the 1990s. But in the last ten years, advances in fuel economy have become more significant, particularly as a result of the hybridization of many models. Since then, a steady rise in average model year fuel economy has recently passed 25 mpg. These factors and emerging travel trends have played a role in reducing oil consumption from its peak, which occurred in 2005. This reduction has occurred in conjunction with an increase in domestic oil production, and has driven U.S. foreign oil dependence to levels not seen since the 1980s.

At the same time, U.S. socio-demographic and social trends have shifted, including population growth, suburbanization, regional migration, and increased female participation in the workforce relative to men. The population growth rate of the United States has been undergoing a gradual decline since the early 1990s and today is about 0.7% per year. While this is far below the pace of many developing nations, it is relatively high for industrialized nations. The U.S. fertility rate has been relatively stable despite a modest decline following the Great Recession. A major driver of U.S. growth is immigration, as nearly 1 in 8 U.S. residents is currently foreign born. The share of foreign born citizens has been increasing for the last four decades and, should the trend continue, the United States projects that 1 in 5 citizens will be foreign born. Research has shown that immigrants tend to travel in ways that are less dependent on the automobile, but gradually adapt to the patterns of the general population with time in the country. At the same time, the Baby Boomer generation is aging into retirement, and tech-savvy Millennials are beginning careers and family life. Collectively, these trends in the United States necessitate unique considerations in transportation policy and planning to accommodate differing travel needs.

Information and communication technology are also changing travel behavior. One of the more notable developments has been the emergence of the shared mobility industry. Beginning with round-trip carsharing in the late 1990s, shared use mobility has continued to evolve into new modes and new applications. Traditional round-trip carsharing has since expanded to all major urban areas and college campuses across the country. But carsharing has also evolved into new forms. One-way carsharing has expanded into many major metropolitan regions, allowing people to pick up vehicles at a location and drop it off anywhere else in a pre-defined region. Peer-to-peer carsharing is an emerging application allowing people to share their personal vehicles and earn some revenue in the process. Shared-use mobility has continued to evolve into Transportation Network Companies (TNC)/ridesourcing applications, which leverage smart phones, information technology, and personal vehicles to move people throughout metropolitan regions. This latest evolution of the shared mobility industry has perhaps experienced the most exponential growth and success, with two nationwide companies established at the beginning of the present decade. Furthermore, the technological advances witnessed in the area of automated vehicles have the potential to merge with the shared-use phenomenon. The future may be a fleet of shared-use autonomous vehicles picking up and dropping off people with high-occupancy trips.

These developments, along with e-commerce, new business models, and active demand management, are cutting-edge technologies better at providing information to achieve efficiency, sustainability, or travel alternatives. Each innovation is in a different stage of evolution, and the early 21st century is proving to be a transformative time for these mobility innovations. With numerous innovations on the horizon, the pace of transportation change is likely to accelerate, but continued research will be needed to better understand its implications.

The existing data from National Household Travel Survey (NHTS) can now be utilized to its full potential using advanced methods of data analytics and modeling. In New York City, the 2007/2008 GPS Pilot Project examined whether incorporating Global Positioning Systems (GPS) technologies into the NYMTC Household Travel Survey efforts provided a cost-effective person-based strategy for collecting both passive and active travel behavior data. It was found that by doing this, they could build more robust demand forecasting models because they had additional time-stamped location data as dependent variables for predicting demand. Several Bayesian statistics models are also being developed by consulting firms and government agencies alike, to tap the huge potential of existing data sources.

Finally, research methodologies and datasets are also adapting to changing technology. Real-time GPS data, though often cumbersome to manage, is allowing researchers to gather and analyze accurate, revealed travel choices. These new data sources are opening new opportunities for the measurement and understanding of travel behavior. As these data sources proliferate, it is expected that new methodologies, which can better harness them, will be developed. However, future research will be needed to overcome existing institutional and technological barriers, such as data sharing, cybersecurity, and privacy. From this perspective, there are still many necessary advances to aid the acquisition and application of new data sources and methodologies that will enable a more complete understanding of travel behavior.

CHAPTER 7.0. KEY FINDINGS AND HIGHLIGHTS

The results of this research scan have yielded a number of insights and conclusions related to the state of travel behavior understanding. Furthermore, the scan also permits the identification of information gaps that can be covered through the application of new data sources that have emerged with information technology advancements. Below, some key information gaps are identified within common measures of transportation.

Vehicle Miles Traveled (VMT)

VMT is currently tracked through an estimation derived from HPMS reports and variations in counts from highway detectors. VMT is one of the most comprehensive measurements we have on travel activity. Yet, it does not capture all activity, and does suffer from some measurement and estimation errors.

Person Miles Traveled (PMT)

PMT is currently measured mostly through surveys such as the NHTS and regional travel surveys. These surveys provide important insights into travel across modes. PMT measurements are snapshots of activity and are infrequently measured due to the large effort required. PMT measurements are also subject to self-reported distance, which includes its own source of bias and measurement error.

Mode Share

Related to gaps in PMT, information on mode share is derived from the NHTS, regional travel surveys, and the ACS journey to work data. The journey to work data provides the most frequent measurement of mode splits across the country. Better understanding of overall changes in mode share is needed on more frequent time intervals and at better spatial resolution. This includes better data on public transit use, bicycling, walking, and other modes, for trips outside of just the commute. For example, trip counts and miles traveled for walking and bicycling are difficult to estimate and infrequently computed.

Telecommuting

Telecommuting is a challenging mode to define and to measure. Yet it is becoming an exceedingly important mode. Better measurement of the share of telecommuting (avoided commuting) is needed. Consistent definitions of telecommuting are also required for improved evaluation and measurement of telecommuting activity.

Trip Purpose (Work v. Non-work)

Similar to the gaps in PMT and mode share, trip purpose is an infrequently measured data point for travel. This data is currently supplied by surveys, and it is difficult to understand evolving distinctions between work and non-work travel, including distinctions in mode share, distance, time of day, discretionary nature, and other attributes on a timely basis. Better spatial and temporal information on trip purpose is needed.

Demographics and Travel Metrics

The association of demographic distributions with data related to other measurements of travel (mode split, VMT, PMT) is limited, and only supplied by NHTS and other regional travel surveys.

Attitudes & Public Perceptions

Attitudes towards mobility have shifted across generations, which impacts the choices made by travelers in different situations. There is limited information on how those attitudes change and limited abilities to forecast attitude changes

Vehicle Occupancy

Vehicle occupancy data is difficult to obtain, yet is critical for better HOV enforcement and better understanding of the impacts of ridesharing services. The ability to identify real-time vehicle occupancy and measure historical vehicle occupancy would be very useful.

From these insights and gap identification, there are several recommendations that can be made for future research towards addressing gaps in understanding travel behavior. These recommendations are outlined below.

Emerging Modes

- Telework is rapidly growing. Yet, telework has remained difficult to measure and understand from the perspective of supportive policies and impacts.
- Improvements are necessary in the study of emerging alternatives to non-work travel (e.g., e-commerce, telemedicine) and innovative business models (e.g., courier network services) to determine their impacts on travel behavior.
- Autonomous vehicles are certain to have profound impact on travel behavior in ways that could be both positive and negative. Research is needed to better determine the projected impacts of AVs on travel behavior, public policy, and linkages to shared mobility.
- Improved research is needed to understand the impacts and dynamics of shared-use mobility modes, including carsharing, bikesharing, and ridesourcing. Research supportive of understanding shared-use mobility can better advance effective policies maximizing and directing their benefits to all populations.

Survey Data Augmentation

- National travel surveys such as the NHTS have played a critical role in our understanding of travel behavior. With the support of technology, advances in survey design could permit new methods to increase the frequency and breadth of data collection and facilitate a more continuous measurement of challenging metrics such as PMT. This could involve the development of “ACS for the NHTS,” a national survey conducted more frequently with a subset of the U.S. population, drawing data from ongoing state and local travel surveys.
- Due to the increasing representation of foreign-born citizens in the U.S. population, survey methods should better engage these populations to maintain an understanding of the travel behavior of immigrants and other growing demographic segments.

Methods and Data

- Leverage smartphone and GPS technology to capture PMT data to supplement traditional travel diaries.
- Evaluate methods to better collect, manage, and store real-time data on various scales (local, regional, national) for future analyses of travel behavior.
- Facilitate the leverage and application of advanced data sources to better measure vehicle occupancy, VMT, PMT, mode shares (walking, bicycling, public transit, etc.), and telecommuting.
- Improve surveys to more comprehensively understand distributions in trip purpose and forecast changing attitudes and public perceptions of travel modes (such as attitude shifts towards the personal automobile).

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