Strategic Issues Facing Transportation, Volume 6: The Effects of Socio-Demographics on Future Travel Demand

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AUTHORS

Zmud, Johanna P.; Barabba, Vincent P.; Bradley, Mark; Kuzmyak, J. Richard; Zmud, Mia; and Orrell, David

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 750

Strategic Issues Facing Transportation

Volume 6: The Effects of Socio-Demographics on Future Travel Demand

Johanna P. Zmud
RAND Corporation
Arlington, VA

Vincent P. Barabba
Capitola, CA

Mark Bradley
Resource Systems Group, Inc.
Santa Barbara, CA

J. Richard Kuzmyak
Renaissance Planning Group
Arlington, VA

Mia Zmud
Metropia
Austin, TX

David Orrell
Systems Forecasting
Toronto, ON

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FOREWORD

By Christopher J. Hedges
Staff Officer
Transportation Research Board

This report presents the results of research on how socio-demographic changes over the next 30 to 50 years will impact travel demand at the regional level. It is accompanied by a software tool, *Impacts 2050*, to support transportation agencies in their long-term planning activities to enhance decision making. This report will help transportation decision makers understand how the population may change over time, how socio-demographic changes will affect the ways people travel, and the kinds of transportation modes and infrastructure that will be needed.

Major trends affecting the future of the United States and the world will dramatically reshape transportation priorities and needs. The American Association of State Highway and Transportation Officials established the NCHRP Project 20-83 research series to examine global and domestic long-range strategic issues and their implications for departments of transportation (DOTs) to help prepare the DOTs for the challenges and benefits created by these trends. *NCHRP Report 750: Strategic Issues Facing Transportation, Volume 6: The Effects of Socio-Demographics on Future Travel Demand* is the sixth report in this series.

The profile of America is expected to change substantially over the next 40 years. According to the U.S. Census Bureau, current trends suggest that the U.S. population is anticipated to increase to 438 million by 2050, more than a 40% increase from the 2008 population of 304 million. This population will be more ethnically diverse; a significant percentage of the projected population increase is attributed to immigration. The population also will be substantially older; it is estimated that more than 20% of the U.S. population will be 65 years or older by 2050, compared to 12.6% currently. The sizeable increase in population will create the need for more housing, employment, and services, which may lead to substantial impacts on travel patterns and demands. It has been estimated that the majority of the U.S. population will live in mega-regions, with more than 80% of the population in metropolitan, urban, and suburban areas. Baby Boomers are expected to choose a “soft retirement” and continue to work part-time beyond retirement age. Young people coming out of full-time education may increasingly choose to enter what they consider temporary, short-term jobs, which they use to finance international travel, volunteering in nonprofit or arts-related careers, and/or continued education. Changes in family structure, participation of women in the labor market, incomes, lifestyles, and social expectations may also occur.

Under NCHRP 20-83(06) a research team led by the RAND Corporation looked at how socio-demographic issues over the next 30 to 50 years are likely to change the population’s transportation needs, travel patterns, and expectations regarding mobility.

The research approach involved identifying a number of plausible future scenarios and development of a systems dynamic model that simulates the demographic evolution of a regional population starting from a baseline of the 2000 census and spanning a period of 50 years. The four future scenarios were developed using a Strategic Assumptions Surfacing and Testing (SAST) technique and include the following: (1) Momentum: gradual change without radical shifts; (2) Technology Triumphs: technology solves many present-day problems; (3) Global Chaos: a collapse in globalism and sustainability, and (4) Gentle Footprint: a widespread shift to low-impact living. The model does not predict which scenario is most likely; instead it predicts how travel demand will change under each of the five sectors: socio-demographics, travel behavior, land use, employment, and transportation supply. The *Impacts 2050* tool enables modeling of changes in these sectors due to socio-demographic changes, the interplay between sectors, and external factors such as attitudes and technology.

The accompanying CD contains *Impacts 2050*, the user's guide, a PowerPoint presentation about the research, and the research brief.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

CHAPTER 1

Introduction

1.1 Research Overview and Objectives

***Impacts 2050* Research Products**

- Research Brief
- *Impacts 2050* Tool
- User Guide
- PowerPoint Presentation

It would not be shocking to anyone that the United States in 2050 will look much different from how it looks today. But what is remarkable is how much different the United States will be compared with rival nations in Europe and Asia. According to the most conservative estimates, the current U.S. population will increase by roughly 100 million by 2050. The vast majority of this growth will be in racial minorities, particularly Asians, Hispanics, and mixed races. In comparison, other advanced countries are projected to actually experience population declines. While the elderly will dominate in many countries, America's population of working-age and young people is expected to continue to grow, so that in 2050 only about one-quarter of the U.S. population will be older than 60 compared with nearly 40 percent in Europe.

Together with shifting energy resource conditions and accelerating technology innovations in vehicles and infrastructure, the structure and social characteristics of the U.S. population will be among the principal factors dictating virtually everything relating to or affecting transportation in the coming decades. In addition to broad consequences (e.g., demand, the nature and use of supply, investment decisions for new infrastructure, planning and forecasting, and all levels of policy development and policy decisions), there will be personal consequences. How will people travel? Where will they choose to live? Where will they work? How will they access the goods, services, people, and information that make for a meaningful life?

It is almost inevitable that the socio-demographics of a society as diverse as the United States will shift over the next 30 to 50 years. How socio-demographics will affect travel behavior in the long term is uncertain. In the face of this uncertainty, a key challenge for transportation decision makers is to understand how the population may change over time, and how socio-demographic changes will affect the ways people travel and the kinds of transportation modes and infrastructure that will be needed.

This type of understanding is essential to prepare for and conduct strategic long-range planning. State departments of transportation (DOTs) and metropolitan planning organizations (MPOs) are required by law to produce a long-range plan, for up to 20 years into the future with an update every four years, as a condition of receiving federal funding. While the production of a specific plan is an important output of this process, the most beneficial outcomes are the policies and strategies that attempt to balance current needs with making responsible, cost-effective, and sustainable long-term decisions. The activities related to long-range planning are continuous and involve a variety of calculations that often stretch the capabilities of the organization. A key challenge is that state DOTs and MPOs often are not in control of the factors that define the assumptions that go into the long-range plans. Such assumptions often focus on socio-demographic factors, and the way socio-demographic trends may play out in the future is uncertain. Uncertainty exists in the inputs, in model relationships, and in the variety of relationships that could be important. Thus, the resulting plans too often are reactive to current transportation challenges, instead of being proactive in adapting to future uncertainties. The research team believes this is caused by a critical gap in the existing suite of analytical tools used in the long-range planning process.

This study addresses future uncertainty by providing transportation planners and decision makers with an increased awareness of how socio-demographic trends may affect long-range transportation conditions or needs. Additionally, recognizing the limitations of traditional planning models, the research team developed a tool to support transportation agencies in their long-term planning activities to enhance decision making.

The tool, *Impacts 2050*, incorporates two elements: scenarios representing visions of possible futures and a system dynamics model for investigating many different plausible futures. *Impacts 2050* was designed to enable users to examine the relationship between socio-demographics and travel demand in yearly increments through 2050. It enables dynamic scenario analysis. The resulting information will enable users to account for these trends in plans and forecasts and to examine policies or other interventions that may offset these trends. An agency may in some cases wish to offset trends and in other cases enhance trends.

Using *Impacts 2050* requires a change in strategic thinking, in which the output of the forecast is a less important ingredient to a long-range plan than is the process of interacting with the model to produce many different scenarios. What becomes important in this environment is asking the right questions, and thus, supporting a change in the way transportation agencies perform long-term planning.

1.2 Organization of the Report

This report is organized as follows:

Chapter 2 discusses the uncertainties that are inherent in the transportation planning process, and introduces *Impacts 2050* as a tool to improve a transportation agency's ability to handle uncertainties and make more informed decisions.

Chapter 3 summarizes eight socio-demographic trends that transportation agencies are already facing that will impact travel demand over the next 30 to 50 years, and that served as the basis for developing a scenario framework.

Chapter 4 discusses the rationale for the joint scenario/modeling approach applied in this research project. It introduces two key elements: scenario planning and system dynamic models.

Chapter 5 details the process by which four scenarios that describe plausible socio-demographic futures were developed. It briefly summarizes the four scenarios, and Appendix A provides detailed scenario descriptions.

Chapter 6 describes a new management and decision support tool, *Impacts 2050.* Information is presented on the structure of the system dynamics model that powers the tool. Detailed documentation on the model structure can be found in Appendix B and also in the User's Guide that accompanies *Impacts 2050.* This chapter also presents and discusses model output across the four scenarios for the five regions that served as test sites for the tool's development. Detailed statistical output is provided in Appendix C.

Chapter 7 presents an approach for identifying and monitoring leading indicators, or early warning signs, that can help in preparing for change. Driving forces in the scenarios are identified and used to select leading indicators. A spreadsheet that served as a tool for identifying driving forces in the scenarios is presented in Appendix E.

Chapter 8 provides an assessment of how *Impacts 2050* may be used by state DOTs, MPOs, and other transportation agencies to assist in their long-range planning processes. It provides a set of recommendations on the strategic responses agencies may take to best cope with the types of uncertainty depicted by the scenarios.

Chapter 9 concludes with several broad observations drawn from each chapter of the report that support and highlight the fact that to effectively deal with the uncertain future in long-term planning, transportation decision makers must make a paradigm shift from planning strategically to thinking strategically. In addition, this chapter includes recommendations from the research team on next steps for enhancing the management and decision support tool *Impacts 2050.*

CHAPTER 2

Long-Range Planning in an Uncertain World

Chapter 2 Takeaways

- Model predictions become less accurate over long time scales.
- Model usefulness does not necessarily increase with complexity.
- Scenarios are a well-researched way of handling uncertainty.
- System dynamics models can be used to realistically illustrate different scenarios.

"For all of its uncertainty
We cannot flee the future."

Barbara Jordan, former member,
U.S. House of Representatives

An aim of this study was to help policy makers and planners in state and local transportation agencies gain an improved understanding of the fundamental relationships between social and demographic factors and travel demand, and how these relationships may change over the next 30 to 50 years. Such information is critical, because it is a basic element in the formulation of long-range transportation plans.

Long-range transportation plans, with horizons of 15 years or greater, are an important part of defining a vision for the future and of establishing strategic transportation investment and system operations directions for a metropolitan area. These plans are often viewed as a process for enabling decision makers to evaluate the strengths and weaknesses of various transportation alternatives.

Decisions regarding future actions are based on implicit and explicit assumptions about the future state of the area in which the decisions will be implemented—for example, how the population in a region may change over time, how socio-demographic changes will affect how or where people will travel, and what kinds of transportation modes and infrastructure will be needed. Thus, transportation planners often are asked to predict socio-demographic trends that will affect future demand for transportation infrastructure. The greater the degree of uncertainty associated with these trends, the more problematic the resulting decisions will be.

2.1 Uncertainty in Forecasts

Long-range transportation planning necessarily depends on uncertain forecasts. These forecasts are generated from travel demand forecast models. Modeling and forecasting are related, but distinct, activities: modeling is about building and applying tools that are sensitive to the policies of interest and respond logically to change, while forecasting is an attempt to envision future conditions. In the current context, it usually involves predicting future travel demand and the resulting multimodal flows or changes in land-use patterns over time. The difference often becomes blurred because there is a tendency to think of anything that comes out of a numerical model as being a hard prediction. But in reality, as a model is run farther into the future, precision in data and forecasts becomes more challenging.

Transportation travel demand models have evolved in recent years from four-step models, which average transport behavior over zones, to more sophisticated agent-based models based on representations of actual populations. Therefore, the unit of analysis is shifted from rough aggregates to the level of the individual traveler. This development makes it possible for modelers to incorporate detailed demographic data. Models can also reproduce nonlinear, dynamic feedbacks, leading to effects, such as congestion.

One manifestation of this important distinction between modeling and forecasting can be seen in model complexity. From a pure modeling perspective, a model is often only considered to be realistic or complete if it incorporates all the necessary data, causative factors, etc., that may be considered to be relevant. The natural result of this process is that models become very detailed and complicated, and accumulate a large number of parameters that cannot be accurately measured from the available data. These are unrealistic desires to have one model that includes all available data to address all questions. The end result is the more data, causative factors, and assumptions that are placed into the model to ensure completeness, the greater the chances are that the added items may not be correct and may actually contribute to arriving at the wrong answer. As complexity increases, models also often become unstable and must be carefully tuned to give reasonable results. They therefore become poor at making predictions, or adapting to different scenarios.

For this reason, the models favored by people who receive regular feedback on their predictions, such as those who work in business forecasting, tend to be quite simple. A detailed survey of forecasting models showed that—perhaps counter-intuitively—the simpler models consistently outperform more complicated models (Makridakis and Hibon 2000). This does not imply that agent-based models are inferior to aggregate models; the latter can be extremely complicated (as with large models of the economy), while agent-based models can be constructed to be quite parsimonious in terms of parameters (see, for example, Orrell and Fernandez 2010). But it is important to bear in mind that advances in modeling, and the creation of more elaborate and apparently realistic simulations, may not translate into advances in forecast accuracy, especially for long-range forecasts.

2.2 Accuracy of Travel Demand Forecasts

Forecasting is by definition a forward-looking activity, but it is useful to also compare how past forecasts have compared with reality. This gives an idea of the nature and magnitude of expected forecast errors. Unsurprisingly, most such data are for forecasts over shorter time periods than that applies here. A summary of studies of travel demand forecast error is given in Parthasarathi and Levinson (2010). The largest available study of project-specific models, by Næss et al. (2006), presents results for more than 210 projects in 14 countries. It found large discrepancies between passenger forecasts and measured results. For rail projects, passenger numbers were overestimated in 90 percent of cases, with an average overestimation of 106 percent. Forecasts were more accurate for road projects, but half had a difference between actual and forecast traffic of more than ±20 percent and, in a quarter of cases, the difference was more than ±40 percent.

Næss et al. (2006) also found that forecast accuracy has not improved with time, or with more advanced models or computer power. In fact,

> Road vehicle forecasts even appear to have become more inaccurate over time with large underestimations towards the end of the 30-year period studied. If techniques and skills for arriving at accurate traffic forecasts have improved over time, this does not show in the data.

While these results are for individual projects over relatively short time frames, there is no reason to suppose that predictions will become more accurate over larger regions or longer time frames. Predictions usually deteriorate with time because of unforeseen effects.

The forecast error is due to a number of factors. For rail projects, it seems that politics is important—passenger demand is overestimated because stakeholders, who want the project to go ahead, favor optimistic forecasts over pessimistic ones (see also Flyvbjerg et al. 2009). Road projects do not show the same systematic bias, so the error is more likely due to model limitations, such as inaccurate estimates of trip generation (based on incomplete data) and land-use development (based on uncertain plans and projections).

Parthasarathi and Levinson (2010) interviewed modelers responsible for making travel forecasts in the Minnesota region. They found that the problem most frequently cited is, "the inability of the model to understand and predict fundamental societal changes," such as increased female participation in the workforce. The locational distribution of forecast demographics was also a source of error. Predictions made in the 1970s for 1990s traffic did not anticipate such changes as a 40 percent increase in home-based work trip lengths, a 43 percent increase in per capita trips, a 39 percent increase in female labor force participation, highlighting the importance of demographics. The tendency to maintain assumptions based on past trends, even after they have lost their validity, has been called "assumption drag."

As another example, Næss et al. (2006) note that the energy crises of 1973 and 1979 led to an abrupt, but temporary, decline in road traffic in Denmark.

> Danish traffic forecasters adjusted and calibrated their models accordingly on the assumption that they were witnessing an enduring trend. The assumption was mistaken. When, during the 1980s, the effects of the two oil crises and related policy measures tapered off, traffic boomed again, rendering forecasts made on 1970s' assumptions highly inaccurate.

To tie this discussion back to long-range planning, forecasting's primary purpose is to generate information useful to decision makers for the specific types of decisions they are facing. The decisions are influenced by the degree of uncertainty associated with forecasts about the future. How many people will live in a region; in what types of households will they reside and by what modes will they travel; what will be the price of fuel; what are the rates of adoption of autonomous, self-driving vehicles? Good decisions (and good policies) should be robust across a wide range of socio-demographic futures. Therefore, to aid with this process, models should be viewed as tools for exploring scenarios, rather than providers of hard predictions, and should be designed to be flexible enough to explore scenarios, while avoiding (as much as possible) traps such as assumption drag. Models may have a poor track record at making precise numerical forecasts of the evolution of complex systems, such as the transportation network, but they are still invaluable for thinking about the future and comparing different possible outcomes (Orrell and Fernandez 2010).

2.3 Handling Uncertainty

A goal of this study was to provide transportation planners and decision makers with an increased awareness of socio-demographic trends and how these may impact long-range transportation conditions or needs. With knowledge of the limitations of models to produce accurate long-range forecasts, the research team focused on developing a tool (*Impacts 2050*) that would help transportation planners and decision makers apply a scenario approach for handling uncertainty. Miller (2004) advocated for scenario planning as a method for addressing uncertainty in transportation forecasts:

> Scenario planning expands upon traditional planning techniques by focusing on major forces or drivers that have the potential to affect the future. By developing scenarios to tell a story of the future, planners are better able to recognize these forces and determine what planning activities can be done today and can be adapted in the future.

The FHWA's web site promotes scenario planning as an analytical tool.

With the tool developed in this study, users should gain an overall understanding of how trends affect future travel demand; be in a position to test and account for these trends in projects, plans, and forecasts; and examine policy or other interventions that may offset or enhance these trends. The tool incorporates two elements: (1) scenarios representing visions of possible futures, considering basic demographic trends, globalization and immigration policy, economic growth, technology advances, transport funding, shifting social attitudes, etc.; and (2) a system dynamics model that represents regional links between population, land use, employment, transport supply, and travel behavior. With both elements, the objective is to provide a mechanism for dealing with uncertainty.

The scenarios were developed to recognize a range of future outcomes, beyond what traditional planning can create. The research team used four scenarios, not to cover up its inability to predict the future, but to help policy makers and planners think about the range of possibilities. The scenarios are multi-layered and complex, and are fundamentally distinct from each other. Titled Momentum, Technology Triumphs, Global Chaos, and Gentle Footprint, the scenarios are discussed in detail later in this report.

The purpose of the system dynamics (SD) model is not so much to predict long-term travel behavior (since there is no evidence that models can perform this task), but to realistically illustrate the different scenarios and provide a higher level of insight and understanding to policy makers and other interested parties. Using the model to gain a deeper understanding of the interaction of the elements of the decision has the possibility of helping planners generate scenarios that provide the most value in considering possible futures.

The SD model segments a region's population by age, household structure, income, race/ethnicity, acculturation, residence location area type, and work status. The model then "evolves" this population over time, simulating the population's transitions from one category in each of these segments to another category over time (e.g., aging the population into different categories: 0–15, 16–29, 30–44, 45–59, 60–74, 75 and older). The evolution of the population over time affects travel behavior. The impacts on travel behavior are indicated in terms of car ownership, trip rates and distance, and mode choice. Land use, employment, and transport supply sectors are present in the model in minimal detail, which enables the incorporation of feedback loops that represent the dynamics of the transportation system.

Neither the use of the SD model in long-range planning nor the application of scenario planning is new. What is new is the integration of both in a single tool that can aid long-range planning.

2.4 Improved Long-Range Transportation Planning

The challenge for policy makers and planners is to make effective use of the tool and the new information that it will provide to actually improve decisions. This entails interacting with the tool itself, not just the outputs of the tool. According to Barabba (2011), no important decisions should ever be based solely on the results of a quantitative model. After extensive experience with models at the U.S. Bureau of the Census, Xerox, Kodak, and General Motors Corporation, he formulated Barabba's Law: "never say, the model says." The intent of the law was to remind modelers and decision makers that people make decisions. Models should not.

So, why should transportation agencies go through all the trouble of using this new tool, based on a complicated SD model, to explore emerging trends and create possible futures? The reason is simple—to increase the chance of making better decisions, such as:

- Supporting long-range plan development.
- Supplementing the capabilities of existing planning models.
- Formalizing the consideration of uncertainty in the planning process.

- Facilitating participation in the planning and decision-making processes.
- Serving as a sketch-planning tool for providing quick and timely answers, as well as supporting sensitivity and exploratory analysis.
- Serving as a "utility" program for providing data inputs to models and the planning process.

With all the uncertainty about the future, one thing is certain: the future will be very different from the present. If policy makers or planners get stuck in the present, let alone being stuck in the past, they will not be able to accommodate future trends. With all the uncertainty, the future reality is better understood by exploring multiple plausible future scenarios than by studying the present. As an example of this, when we were developing the Technology Triumphs scenario, we listed that sometime in the distant future society would see autonomous vehicles. So now, only two years later and Google has autonomous vehicles actually being tested on the street. Also several other "traditional" manufacturers have recently announced their intent to develop versions of these vehicles as well.

The art of scenario planning lies in blending the known and the unknown into a limited number of internally consistent views of the future that span a very wide range of possibilities. This study blended what was known about current socio-demographic trends with the possible evolution of these trends to examine the influence on people's future travel behavior in the future. In doing so, four possibilities for how this might unfold were constructed. The study team took a systems approach by speculating on how socio-demographics and travel behavior would interact with land use, employment, and transportation supply sectors to generate future scenarios. The outcome of this effort was the identification of key socio-demographic drivers related to population size and growth; population structure and composition; cultural and social diversity; household-based economic activity, geo-demographics, attitudes, and technology use; and incorporation of assumptions about these into the tool. A final focus was on impacts in terms of passenger travel and on travel by auto, transit, and nonmotorized modes.

The next chapter summarizes eight socio-demographic trends that transportation agencies are already facing that will impact travel demand over the next 30 to 50 years. These trends have been drawn both from the team's experience and expertise in this area of study and from a review of literature. They are important to this study, as they formed the conceptual framework for the development of the four scenarios and the structure of the SD model.

CHAPTER 3

Key Trends, Drivers, and Projected Impact on Travel Behavior

Starting just after World War II, the number of miles driven annually on America's roads steadily increased. The rising numbers were related to societal shifts, such as women joining the workforce, families moving to the suburbs, and the greater affordability of more cars for more people.

As indicated in Figure 3-1, vehicle miles traveled (VMT) per capita tracked growth in gross domestic product (GDP) per capita from the 1930s to the 1960s. After that, VMT per capita grew at a higher rate than GDP per capita until around 2007. Then, Americans started driving less. The question is, why? Certainly, high gasoline prices or the cost of driving could have been factors. In 2007, gasoline prices reached the highest level since the 1981 oil shock (Money CNN 2007). According to a 2013 auto club AAA report, on average, the cost of driving 15,000 miles a year rose 1.2 cents per mile in 2012, with increases in fuel, tires, financing, license, registration, and taxes (AAA 2013).

Sivak (2013a) analyzed FHWA and Census data from 1984 to 2011 to ask and answer the question, "Has motorization in the U.S. peaked?" His research, which examined the total VMT of light-duty vehicles [cars, pickup trucks, sport utility vehicles (SUVs), and vans] from 1984 to 2011, found that total VMT peaked in 2006 at 2.8 trillion miles. In 2011 (the latest year for which data are available), the number was 2.6 trillion miles (a 5 percent reduction from 2006). Sivak noted decreases in VMT per licensed driver, per household, and per registered light-duty vehicle as well. Part of the answer lies in the economic recession, which has had a very slow recovery time. But since these rates peaked before the onset of the recession (prior to 2008), Sivak concluded that they reflect other societal changes that influence the need for vehicles. It is clear that VMT per capita is declining, but it is not evident what will happen or why it will happen in the future with a full economic recovery. Given numerous changes occurring in population, demographics, and travel patterns, this situation illustrates the fact that the future is difficult to predict and is shaped by many interacting factors (Curtis and Perkins 2006; Polzin 2006; Guequierre 2003; Polat 2012).

Chapter 3 Takeaways

8 Socio-demographic Trends Associated with Travel Demand

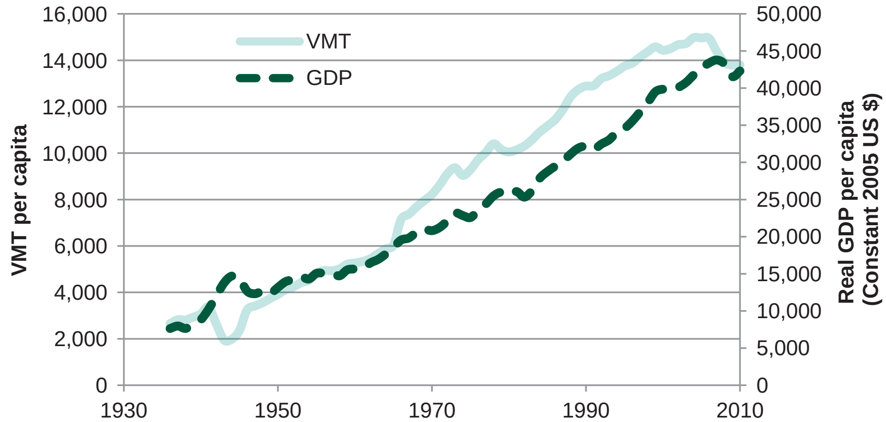
- Trend 1: The next 100 million
- Trend 2: The graying of America
- Trend 3: The browning of America
- Trend 4: The changing American workforce
- Trend 5: The blurring of city and suburb
- Trend 6: Slow growth in households
- Trend 7: The Generation C
- Trend 8: The salience of environmental concerns

"We have to face the growing reality that today young people don't seem to be as interested in cars as previous generations."

Jim Lentz, Toyota President
Author

3.1 Eight Socio-Demographic Trends

The following sections discuss eight key trends (past and future) associated with the socio-demographic variables that contribute to the impact on U.S. travel demand and various aspects of travel behavior (e.g., VMT, car ownership, mode choice, and trip rates). Those variables



Sources: VMT data from FHWA 2012a; GDP data from BEA 2013.

Figure 3-1. Trends in VMT and GDP—1930 to 2010.

include age, household structure, acculturation, race/ethnicity, household income, workforce participation, and residential location. In addition, in selecting these trends, the study team focused on several external factors that are intertwined with socio-demographics, such as changes in vehicle and information technologies and cultural shifts in attitudes toward sustainability or environmental consciousness.

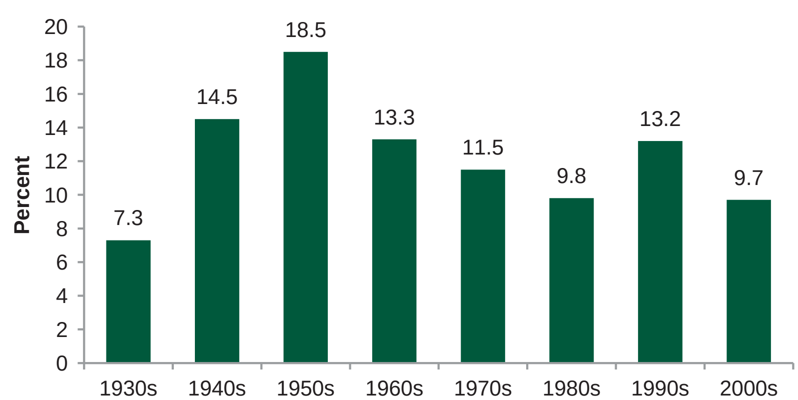
It is important to note that demographic trends will vary substantially by region of the country. A review of national socio-demographic trends is provided here.

Trend 1: The Next 100 Million

The United States is growing more slowly.

- **Drivers**: Population growing but aging, declining fertility rates among white women, extended life span, and less immigration.
- **Impact on Travel Demand**: Overall increase in total VMT due to population growth; VMT per capita appears to be declining.

The 2000s marked the lowest decennial rate of population growth since the Depression (see Figure 3-2). Between 2000 and 2010, the U.S. population grew by 27.3 million (about 10 percent),



Source: Brookings Institution 2010.

Figure 3-2. Population growth by decade, 1930s–2000s.

which was smaller than the growth from the decade before (1990 to 2000), both in absolute terms and as a percentage of initial population. The decrease from the 13 percent growth in the 1990s reflects slower U.S. economic growth, reduced immigration, declining fertility rates among white women, and aging Baby Boomers. Whether this decade-long trend in slowing population growth represents a long-term change will be influenced by the extent to which the relevant societal changes become permanent.

Net change in the U.S. population results from adding births, subtracting deaths, adding people who migrated to the United States, and subtracting people who left. Based on these factors, the U.S. Census Bureau projects that the U.S. population will grow over the next four decades (2010–2050) from 310 million to just over 400 million by 2051 (Census 2013). Based on trends from the last four decades (1970–2010), it is estimated that the majority of the population growth (to 2050) will be due to immigrants and their descendants. During these past decades, the U.S. population increased by 52 percent, from about 203 million to 310 million (Hobbs and Stoops 2002). Much of this growth—32.7 million people—occurred during the 1990s. This was the largest numerical increase of any decade in U.S. history, although the growth varied geographically, with large population increases in some areas of the country and little growth or decline in others. The 1990s population growth was largely immigration-driven. The previous record increase was in the 1950s, a gain fueled primarily by the post-World War II Baby Boom.

Total population growth is also due to a decline in U.S. mortality. One measure of mortality levels, independent of population age structure, is life expectancy at birth. Life expectancy has increased at a steady rate, with occasional one-year declines, over the past 35 years. There is a lack of consensus as to whether life expectancy will continue to increase, or is approaching some biologically fixed limit (Sonnega 2006). Increasing life expectancy at birth (and thus decreasing mortality rates) clearly leads to increases in the total population, all else being equal.

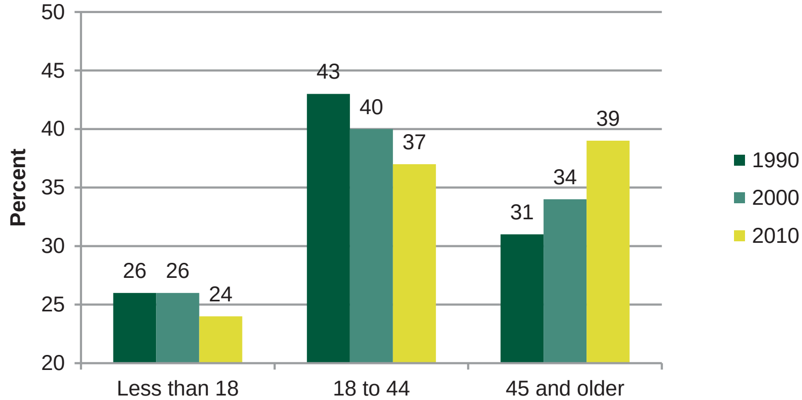
Also, it is important to note that America's population is growing at a faster rate than the rest of the world's developed nations. An article in *The Economist* postulated that by 2040, and possibly earlier, America will overtake Europe in population. According to past trends, any population growth should stimulate an increase in total U.S. VMT (*Economist* 2002).

Trend 2: The Graying of America

America is becoming "grayer." The population age 65 and older will significantly increase as the Baby Boom generation enters this demographic group.

- **Drivers**: Population aging, extended life spans, "boom-and-bust" birth rate patterns.
- **Impact on Travel Demand**: Decreased per capita VMT, decreased work trips, increased vehicle age, decreased auto ownership, increased carpooling, decreased transit use.

Population aging is evident in the increasing share of the population in the older age categories as the Baby Boom generation becomes older (see Figure 3-3). The large Baby Boom cohort is just now reaching age 65. The oldest members of the generation, born between 1946 and 1964, entered seniorhood at the end of the 2000s, as the youngest members crossed fully into middle age (Passel and Cohn 2008). As the Boomers age, the percentage of Americans who are age 65+ is estimated to nearly double from one of every 8 Americans in 2000 to more than one of every 5 in 2050. Their growing numbers, whose households are smaller on average than adults under 65, has tended to add to a decreasing overall size of households over the past several decades (discussed later in this chapter).



Source: Brownell et al. 2013.

Figure 3-3. Percentage of U.S. population by age group, 1990–2010.

When talking about the aging of the U.S. population, it makes sense to discuss this in terms of the succession of accepted generations, demarcated by historical circumstances. The United States has experienced a generational boom-and-bust birthrate pattern, as described below:

- Depression Babies—Born 1930–1945 and age 65–80 in 2010. Their numbers are small due to low birth rates in a poor economy.
- Baby Boomers—Born 1946–1965 and age 45–64 in 2010. Their numbers are large, and their entry into any age group had a major impact on that group's growth.
- Generation X/Baby Bust—Born 1966–1980 and age 30–44 in 2010. Their numbers are small, being an "echo" of the Depression era generation.
- Generation Y/Millennials—Born 1981–1995 and age 15–29 in 2010. As the children of the Baby Boom generation, their numbers are relatively large. This generation is much more racially and ethnically diverse and will become more so, as immigrants gradually increase the number of young adults in the United States.

During the last several decades, Baby Boomers, most of whom are non-Hispanic white, have dominated the U.S. population. But as Baby Boomers reach old age, their dominance is being replaced by another younger cohort (Millennials) that is much more likely to be Hispanic, Asian, or multiracial (Jacobsen et al. 2011). The rapid increase in diversity among younger cohorts may be creating a new kind of generation gap. Although historically the generation gap has been defined by different cultural tastes in music, fashion, or technology, this new demographic divide may have broader implications for transportation-related planning and policy making, as is discussed later in this chapter.

Age plays a significant role in patterns of vehicle use. Traditionally, it was well established that VMT levels change with age and were at their highest for middle-age adults who are in peak levels of both work-related and household-serving travel. For the Depression era generation, there is also decreasing capability to drive. For Baby Boomers, there is less work travel as they enter retirement. At the same time, Sivak and Schoettle (2011) found substantial increases from 1983 to 2008 in the percentage of older people with a driver's license. For people age 65–69, the portion increased from 79 percent in 1983 to 92 percent in 2008, and for people age 70+, it increased from 55 percent in 1983 to 80 percent in 2008. While younger people appear to be delaying licensing as discussed later in this chapter, older people are retaining their licenses and continuing to drive (Stokes 2012). Still, per person, older people also tend to drive less, so VMT per capita will be less.

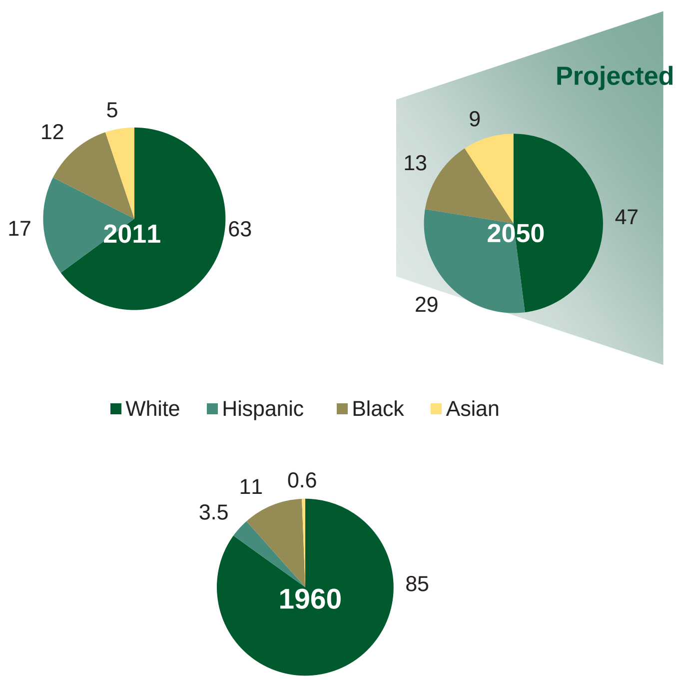
It is also clear in recent cross-sectional data sets at the regional level that the percentage of trips people make by nonauto modes (transit, walk, and bike) tends to decrease with age. This can be explained to some extent by the physical demands of biking, walking, and getting to and from bus stops becoming more difficult with age. However, the findings could also be explained by cohort effects, where older generations have gotten "out of the habit" of walking and biking, which they may have done more when they were younger. As an example, in a 2010 survey by KRC Research and Zipcar, participants were asked to what extent they agreed with the statement: "In the past year, I have consciously made an effort to reduce how much I drive, and instead take public transportation, bike/walk or carpool when possible (KRC 2010, Davis et al. 2012)." Only 24 percent of people age 55+ agreed with this statement, compared with 31 percent of those age 45–54, 41 percent of those age 35–44, and 45 percent of those age 18–34.

Trend 3: The Browning of America

America is becoming "browner." The white population has grown more slowly than every other race group in the second half of the 20th century.

- **Drivers**: Structural changes in population distribution by race/ethnicity, relatively high fertility rates among Hispanic women, continuing immigration in younger age groups.
- **Impact on Travel Demand**: Increase in VMT per capita, increase in auto age, greater public transit use.

White non-Hispanics accounted for a majority of the U.S. population in 2010, but their share has declined over time as the shares of other groups, particularly Hispanics and Asian/Pacific Islander populations, have grown significantly faster (see Figure 3-4). Immigration policy reforms in 1965, and more significantly in 1986, resulted in a wave of immigration between 1965 and 2000. As an example, the Hispanic population more than tripled from 1970 to 2000, from



Source: Census Bureau 2011 Population Estimates (Passel and Cohn 2008).

Figure 3-4. Population by race and ethnicity, actual and projected (% of total).

about 9 million to 35 million. Between 2000 and 2010, the total U.S. population grew by 27 million, the U.S. Hispanic population grew by 15.2 million—56 percent of the total in national growth (Arce 2011). In 2010, Hispanics numbered nearly 50 million and accounted for 16 percent of the U.S. population.

The U.S. population is bound to become more diverse over the next 30–50 years due to the demographics of America's children. Between 2000 and 2010, the number of children in the United States grew by less than 1.9 million. A closer look shows that the number of Hispanic children grew by 4.8 million, and the number of non-white, non-Hispanic children grew by just 1.4 million. Meanwhile, the number of non-Hispanic white children *shrank* by 4.3 million—creating the increase of less than 1.9 million children overall. Another way to look at this is that today 80 percent of Americans over the age of 65 are white non-Hispanic, and only 7 percent are Hispanic. In contrast, 55 percent of children under age 18 are white non-Hispanic, and 23 percent are Hispanic.

Although the Census Bureau expects Hispanic birth rates to drop in the coming years due to acculturation, their rates are currently higher than those of non-Hispanics of any race (2.7 compared with 1.83 for non-Hispanic blacks and 1.90 for non-Hispanics of other races) (Pendall et al. 2012). So even as Hispanic birth rates fall, Hispanics will constitute larger percentages of the national population, resulting in more total births, even if the rate is lower.

Based on such influences, the Census Bureau projects that the share of children who are Hispanic will rise from 23 percent today to 35 percent in 2050, which will have major implications for the Hispanic proportion of the total population (Arce 2011). In 2030, an estimated one of four (24 percent) Americans will be Hispanic; in 2050, three of ten (29 percent) will be Hispanic. Births, rather than immigration, will play a growing role in Hispanic and Asian population growth. As a result, in the future, a much smaller proportion of both groups will be foreign-born than now.

Current travel demand forecasting models rarely explicitly use input variables related to race, ethnicity, or acculturation level. Their effects are picked up indirectly though other variables, such as household income and geography. As a result, the influences of immigration and acculturation on travel behavior over time have received very little attention in the field of travel demand forecasting. Yet, because they could be very important considerations for the future, they are accounted for in the scenario analysis tool *Impacts 2050.*

The 2009 National Household Travel Survey (NHTS) data show that drivers and workers per household are significantly higher for U.S.-born Hispanics than for foreign-born Hispanics and non-Hispanics, indicating a greater propensity for trip making (FHWA 2012b). U.S.-born Hispanics also have more vehicles per household and own more newer vehicles compared with foreign-born Hispanics. Foreign-born Hispanics show a higher propensity for carpooling, walking, and transit due to a number of factors, including a lack of driver's license and the costs associated with owning a vehicle and driving (Liu and Painter 2012). As Hispanics become a larger portion of the total U.S. population and if the trends among Hispanic households continue, then the United States could experience increasing public transit use and aging of the vehicle fleet.

Trend 4: The Changing American Workforce

America's workforce is growing older, more female, and more diverse.

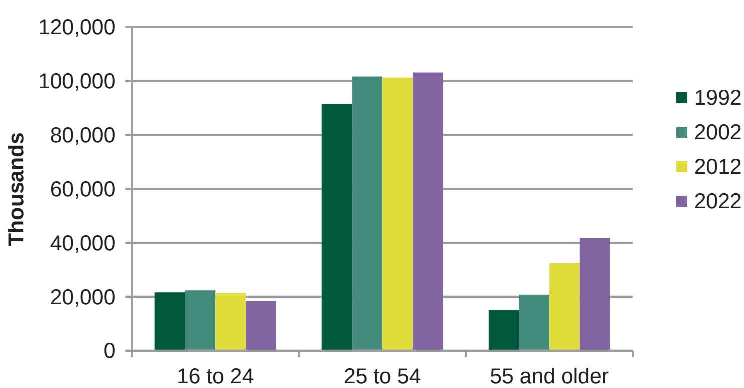
- **Drivers**: Boom-and-bust birth rate patterns, population aging, female work participation patterns, female longevity, structural changes in racial/ethnic distribution of labor force, immigration.
- **Impact on Travel Demand**: Decreased VMT per capita, increased work-related VMT, lower growth in work-related VMT, increased carpooling.

The overall size of the U.S. labor force has been increasing over time due to population growth and increased female participation in the labor force. Between 1980 and 2010, the proportion of women in the labor force increased from 52 percent to 59 percent of all women over age 16, while the proportion of men decreased from 77 percent to 71 percent of all men over age 16 (Hobbs and Stoops 2002).

The labor force is projected to increase by 10.5 million in the next decade, reaching 164 million in 2020 (Toossi 2012). This represents a slower rate of growth than previous decades, primarily the result of a slower rate of population growth since 2000 and a decrease in the labor force participation rate stemming from the 2007–2009 recession and its aftermath. The Bureau of Labor Statistics (BLS) bases its labor force projections on the civilian noninstitutional population (age 16 and older).

The population will continue to exhibit structural changes that will have significant impacts on the U.S. workforce (see Figure 3-5). For example, according to the BLS, the share of 16–24-year-olds in the workforce is declining—from 17 percent in 1992 to 16 percent in 2012 to a projected 14 percent in 2022. Even more significant declines are observed among 25–54-year-olds, who represent the prime age group for workers. This group's share of the civilian noninstitutional population dropped from 56 percent in 2002 to 51 percent in 2012, and is projected to drop further to 48 percent in 2022. This "baby bust" generation reflects the drop in birth rates that took place from 1965 to 1975. By contrast, the 55 and older age group increased its relative share in the civilian noninstitutional population from 26 percent in 1992 to 28 percent in 2012, and is expected to grow to 38 percent in 2028. Interestingly, the share of women in this group was 8.7 million more than men in 2010, and is expected to be 7.9 million more in 2022. So as the civilian noninstitutional population shifts to higher age groups, it becomes more female.

These structural changes will have significant impacts on labor force participation rates, which have declined over the past decade. The primary driver of this overall trend is the aging workforce. As the Baby Boom generation moves from middle age, with high participation rates, to the older age groups, with significantly lower participation rates, the overall labor force participation rate will decline. The trend accelerated during the recession, suggesting that many more people dropped out of the workforce than otherwise would have if the economy were in better shape. This rate peaked at 67 percent from 1997 to 2002, and then declined from 2002 to 2012, dropping to 64 percent. As the economy improves, however, the workforce will continue to age (Toossi 2013). All things being equal, the United States will experience slower economic growth, which should result in decreased VMT per capita.



Source: BLS, Monthly Labor Review, December 2013 (Toossi 2013).

Figure 3-5. Civilian labor force by age.

As noted, the U.S. Hispanic population is growing at the fastest rate of all racial and ethnic groups. The Hispanic share of the civilian noninstitutional population is projected to increase from 12.4 percent in 2002 to nearly 19 percent in 2022 (Toossi 2013). Hispanics in the aggregate and Hispanic men had the highest labor force participation rates in 2010. Also, Hispanics have a younger population than other racial and ethnic groups and a greater proportion in the prime working-age groups. These trends will continue and will increase the trend of even more racial and ethnic diversity in the workforce in the next four decades.

Labor force participation is important because commute trips are a major contributing factor to peak period congestion. In 2010, 86 percent of workers drove to work (76 percent alone, 10 percent in a carpool) (McKenzie and Rapino 2011). The percentage of Hispanic and Asian workers who drove alone did not exceed 70 percent. While 5 percent of all workers used public transport, the rate of public transit use among foreign-born workers was nearly twice that of native-born workers (11 percent versus 4 percent). However, as Hispanic workers acculturate, their use of public transit is likely to decrease, while their auto use increases.

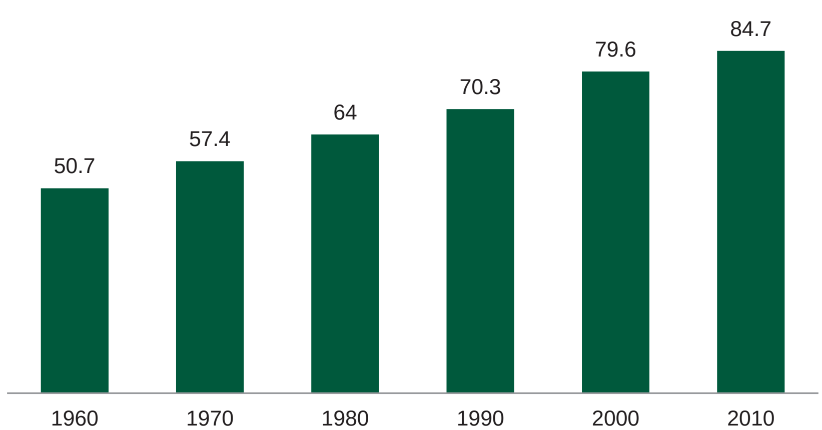
Trend 5: The Blurring of City and Suburb

The differentiation between cities and suburbs is fading.

- **Drivers**: Population growth, housing starts, population aging, age structure, household structure.
- **Impact on Travel Demand**: Decreased VMT per capita, increased nonmotorized trips, increased transit trips.

U.S. population density, defined as the number of people per square mile of land area, increased from 50.7 in 1960 to 87.4 in 2010 (see Figure 3-6). Over the same period, central cities have become less dense, and the density of suburbs has changed very little (Census 2012, Hobbs and Stoops 2002). However, at the turn of the 21st century, urban population growth accelerated. Census data indicate that many city centers grew faster than their suburbs between 2010 and 2012 for the first time in decades (Census 2012). Viewed as a whole, though, U.S. suburbs have continued to grow faster than city centers in every decade since the 1920s.

Nevertheless, the division between city and suburb is blurring. There is no longer always a clear line between an economic center where people work and suburbs where people live. Both can be home to employers and residences. It is also misleading to think of all suburbs in the



Source: Census 2012 and Hobbs and Stoops 2002

Figure 3-6. Number of people per square mile of U.S. land area.

same way; in the past decade, inner-ring suburbs have experienced population changes more similar to those in center cities than to outer-ring suburbs. Data from the 2010 Census also show that many closer-in suburbs linked to a city with public transit or well-developed roadways are benefiting from strong city growth, while exurbs near the metropolitan edge are not prospering quite as well. And many trends vary with the region of the country and the economic prosperity of the metropolitan region.

One factor that is contributing to the blurring of cities and suburbs is that U.S. internal migration rates have been declining for several decades (Census 2009). These rates reached record lows in 2009, with 2 percent of Americans moving from one state to another, and 4 percent moving from one county to another (Cooke 2011). The most recent spike in migration rates occurred in the late 1990s (along with strong economic and population growth). Then migration rates began a strong downward turn that was accelerated by the economic recession of 2007–2008 and has continued long after, indicating that economics does not completely explain the trend.

Behind the total numbers, different trends are happening in suburban and urban growth. As the Baby Boomers age, many of them are choosing to remain in suburban areas. As a result, the suburbs are both growing and aging quicker than central cities. An AARP analysis of 2010 Census data showed that 9 of 10 older adults nationally were living in the same communities where they raised their children (Faber et al. 2011). In 2000, 34 percent of suburban residents were over 45; by 2010, 40 percent were. In contrast, in central cities, the population over 45 increased from 31 percent to 35 percent. More and more suburban households are made up of singles, empty nesters, or retirees—they just happen to be older than urban residents fitting these household structure types. However, this trend is not necessarily consistent across the country; some metropolitan suburbs have successfully attracted younger residents, while others have shed them (Frey 2011).

Among central cities in the 100 largest metropolitan regions, two-thirds gained population from 2000 to 2008, continuing a trend that began in the 1990s. Some of this was attributed to immigration, because the largest cities remain magnets for newcomers, and some to the fact that as housing prices began to decline in 2006, center city residents who might have moved to the suburbs instead remained in cities.

In a recent study by the Urban Land Institute, Millennials were more likely than older Americans to prefer living in a big city, and showed the strongest preference for communities with mixed uses and different types of housing (BRS 2013). Likewise, 2010 Census data indicate that 20–34-year-olds who are delaying marriage much longer claim a disproportionate share of new city residents since 2008. Urban markets have greater job densities that are appealing to younger adults facing poor job prospects due to the recession. In Washington, D.C., for example, 28 percent of recently arriving migrants (2008–2010) were age 25–34, compared with the 15 percent they comprised of the region's population (Sturtevant 2013).

In cities, especially their centers, car ownership and use are declining. According to 2010 Census data, the share of metropolitan residents without a car has grown since the mid-1990s. Currently, 13 percent of people in cities of more than 3 million people have no car, compared with 6 percent of people living in rural areas. There are various reasons for this. Public mass-transit systems are, in the main, faster than they used to be, with increased capacity in many cities. More recently, private alternatives to car ownership or car-sharing services, such as Zipcar and Car2Go, have growing membership. In addition, an emerging autonomous vehicle market may also influence car ownership and use. Such population and demographic changes are generational events that will take decades to fully shake out. It is difficult to know exactly what form it will ultimately take, but re-energized cities and more compact suburbs may lead to a less car-dependent way of life, with more walking and biking and use of public transit.

Trend 6: Slow Growth in Households

The rate of new household formation has plunged since 2006, creating more single households and also more multigenerational and larger households.

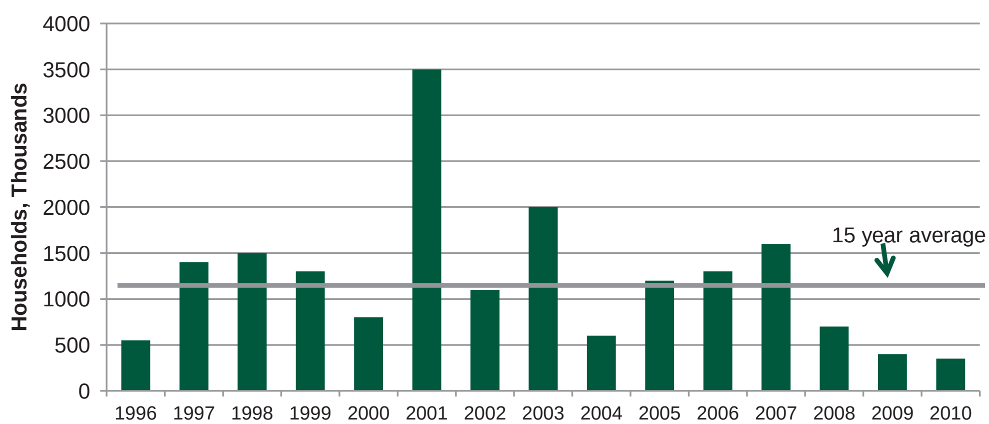
- **Drivers**: Poor labor market, aging population, lifestyle choices of Millennials.
- **Impact on Travel Demand**: Decreased per capita VMT, decreased auto ownership among young people, increased carpooling, increased public transit use.

Between 2006 and 2010, an average of 850,000 households were formed per year, compared with an average of 1.68 million per year over the previous five years (see Figure 3-7). In fact, household formation during 2006–2011 appears to have been far lower than in any five-year period over the past 40 years (Paciorek 2013). New households can be formed when children move out of their parents' homes, when couples separate, or when unrelated individuals choose to live singly after previously sharing a residence. The number of households can decline if two households combine, either through marriage or by sharing a residence to reduce housing costs. In the current environment, household formation rates may well be depressed both because fewer young people are living on their own, because established households are combining to lower costs, or because of the loss of homes through foreclosure.

While the total U.S. population increased greatly during the 20th century, the percentage increase in the number of households was even greater, reflecting a trend of higher proportions of people living in smaller households (Hobbs and Stoops 2002). The average household size has been decreasing from 4.6 people per household in 1900 to 3.3 in 1960 to a low of 2.59 in 2000. The long trend of falling household sizes had five main drivers: lower fertility or fewer children, aging Baby Boomers, longer life spans, women entering the labor force, and rising incomes.

Then between 2000 and 2010, the average U.S. household size rebounded to its 1990 level of 2.63. This rebound has been tied to young adults responding to the "Great Recession" by moving back in with their families and delaying moving from home for the first time (Kochhar and Cohn 2011, Taylor et al. 2010). American Community Survey data indicate that in 2006, prior to the Great Recession, 15 percent of young adults age 25–34 lived in the same household with one or both parents (Payne 2012). In 2010, the share among this age group living with parents was 18 percent, reflecting an increase of approximately 1.27 million young adults living with their parents.

Residing in the parental home is often an adaptive strategy during times of economic distress (Furstenberg 2010). Over time, single young adults are consistently more likely to live in their parent's home. Just more than three-fourths did so in the 1940s, and about half in 2010. What



Source: Federal Reserve Board of Cleveland, Economic Commentary, No. 2012-12, 2012 (Dunne 2012).

Figure 3-7. Net new households, 1996–2010.

is different about today is that the age at first marriage has increased. The vast majority (90 percent) of 18–24-year-olds have never been married. So there is both an economic element to this trend, but also an element of the lifestyle choice of the Millennial generation.

This living in another's home is not just a lifestyle choice of the young. According to the Pew Research Center, in 2008 some 49 million Americans, or 16 percent of the total U.S. population, lived in a family household that contained at least two adult generations or a grandparent and at least one other generation (Taylor et al. 2010). That is a significant increase from 1980, when the figure was about 28 million, or 12 percent of the population. There are a number of possible factors for this increase, from population aging to financial reasons to the growth of the Hispanic and Asian populations.

The composition of households may affect transportation demand through both the number of people and their ages and relationships. In particular, households with children have higher VMT than households without children. According to the 2009 NHTS, households with children averaged 30,400 VMT per year, while households without children averaged only 14,400 VMT per year (FHWA 2012b). But 2010 Census data indicate that households with children under 18 years have grown at the slowest rate over the period from 1960 to 2010, and increased by only 0.5 percent between 2000 and 2010. Also, young adults (Millennials and Gen X) are delaying marriage, which also has a depressing effect on creating households with children.

Over this same decade (2000–2010), households without children under 18 years increased by 15 percent, from 37.2 million to 42.8 million. Single-person households also increased by 15 percent, from 27.2 million to 31.2 million. Multiple-person nonfamily households increased by 23 percent, from 6.5 million to 8 million.

It is also likely that the low propensity to acquire a car could be related to young adults living with their parents. The probability of buying a new vehicle peaked with people 55–64 years of age (Sivak 2013b). In 2011, one vehicle was purchased for every 14.6 drivers in that age group. By comparison, the rate was one vehicle for every 222 drivers age 18–24 and for every 35 drivers age 25–34.

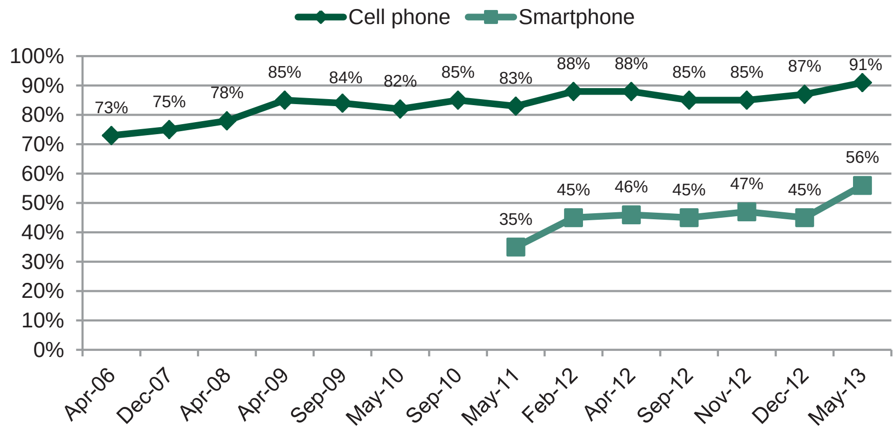
Trend 7: The Generation C

Mobile broadband will become increasingly more important and ubiquitous, creating a new Generation C.

- **Drivers**: Technology evolution, lifestyle choices, age structure.
- **Impact on Travel Demand**: Reduced VMT per capita for some trip purposes, decreased car ownership.

The growing influence of digital and mobile devices in the way people live, work, and socialize has spawned a new generation. Generation C is not necessarily a demographic group, as it is a lifestyle segment. It represents people of any generation who are connected, communicating, content-centric, computerized, and community-oriented (Friedrich et al. 2010). Generation C is "always clicking." However, some researchers, such as A.C. Nielsen, have identified Generation C as the hyper-connected group that is currently 18–34 years of age (Nielsen 2012). Born during or after the introduction of digital technology in the 1990s, this generation has been interacting with technology from an early age.

The mobile industry is constantly evolving and growing at an astronomical pace. For example, just over six years ago, Apple sold its first iPhone. In 2012, Apple shipped about 250 million iPhones worldwide (Pelson 2012). The intrinsic value of owning a mobile device has significantly changed in recent years. What was once simply a constant voice connection to anyone with a telephone is now enabling communications in a variety of different ways, such as text messages, e-mails, social media updates, instant messages, blog posts, Web searchers, shopping, and much more.



Source: Pew 2013b.

Figure 3-8. Percentage of American adults by cell phone and smartphone ownership.

Trend data indicate that these alternative means of communication have thrived among mobile phone users. A 2013 Pew Research Center survey found that 91 percent of American adults own a cell phone and 56 percent of adults own a smartphone (Pew 2013a) (Figure 3-8). Ownership varies by generation—with 79 percent of Millennials reporting owning a smartphone, compared with 69 percent of Gen X, 47 percent of Baby Boomers, and 18 percent of Depression era respondents. Urban and suburban ownership were virtually the same, at 59 percent while rural ownership was 40 percent (Pew 2013b).

It appears that the convenience and cost of mobile devices may have created a shift in the need or desire for a fixed-connection computer in the home. Yet, nearly one third of Americans still lack home broadband access (NTIA 2013). This is where the "digital divide" manifests itself. Poor, rural, and ethnically diverse households have long lagged behind in the rate of home broadband adoption. Hispanics are less likely to have broadband at home than any other demographic group, and they are far less likely to have it than whites and Asian Americans: 65 percent of whites and 69 percent of Asian Americans have broadband at home, compared with only 45 percent of Hispanics, 46 percent of Native Americans, and 52 percent of African Americans (Livingston 2011). Also, 18 percent of African Americans and 16 percent of English-speaking Hispanics are mobile phone-only wireless Internet users, compared with 10 percent of whites. According to another measure, Hispanics and African Americans are more than six times as likely as non-Hispanic whites to use their mobile phones as their sole means to access the Internet. When put together with the facts that Hispanics are growing as a percentage of the population and that Millennials and Gen X'ers have very high smartphone usage, this trend suggests that reliance on fixed broadband connections will decline over time.

Research suggests that cohort effects alone will change the travel behavior of the next generation in unique ways from their predecessors (Blumenberg et al. 2012). One of the key features of digital technologies is that they enable people to perform activities remotely, rather than in person. This type of freedom could displace the perceived freedom granted by ownership of a car—which has long been a key selling point for auto manufacturers (Goodwin 2012). Hallett and Stokes (1990) made an interesting prediction:

> Another possibility is that some new product could hit the market which would make the car redundant in the psychological sense . . . some computing product (probably portable) could maybe be produced which would cater to power, or freedom desires.

However, they also go on to say that they do not believe this was at all likely at that moment (in 1990).

Even among early adopters, researchers focused on whether this technology would result in substitution for actual trip making. Since then, studies have documented various small effects—slightly less or more trip making, depending on the trip purpose. The big effect many researchers anticipated might have been missing, because adults had already established their typical travel patterns by the time they started interacting with digital technology in the 1990s. Might we find different effects among the digital natives?

The recent change in driving patterns among younger people may be related to their mobile device use. The majority of American teens today delay getting a driver's license. According to the AAA Foundation for Traffic Safety, less than half (44 percent) of teens obtain a driver's license within 12 months of the minimum age for licensing in their state, and just over half (54 percent) are licensed before their 18th birthday (Tefft et al. 2013). This contrasts with earlier generations. In 1990, The FHWA's *1990 Nationwide Personal Transportation Survey* found that 41 percent of 16-year-olds, 70 percent of 17-year-olds, and 77 percent of 18-year-olds were licensed drivers (RTI 1991).

For today's Millennials, influences have included additional requirements and costs associated with getting a driver's license, greater access to mobile technology, and attitudinal shifts that favor low-carbon transport, especially among urban dwellers. More recent data from FHWA's 2009 NHTS indicates that the share of automobile miles driven by people age 21–30 in the United States fell to 14 percent in 2009 from 18 percent in 2001 and 21 percent in 1995 (FHWA 2012b). Meanwhile, 2010 Census data show the proportion of people age 21–30 increased from 13 percent to 14 percent (from 2000 to 2010), indicating that this age group went from driving a disproportionate amount of the nation's highway miles in 1995 to under-indexing for driving in 2009 (Census 2012).

While earlier generations embraced a concept of mobility structured around highways and automobiles, digital natives appear to be delaying the acquisition of a driver's license, driving less, and doing more activities digitally. Researchers have examined the role of social networking sites in changing travel behavior (Binsted and Hutchins 2012) and trends regarding young people driving less (Davis et al. 2012). But quantifying in a rigorous way such potentially significant changes for their impact on future travel behaviors is challenging.

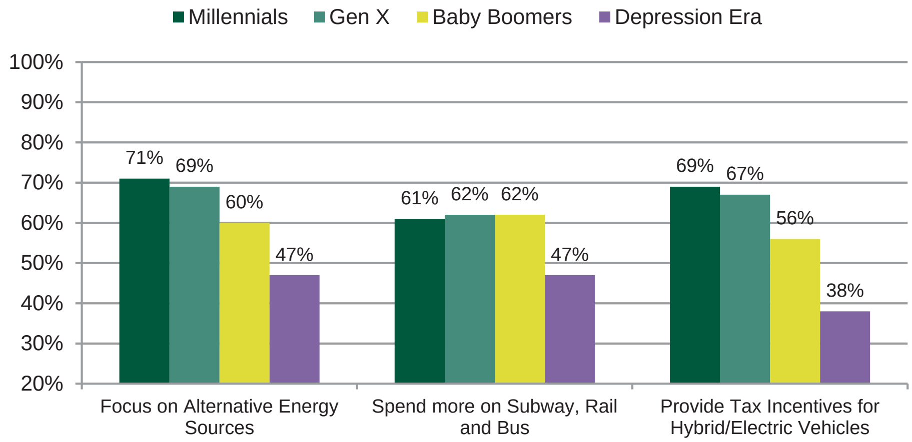
Trend 8: The Salience of Environmental Concerns

The generational divide over the nation's energy and environmental priorities is still strong but will decrease over time.

- **Drivers**: Age structure, population aging.
- **Impact on Travel Demand**: Lower car ownership, more transit and nonvehicle travel by younger generations due to elderly population shrinking.

According to a 2011 Pew Research Center poll, different generations of Americans have starkly different views on some of the social issues facing the United States today (Pew 2011). While the generational differences in views on energy and environmental priorities are not as pronounced as for some other issues (such as diversity, gay marriage, or civil liberties), generational differences exist.

In terms of energy and environmental priorities, 71 percent of Millennials say the United States should focus on developing alternative energy sources, rather than expanding oil, coal, and natural gas exploration. Roughly the same percent (69 percent) of Gen X'ers and 60 percent of Baby Boomers agree. But only 47 percent of Depression era respondents agree. The same



Source: Pew 2011.

Figure 3-9. Generational differences in views on energy and environmental priorities: percentage in agreement.

attitudinal distribution is seen on the question of whether stricter environmental laws and regulations are (1) worth the cost or (2) cost too many jobs and hurt the economy. For Millennials, the split in agreement with these two statements was 57 percent and 35 percent; for Gen X'ers, 57 percent and 37 percent; for Baby Boomers, 54 percent and 40 percent; and for Depression era respondents, 40 percent and 49 percent (Pew 2011).

The same Pew Research Center survey asked about policies to address America's energy supply. Regarding a policy option to spend more on subway, rail, and bus systems, 61 percent of Millennials favored this solution, compared with 62 percent of Gen X'ers, 62 percent of Baby Boomers, and 47 percent of Depression era respondents. With respect to another policy that addressed tax incentives for buying hybrid/electric vehicles, 69 percent of Millennials favored the policy, compared with 67 percent of Gen X'ers, 56 percent of Baby Boomers, and 38 percent of Depression era respondents (Figure 3-9).

Generational differences in attitudes relating to environmentally conscious behaviors are also observed in other research. In the 2013 Urban Land Institute study, convenience to public transit in one's community was important to 57 percent of Millennials, 45 percent of Gen X'ers, 50 percent of Baby Boomers, and 50 percent of Depression era respondents, while walkability was important to 76 percent of Millennials, 67 percent of Gen X'ers and Baby Boomers, and 69 percent of Depression era respondents (BRS 2013).

Millennials are the generation most likely to prefer living in a big city and most eager to live in a place with extensive public transit options. More of them use public transit to commute than any other generation. As the U.S. population ages and older generations pass away, attitudes and behaviors of Millennials will have greater and greater influence on Americans' environmental footprint.

These eight trends highlight the range of uncertainties transportation agencies are facing in their long-range planning. They make clear that the potential impact of these trends on travel demand is conflicting, evolving, and incomplete. This situation illustrates the fact that the future is unpredictable and shaped by many interacting factors. This is where scenario planning comes into play, as is discussed in the next chapter. It is not clear which trends will dominate the others or will change over time or remain moving in the same direction.

CHAPTER 4

Study Approach: Scenario Planning and System Dynamics Model

The goal of this research is to provide transportation planners and decision makers with an increased awareness of socio-demographic trends and how these may impact long-range transportation conditions or needs. This capability is delivered through the written findings and principles compiled in this final report, and also through analysis based on the application of a tool comprised of a SD model and scenarios. This joint scenario/modeling approach is unique.

The SD model simulates the demographic evolution of a regional population through 2050, while indicating the impact on travel demand and considering the influence of employment, land-use, and transport supply sectors. The scenarios are exogenous to the SD model. Their influences on demographic evolution and travel demand can be explored by manipulating SD model parameters that are linked to scenario assumptions. Together, the scenarios and the SD model provide an understanding of the fundamental relationships between social and demographic factors and travel demand, and how these relationships may change over time. The model more fully develops the socio-demographic sector and linkages to travel demand better than other models in the area of modeling. Detailed documentation on the validity of the internal relationships in the model can be found in Appendix B.

Chapter 4 Takeaways

- This research applies a unique joint scenario/modeling approach.
- Scenario planning is an effective way for agencies to deal with complexity and uncertainty.
- System dynamics methodology is well suited to the needs of various analytical challenges in transportation.

"The only relevant discussions about the future are those where we succeed in shifting the question from whether something will happen to what would we do if it happened."

Arie de Geus, former coordinator, Group Planning, Shell International Petroleum Company

4.1 Rationale for Approach

The rationale for the joint scenario/modeling approach developed from the team's review of methods used to forecast travel demand, focusing in particular on how those methods account for changes in socio-demographic factors. Travel demand forecasting is a broad topic, and the team has not attempted to cover all aspects in this document.

For readers interested in the state of the practice in travel demand forecasting, we recommend Donnelly et al. (2010).

The team considered five general types of models in its review: (1) project-specific models, (2) regional models, (3) statewide models, (4) strategic models, and (5) land-use models. A brief description of each is given below.

- Project-specific models—First developed in the transportation field to predict the effects of road capacity projects on traffic flows and congestion, project-specific models remain the type of model most commonly used today. They typically focus on a specific transportation corridor and set of intersections, with the assumption that the changes being modeled will not significantly affect wider regional traffic patterns. In most cases, the number of trips entering the area at any given time of day is taken as a given, based on observed counts, so the demographic profile of travelers and possible changes in travel behavior (shifts in travel mode, destination, trip frequency, etc.) are not modeled in detail.

- Regional models—Every U.S. MPO is required to prepare a regional transportation plan (RTP) periodically to qualify for federal (and state) transportation funds and to demonstrate compliance with environmental regulations. The time horizon of these forecasts is typically 25 years, and the MPO region may cover a single county or several counties. Regional modeling is where a great deal of methodological development is taking place. In recent years, the shift has been away from aggregate, zone-based models with a very limited amount of demographic detail toward disaggregate, parcel-based models that simulate the travel behavior of each individual in a detailed, representative population database. Currently, most regional travel demand models are used for forecasting, and, in most cases, little attention is paid to the level of uncertainty in the forecasts and the possible risk entailed.
- Statewide models—State DOTs are responsible for providing and maintaining major highways and rural roads, which are the main intercity travel connections (and sometimes the major intracity corridors as well). Most states maintain a statewide travel demand forecasting model to assist in planning highway capacity. Statewide models tend to be more aggregate and less behaviorally detailed than regional models. But like the regional models, they do not explicitly address uncertainty.
- Strategic models—Strategic models are used to consider large policy or imposed changes on the population (e.g., fuel prices). They are sometimes developed within an SD framework, sometimes as a stand-alone program, usually without explicit transport network loading, but sometimes with network supply effects being modeled. This is an emerging trend in long-range planning, where there is awareness that one cannot actually forecast the future, and many scenario possibilities need to be studied so that a policy or investment strategy that minimizes risk, or moves toward some desired goal(s), can be followed. The need to consider many scenarios implies "fast" models. These models also tend to take into account the path through time into the future (path-based), rather than the traditional "end-state" approach followed in most local, regional, and statewide travel forecasting models.
- Land-use models—Land-use modeling can be thought of as a complement to travel demand modeling—a very important complement with respect to demographics. Land-use models tend to be run dynamically through time, keeping track of the types of buildings and residential and commercial uses of each parcel of land, and simulating the transactions of the property market as subject to zoning restrictions and economic forces. Ideally, a good land-use model will be integrated with a good travel demand model, with the land-use model predicting how different types of people, households, businesses, and jobs will be distributed throughout the region, and the travel demand model predicting the travel patterns and traffic congestion that result.

Table 4-1 provides a side-by-side comparison of the typical characteristics of these models.

The research team's review concluded that none of the travel demand models currently applied in the United States uses a fully detailed demographic evolution model. But, the strategic or integrated land-use models seemed to be most relevant for this study's purposes. In addition, the team surmised that it was important to consider the dynamic feedback loops between travel demand and socio-demographic factors. Not only do demographic and socioeconomic factors influence travel behavior, but travel behavior (as it manifests in the aggregate) can, in turn, influence a region's socioeconomic and demographic profiles.

The review of travel demand modeling and forecasting was extended to examine emerging issues and evolving models, and to address accuracy and uncertainty in travel forecasts.

Table 4-1. Overview of travel demand model types considered.

Model Characteristics	Model Types Considered				
	Project-Specific	Regional	Statewide	Strategic	Land-Use
Typical areas of focus	Road design, traffic flow, level of service.	Policy costs and benefits, air quality. New Infrastructure (e.g., transit or a new road)	Main highways, freight, longer-distance travel.	Broader range of strategies.	Residential and commercial land, zoning.
Typical time horizon	0–10 years	10–25 years	10–30 years	20–50 years	5–30 years
Typical spatial boundary	A corridor or neighborhood.	A region or county.	A state or group of states.	Varies.	A region or county.
Typical level of spatial detail	Fine level. All road links and intersections.	Zones are blocks or larger. Only major roads, arterials.	Broader detail. Only major intercity roads.	Broader detail. Spatial abstraction.	Individual parcels or grid cells.
Travel demand relationships included	Few. Use fixed demand. Focus on traffic flow.	Advanced models include a broad range of behavior.	Some, but usually less detail than regional model.	Focus on key behavioral aspects of interest.	Few. Focus is on land market behavior.
Demographic detail typically included	Very little.	Advanced models include a wider range of variables.	Some, but usually less detail than regional model.	As much as needed for the topic area.	Can include a wide range of variables.

This examination deduced that advanced, activity-based travel demand models have adopted an agent-based, micro-simulation approach, with greater spatial and temporal detail to better handle emerging issues. This approach is more realistic than older, aggregate-based approaches, and should lead to increased accuracy for certain short-term types of modeling and prediction. However, it was concluded that the agent-based, micro-simulation approaches will not lead to more accurate predictions when considering a range of future possibilities, which is the context for the research. Thus, the team arrived at the decision to adopt an SD modeling framework that illustrates feedback loops, which is complemented by a scenario approach to account for uncertainties in forecasts. Before we explain our SD modeling approach, however, it is beneficial to discuss our rationale for using scenario planning.

4.2 Scenario Planning Approach

Chapter 3 identified key socio-demographic trends that will impact travel demand over the next 30–50 years. These trends are based primarily on straightlining of current trends carried into the future and also on analysis and projections based on known factors. Transportation agencies face strategic decisions in terms of how to cope with or adapt to these trends and their impact on travel demand. These are complex questions that depend on a variety of difficult-to-predict factors beyond the control of transportation agencies. Also, the impacts of the trends on future travel demand are to a large extent uncertain, incomplete, evolving, or conflicting.

Scenario planning is one way transportation agencies can deal with such complexities. Scenarios are generally a way of thinking about the future. Scenario planning is typically defined as a process of surfacing a set of plausible alternative futures, determining a range of possible consequences, and identifying strategies or policy options that would be robust across the set of futures (Lempert et al. 2003). Most authors attribute the introduction of scenarios to Herman Kahn through his work for the U.S. military in the 1950s at the RAND Corporation, where he developed a technique of describing the future in stories as if written by people in the future. He adopted the term "scenarios," which was originally used in the context of performing arts, to describe these stories (Chermack et al. 2001 and Khan 1965).

Today there is a rich variety of scenario approaches, reflecting different aims and interests and the characteristics of different fields of application. Among others, two types of applications have brought the scenario technique to the forefront in recent years. On the one hand, there has been the production of global scenarios, whether issue-based, mainly explorative scenarios focusing on climate change, water, etc., or integrated normative visions of the future; and on the other hand, there have been more locally scaled scenarios focusing on the potential of development of a specific region or city.

In addition, varying uses or ways of thinking about the future are often interrelated with the term scenario (Sparrow 2000, Dreberg 2004):

- Sensitivity analysis is a technique typically used to determine how different values of an independent variable will affect a particular dependent variable under a given set of assumptions, and is often used in mitigating risks in forecasts. But in effect, sensitivity analysis is more akin to a predictive mode of thinking about the future than uses below.
- Contingency planning is a plan devised for an outcome other than in the usual (expected) plan, and is often used for military or civil emergency planning. But contingency planning could also be applied to decision making in corporate or public policy.
- Normative approach seeks to envisage how society or some sector or activity could be designed in a better way than its present mode of functioning. This approach identifies solutions to fundamental societal problems by defining normative goals and exploring the paths leading to these goals.
- Exploratory analysis is in the form of coherently structured speculation, so many different developments or possible events can be described. Its strategic purpose is to better prepare decision makers and planners to handle emerging situations, recognizing that it is impossible to predict what will actually happen.

Many methodologies are available to develop scenarios, as discussed in Amer et al. (2013). There is no single "correct" method, and different contexts require different scenario methods. The scenario methodology used in this project was based on expert elicitation and strategic assumption surfacing, as noted in detail in Chapter 5.

The team started the scenario development process by identifying the key factors (i.e., influencers) on travel demand, in order to develop a scenario framework. Such a framework provides a clear logic and structure for describing the scenarios and differentiating them from one another. The initial catalog of socio-demographic drivers was organized into six categories: (1) population size and growth, (2) geo-demographics of population size and growth, (3) population structure and composition, (4) household-based economic activity, (5) cultural and social diversity, (6) and external factors intertwined with socio-demographics—i.e., urban form, technology, infrastructure investment. These drivers formed the basis of the scenario framework (see Table 5-1 in Chapter 5). Using this framework as an organizing structure, the team produced four scenarios of hypothetical futures that were distinct from each other and yet internally consistent, as discussed in Chapter 5.

Using the framework to develop the scenarios ensured that the scenarios focused on the joint effect of many factors and, thus, captured both the complexity and the uncertainties inherent in describing the impact of socio-demographics on travel demand. Relating this to the trends presented in Chapter 3, scenarios can help decision makers and planners to understand how the various strands of the complex tapestry of socio-demographic trends will move if one or more threads (or trends) are pulled in one direction versus another. When the various factors are considered together, one realizes that certain combinations could magnify each other's impact or likelihood. For instance, an increased trade deficit may trigger an economic recession, which in turn creates unemployment among young adults who put off forming new households by moving in with their parents, which then reduces VMT in a region.

Despite the growing popularity of scenario planning, a number of misconceptions remain about what it is, when it should be used, how it should be deployed, and what benefits it can yield. All too often, scenario approaches deteriorate into little more than a conventional forecasting effort that involves assigning explicit probabilities to potential outcomes. Or, at the other extreme, scenario planning devolves to loosely grounded futurist musings with little if any relevance to current circumstances.

The art of scenario-based, long-term planning is to connect the work of "what ifs" with down-to-earth decision-making processes. The proposed joint scenario/modeling approach is designed to do just that. The SD model enables the running of many different scenarios to examine travel behavior outcomes at different points in time. So *Impacts 2050* can integrate the scenarios into the long-range planning process of DOTs and MPOs.

4.3 SD Modeling Approach

While the objectives of the study did not explicitly call for a "model" as a product, the research team believed that the stated goal could not have been achieved without creating and using such an analytical tool. To recap, in arriving at the modeling approach the team recognized the following:

- Conventional transportation planning models used for estimating travel demand tend either to be limited in scope in terms of the types of variables that are represented, or to have very long run times (hours, days, or even weeks), which limits the range of assumptions that can be practically tested for long-range forecasting.
- It is unrealistic to believe that any traditional forecasting procedure could predict future outcomes with a high degree of certainty, given the large uncertainty in the inputs, the many factors at play, and the inter-relationships that may change over time. For example, a 30-year simulation of the land-use and activity-based travel model of the San Francisco Bay area would require 216 hours, or nine days of computation time (Waddell et al. 2010).
- Given these issues, the team decided to use an SD modeling approach because it not only is a method designed for scenario testing, leading to understanding how and why things may change over time, but is also an approach that facilitates rapid, "hands-on" analysis of many scenarios.

SD was first developed by Jay Forrester at Massachusetts Institute of Technology in the 1960s. One of his first applications was the longer-term evolution of urban land use and population, as described in his book *Urban Dynamics* (Forrester 1972). The SD approach has developed and evolved since then, and has been applied in dozens of different fields, including business management, economics, biology, the physical sciences, and various aspects of the social sciences. These models are typically developed using recent time series data for key variables, and calibrating the model to reproduce the time trends for those variables reasonably well. Because, as described below, the focus of such models is typically on exploring scenarios and policies, rather than producing long-term forecasts, there has been very little emphasis in the literature on exploring the predictive accuracy of the models over time. One exception is the model used for the well-known "limits to growth" study in the 1970s. Updates to that study have been published to show how well the model has been able to track actual trends over time (Bardi 2011).

Although still relatively new in transportation modeling, the SD approach has been applied to address similar objectives as in this study. For example, Fiorello et al. (2006) developed an SD model that covers the European Union and larger Europe. The model includes a population module that evolves the population for 29 countries by age in one-year increments through cohort survival, in-migration, and intermigration. In the United States, an SD model was developed to evaluate policies for development of the Las Vegas Valley (Stave and Dwyer 2006). This model deals specifically with the population by age, including births, deaths (cohort survival), and migration based on "attractiveness" for a large number of alternative scenarios in a path-based analysis. Also, there have been a few cases over the years where the urban dynamics model has been updated and extended to deal with transportation and land-use interactions. But in general, the SD approach has not been used extensively in modeling travel behavior (a range of applications can be observed by looking at the list of conference proceedings for the System Dynamics Society at www.systemdynamics.org/society_activities.htm).

Travel demand modeling has tended to develop its own network-based, static equilibrium-based modeling approaches. Generally, these methods have been developed independently from approaches used in other fields. While travel demand modeling methods have their strengths—particularly the more recent activity-based approaches—the SD approach seemed more appropriate to use for this project for a number of reasons.

Two main aspects relate to model fidelity and are termed structural accuracy and statistical accuracy:

- *Structural accuracy* refers to having the correct set of variables in the model, and the correct set of causal relationships linking those variables.
- *Statistical accuracy* refers to the exact numerical parameters and functional forms used in defining the model relationships.

Generally, the emphasis in travel demand modeling has been on *statistical accuracy*, using a fairly limited set of variables and relationships, with most of the effort devoted to estimating and calibrating the parameters of the models. Such an emphasis may be appropriate for shorter-term forecasts, where many variables and relationships can be assumed to remain constant or to be exogenous and one-directional—i.e., they influence travel behavior, but changes in travel behavior do not feed back to influence them.

The farther that one expands the time horizon and the range of scenarios under consideration, the more important structural accuracy becomes relative to statistical accuracy. When one is predicting far out into the future, the range of uncertainty in the input variables becomes larger and larger, and the use of precise statistical relationships becomes less and less relevant. The emphasis becomes less on numerically accurate forecasts and more on qualitatively accurate depictions of how different variables and relationships will evolve over time. Correspondingly, the approach for calibrating and validating a model depends less on obtaining exact matches to a limited number of data items and more on trying to match the qualitative trends that have been observed in the real world over a length of time (e.g., running a model simulation from 1970 to 2010 and comparing the "predicted" trends with actual trends over time).

The SD modeling approach is focused on model structure, using a framework based on physical entities that build up or diminish over time (stocks), the rates of change in those entities (flows), and the relative timing of those changes (delays). The focus is also on *feedbacks* within the system—whether various modeled relationships tend to reinforce each other ("positive" feedback), or work in opposition to each other ("negative" feedback). For longer-term models, this distinction is critical, because negative feedback relationships tend to lead to constrained behavior that is fairly stable over time, while positive feedback relationships, although rarer, can lead to exponential growth or other forms of unstable behavior over time. As a result, the model structure makes it so that the predicted behavior is more sensitive to some variables and relationships than others, even if one would not expect so from looking at the relative size of the numbers used to parameterize the relationships. Describing a complex system in this way is often useful in illustrating how seemingly simple rules may result in a complex, nonlinear system (Pfaffenbichler 2011).

The critical importance of the dynamic model structure, even more than the model parameters, may seem like a strange concept, particularly to those who have worked in the static world of travel demand modeling for some time. However, for a model with a long time horizon and a wide scope, this way of thinking can be very valuable.

The main purpose of the model used in this study is not to provide long-term forecasts—without a crystal ball, those forecasts would almost certainly be wrong and not very useful. Rather, the model's main purpose is to facilitate the running of many different scenarios. SD models typically do not model transport network loading explicitly, but include some simple representations of network supply effects. This approach is proven to greatly reduce model run times—typical SD models are capable of producing 50-year forecasts in less than a minute—which makes the exploration of a large number of scenario tests possible.

There are many examples of the value of running many different scenarios. For example, transportation agencies can visualize how and why various possible futures may occur and reflect on how political, social, and economic changes may affect operations and plan accordingly. Another example is the fact that when a number of different scenarios are produced, many perspectives can be included and a policy or planning discussion does not have to revolve around the advocacy of fixed positions. Finally, in running many different scenarios, issues may be surfaced by exposing the underlying forces in a region that otherwise would not be considered in the planning process. The bottom line is that the analysis of these scenarios can assist in decision making and resource allocation.

Chapter 5 provides more detailed information about the scenarios developed, and Chapter 6 presents *Impacts 2050*, the underlying SD model structure, and its outputs.

CHAPTER 5

Future Scenarios: Process and Narratives

Chapter 5 Takeaways

Four scenarios were developed through a SAST methodology:

- Momentum: gradual changes without radical shifts.
- Technology Triumphs: technology solves problems.
- Global Chaos: collapse in globalism and sustainability.
- Gentle Footprint: widespread shift to low-impact living.

"The best way to predict the future is to create it."

Peter Drucker, writer, management consultant

5.1 Scenario Development and Assumption Testing

Good scenarios are built on good data and contain alternative visions of how the data move forward. The process for developing and refining the research team's scenarios and the assumptions underlying them began by organizing the key trends outlined in Chapter 3, as well as other factors, into a broad set of key drivers: (1) population size and growth, (2) geo-demographics of population size and growth, (3) population structure and composition, (4) household-based economic activity, (5) cultural and social diversity, (6) and external factors intertwined with socio-demographics—i.e., urban form, technology, and infrastructure investment. In each of the categories, the team identified elements or factors that were predetermined and those that were uncertain.

- *Predetermined* elements are outcomes that are considered to be highly likely over the time frame of the scenarios and will lead to outcomes that can be relied upon (i.e., percentage of people over age 65 at some future point in time). These elements describe the known future implications of something that has already happened.
- *Uncertainties* are the potential changes that we are unsure about—the direction of change, the resulting outcome, or the pace of evolution. Uncertainties are outcomes that could resolve in any number of ways (i.e., direction of immigration policy reform). In scenarios, these were to be explored as various alternatives.

The research team then used a specialized technique—Strategic Assumptions Surfacing and Testing (SAST)—to identify (surface) and extend (test) the assumptions underlying the key factors on which the broad scenarios were built.

5.1.1 SAST Methodology

Introduced by Mason and Mitroff in 1981, SAST is a process for surfacing the underlying assumptions of a policy or plan and creating a map for exploring them and better understanding their effect. SAST incorporates the following principles:

- Adversarial—Based on the premise that the best way to test the validity of an assumption is to fully understand the arguments that both support and oppose it.

- Participative—Based on the premise that the knowledge and resources necessary to solve and implement the solution to a complex problem are distributed among a group of individuals that has been formed to represent alternative points of view.
- Integrative—Based on the premise that a unified set of assumptions and action plans is needed to guide decision making, and that what comes out of the adversarial and participative elements can, at some point, be unified.
- Managerial Mind Supporting—Based on the premise that exposure to assumptions deepens the insight into a critical planning issue, either public or private.

SAST was applied in a 1.5-day workshop that included members of the NCHRP oversight panel, members of the research team, and outside experts. Altogether, the 26 workshop participants represented the fields of socio-demographics, transportation policy and planning, and travel demand modeling (we acknowledge these individuals in the acknowledgments section). Vince Barabba, a member of the research team, who had previous experience with this methodology while at the U.S. Bureau of the Census and at General Motors Corporation, served as the facilitator for the planning and workshop process. The specific purpose of the workshop was to test whether the factors that had been identified as "significant driving forces" were in fact significant, and whether the assumptions linking these drivers to travel demand impacts were valid. In addition, to the degree possible in the short 1.5 days of the workshop, the importance and degree of certainty associated with each assumption were evaluated.

Prior to the workshop, the research team had outlined four scenarios based on research in prior study tasks:

- Momentum—Gradual changes without radical shifts.
- Technology Triumphs—Technology solves all problems.
- Global Chaos—Collapse in globalism and sustainability.
- Gentle Footprint—Widespread shift to low-impact living.

The framework is structured around the significant driving forces and the basic factors that were expected to be inputs to the SD model. These factors constitute the rows in Table 5-1, while the columns in Table 5-1 contain the scenarios. The Momentum scenario may be seen as the most linear, or "business-as-usual" case. The other three scenarios are distinct changes from that case. All scenarios were created to maximize the differences between them and to ensure that as many possibilities as possible were considered.

Prior to the workshop, each participant was presented with the four scenarios, and was asked to select the scenario that he or she felt most capable of defending. At the workshop, participants were split into four small (4–6 people) working groups consisting of individuals who agreed, in principle, to support the scenario to which they had been assigned. In the workshop, the differences among scenarios (and concomitantly among groups) were reinforced by asking the members of each group to role play their particular scenario position—even when it sometimes required stating and supporting an underlying assumption with which a member of the group did not personally agree.

To enhance each participant's sense of involvement in the scenario, each group was asked to give itself a label that best expressed the spirit of its position:

Momentum → Groundhog Day (Extreme Gradualism)

Scenario of minimal change; continuing path we're on; continuing service economy; less disposable income; very little happens to change debt; strong international competition; many ways of coping when things get bad, so change is not necessary; permanent cycles with "blips," ebbs, and flows; adopting a history-repeats-itself theme.

Table 5-1. Scenario framework: Key factors and indicators used in scenario development.

Factor	Momentum	Technology Triumphs	Global Chaos	Gentle Footprint
Economic Growth Personal income, employment rates.	Generally modest economic growth. No growth in overall employment or average income.	Technology economy fuels economic growth, employment is high, incomes rise for a few "elites."	Frequent storms, floods, droughts, tsunamis, etc., lead to widespread casualty, famine, war, and general economic chaos. There is negative economic growth and high unemployment.	Growing environmental ethos among each generation leads to drastic policies and investments to curb fuel use and emissions; new industries; new occupation mix with a diverse set of economic and employment effects.
Immigration Policy Immigration rates, population growth, fertility trends.	Number of legal and illegal immigrants continues to grow at recent rates, leading to 100 million+ total population growth.	Increased legal immigration as new tech workers are needed to fill jobs.	With high unemployment, scarcity, fear, there is a strict lockdown on borders.	Cutbacks in energy use and economic activity initially lead to decreased immigration.
Basic Demographic Trends Age distribution, gender roles, life expectancy, mortality rates, household size and structure.	The aging of the population increases somewhat, although average life expectancy peaks due to complications from obesity. Average retirement age goes up somewhat. Gender gaps in employment and roles continue to disappear.	Mortality rates decrease substantially.	Life expectancy declines, starts to work against aging of the population. Unemployment is highest among males, uneducated. Reaction against working mothers—toward traditional roles.	Environmental ethic to have fewer children per household. Shift to healthier lifestyles (more exercise and local foods) leads to higher life expectancy.
Energy Supply and Demand Prices, fuel types, environmental attitudes.	Energy prices continue to increase slowly overall, with periodic spikes followed by decreases.	With new energy technologies, the price of energy eventually levels off and becomes stable or even declines.	Energy demand and supply are both disrupted. Prices are unstable and generally rising.	High carbon taxes and other market policies make energy more expensive. The shift to noncarbon fuels makes energy security less important.
Technology Advances Information and communication technologies (ICTs), vehicle technologies.	ICTs modify how and where people work and play. Slow shift toward hybrid and plug-in electric vehicles. Use of SUVs and pickup trucks remains strong. Intelligent vehicles make driving safer, but not automatic.	Virtual living is a reality. Many high-level tasks in business and government are run by artificial intelligence systems. Robotic systems handle all transportation needs.	Technology advances slowly or nearly halts.	The shift toward smaller, more efficient vehicles and alternative fuels accelerates, as does investment in rail and other forms of transit. High-speed rail replaces a large fraction of the air market.
Role of Government in Transportation Infrastructure Pricing, supply.	Federal role decreases, with more power to the states. Very few new highway miles are added, and maintenance of existing miles remains a challenge. Fuel taxes and other pricing remain low compared with other nations, but much road infrastructure is tolled.	Private (technology) sector directs transportation infrastructure investments.	Very little investment in new capacity or maintenance, but slow economy leads to slowdown in demand, less congestion. Very little investment in public transportation or air network.	Federal government role is strong. There is little investment in new road capacity, as priorities are toward transit, rail, and more efficient vehicles.
Urbanization Land-use policies, open-space protection, regional shifts.	Population continues to shift toward urban areas. Infill and transit-oriented development grow due to high demand.	The entire country is wired. Economic activity diffuses from population centers. Technology enables people to locate where they wish to work and to recreate virtually.	High food prices, disrupted agriculture sector, and high unemployment lead to more self-production of foods. Cheap land helps enable "back to the land," small farms, co-ops—low technology. Urban centers and inner suburbs revert to slums.	Land-use policies strongly promote efficient infill development, with an emphasis on meeting most needs within walking distance. Even suburbs become denser.

Technology Triumphs → Tech Nirvana

Technology deals with goals and ramification of goals, ever-evolving, and solutions come quickly; if there is a problem, technology solves it; global tech race is healthy and competitive; role of government is to respond to technological issues; people will travel less and faster because of technology; do people want to be "there" in person or travel electronically?

Global Chaos → Neo-Isolationism

Largely negative scenario: economic–political breakdowns, borders tighten up, supply chain and international travel (flows into United States) break down, shrinking trade and travel patterns, United States takes care of its own first, state or regional divides could emerge, localism dominates. Root causes of collapse: climate change, collapse of energy systems, interruption of world food systems, terrorism, disease, unstable financial growth.

Gentle Footprint → Clean and Green

Strong state government role; focus on urban design, walkable neighborhoods, move from big houses to small apartments; growth in energy sector, clean businesses, young entrepreneurs; consumerism decreases, simpler and healthier lifestyles; expect an increase in economic activity; every house will have fuel cells, solar cells; more charging stations for cars, trend toward rechargeable hybrids, use less or no car.

The basic purpose of the workshop at this time was not to decide which scenario was most likely, but rather to surface as much as possible the assumptions underlying each scenario. Assumption surfacing began with each group working independently to develop a list of stakeholders (people, organizations, and institutions) for decisions related to the position of the group's scenario—that is, the stakeholder who would be affected by or could affect a final decision. Next, assumptions were identified that had to be posited for a given scenario to result. The stakeholders and assumptions identified for each scenario are presented in Table 5-2. With a deeper understanding of the critical assumptions that would have to be true for one scenario to prevail, each group was ready to defend its position against those of the other groups.

After the presentation of the assumptions, the groups met individually to determine which of the many assumptions presented, if true, would be most damaging to their own position: "If that were true, could we pull off this scenario?" A debate was conducted, with each group challenging the most damaging assumptions to its own point of view, and the group for whom the assumption was critical defending the assumption. The content of this debate is presented in Table 5-3. For example, the damaging assumptions to the Momentum assumptions appear in the Momentum row under Technology Triumphs, Global Chaos, and Gentle Footprint.

The significance of the "damaging assumptions" is that they indicate those assumptions in the scenario that most differentiate it from the other scenarios. Therefore, these assumptions are, in fact, the most important ones for that scenario. As a result of the discussion on damaging scenarios, four issues that continually surfaced during the debate were determined to be the most crucial to scenarios pertaining to the impact of socio-demographics on future travel demand:

- Immigration
- Labor force/jobs mix
- Household composition
- Household movement

The SAST workshop was not intended to select or choose the "right" scenario, but was intended to formatively evaluate the utility of the scenarios in illustrating alternative futures.

Table 5-2. Stakeholders and stakeholder assumptions for each scenario.

Scenario	Stakeholders	Assumptions
Momentum	Working People	Shifts in type of job/training, job mobility; strong voting block; middle class lives comfortably, American dream alive; incomes to stay at reasonable level, personal mobility affordable; accept user fees for roads.
	Government (County)	Allows things to continue as is; encourages local economic development; car-oriented, sovereignty over land use.
	Organized Labor	Controls on imports, immigration controls, prospects for education and training.
	Land Development/Home Builders	Favorable treatment needs to remain strong; home starts is a leading economic indicator; need for continued immigration, immigration oscillates with little regard to policy; economy is main driver; mortgage assistance.
Technology Triumphs	Government (National)	Demand-driven world; global free market; invests in public goods; protects intellectual property rights.
	Consumers	Everyone has adequate buying power, sufficient skills to be part of workforce.
	Private Sector	Capital sufficient to monetize emerging technology; technology brings positive results or finds solution; labor force exists to continuously produce innovation.
	Educators	Stay ahead of technology; people willing to learn.
	Privacy Advocates	Advances make it possible to protect privacy; agree to technology solutions.
	Intellectual Property Creators	Intellectual property can be protected; replace resources with technology.
Global Chaos	Government	Fear dominates decision making; self-preservation triumphs over globalism; society unsuccessfully addresses carbon fuel limits; supply chains break down.
	Employers	American economy can do without immigrants; self-preservation triumphs over globalism and sustainability; society unsuccessfully addresses carbon fuel limits.
	Energy Suppliers	Society unsuccessfully addresses carbon fuel limits.
	Consumers (Middle Class, Affluent)	Fear dominates decision making; self-preservation triumphs over globalism and sustainability; "less" is acceptable—"satisficing" becomes the norm.
	Foreign Governments	Collapse in global cooperation; supply chains break down.
Gentle Footprint	Politicians	Needs to be a legal foundation for energy choices, land-use policies, health care policies.
	Existing Landowners	Want to protect their land, move to a green society, keep farming.
	Citizens	Consumers are environmentally aware, main drivers underneath scenario, spreading and building awareness of a green future.
	Developers	Rules to facilitate environmentally friendly, built environments; they can make money regardless of how land is zoned.
	Utilities	Need to face pressure and control to go green.
	Industries, Business Groups	Majority of people are environmentally aware or opportunists who will take advantage of market demand to move into greener businesses; going green does not affect the economy.

The workshop discussion indicated that the initial four broad scenarios—Momentum, Technology Triumphs, Global Chaos, and Gentle Footprint—worked well to describe four unique future alternatives that illustrate some extreme future cases. Workshop participants did not have to stretch to defend them; in fact, they embraced their scenarios, indicating that each resides in a realm of plausibility. In addition, the set of factors and indicators as presented in Table 5-2 represented an early, yet robust and efficient, framework for describing each scenario.

Table 5-3. Most "damaging" assumptions by scenario.

Scenario	Assumptions Challenged			
	Momentum	**Technology Triumphs**	**Global Chaos**	**Gentle Footprint**
Momentum	N/A	Demand-driven world. Global free market. Technology ensures adequate resources.	Self-preservation triumphs over globalism and sustainability.	Government imposes land-use (go green) values because of citizen demand.
Technology Triumphs	Immigration thrives. Cost of global shipping increases.	N/A	Less or "satisficing" is acceptable. Fear dominates decision making. Self-preservation triumphs over globalism and sustainability. U.S. economy can make do without immigrants.	Government imposes land-use (go green) values because of citizen demand. There are economic losers (like industry and utilities).
Global Chaos	Immigration thrives. Income is stable. Housing is affordable.	Everyone has adequate buying power. Demand-driven world. Global free market. Technology ensures adequate resources.	N/A	Healthy sustainable economy. Stable and successful leadership.
Gentle Footprint	Living the American dream is good and brings income stability. Personal mobility is affordable.	Government will invest in public goods, which is necessary in the absence of market. All technology has good outcomes. Everyone has adequate buying power.	Society will not successfully address carbon fuel limits. Fear of others dominates decision making. Self-preservation triumphs over global sustainability.	N/A

5.2 Scenario Descriptions

After the workshop, the scenario framework was refined (that is, the significant sectors and factors), based on research for the SD model development. But the basic assumptions underlying the scenarios and their names changed very little. Appendix A provides full narrative descriptions of these scenarios, keeping with common practice in this field of writing the content from the future vantage point of 2050. Each scenario prioritizes certain driving forces in the future to create different interpretations of how present-day uncertainties will move to resolution.

The Momentum scenario has been developed to represent the business-as-usual case. It is the most linear scenario and is based on demographic transitions over time by age, race/ethnicity, acculturation (if immigrant), and household type (e.g., married, children). The transitions include births, deaths, marriages, divorces, higher and lower household incomes, and labor force participation.

The other three scenarios are distinct changes from the Momentum scenario. All scenarios were created to maximize their differences, with each representing very distinct and differentiated possible futures:

- Momentum—The current state of the country in 2050 would still be recognizable to any transportation planner who had worked in 2010. Change has been incremental, based primarily on population dynamics, and we have not experienced any major shifts from prevailing demographic, economic, or technology trends. Nor have there been major policy shifts.

America has become "grayer" as the Baby Boom generation has aged and "browner" as the white population has grown slower than every other racial group. Likewise, the U.S. labor force has grown older and more diverse. Overall VMT has increased, but per capita VMT has declined. Baby Boomers have continued their reliance on the auto as their primary travel mode, but young adults have declining driver's licensing rates, auto ownership, and auto usage. Young adults also rely more on technology to substitute for travel when possible, but telework is not prevalent due to the fact that most of them access the Internet via mobile devices. Road congestion has decreased only somewhat. Federal gas taxes have risen a few times, but not enough to keep up with the increases in fuel economy. As a result, with less federal funding, many states have had to increase their own funding streams if they want to maintain their existing road network.

- Technology Triumphs—Technology has saved us from ourselves. While the United States faced some difficult challenges in the 2010s, many of these have been mitigated by innovations through 2050 that helped us live longer, reduce our carbon footprint, connect our world, and travel more easily and safely. Autonomous vehicles have changed how people travel, and data-intensive communications technology has significantly affected how much people travel. Commute travel has declined, since a high proportion of office workers now work from home with new types of mobile devices, and most schooling and health care are conducted online. Fewer people live near their jobs, since their physical presence is seldom required. Much socializing also takes place virtually, and many weekly necessities are delivered to people's doors. The travel that does take place tends to be faster, cheaper, and more convenient than ever.
- Global Chaos—The past few decades have challenged Americans' general optimism, and the world has become a far different and more difficult place in 2050. Several trends intersected to bring about a distressing "new normal": growing financial instability at a global scale, a continuing great U.S. recession, the increasing and visible impact of climate change, and a reactionary sense of new isolationism. The results, which affect most of the world, are heightened insecurity (over jobs, food, and oil) and chronic conflicts (over jobs, food, and oil). Widespread unemployment means that far fewer people are on the roads and transit systems. With state and local governments collecting relatively little revenue, they have a hard time maintaining the existing infrastructure or responding to crises like returning travel to normal after a major storm. Walking and cycling are far more popular now, but generally out of necessity rather than choice, and people with cars often make extra money on the side as gypsy cabs.
- Gentle Footprint—After droughts and "super storms" began plaguing the United States in the 2010s, both public consciousness and political will in the 2020s began shifting toward taking more serious action to slow climate change. While it was too late to curb the rise in carbon concentration in the atmosphere, the United States has made surprisingly good progress in adopting a variety of means to reduce energy consumption. Many lifestyle changes that may once have been considered radical are now mainstream, particularly since the generational divide between Baby Boomers and younger generations on energy and environmental priorities has narrowed over time. Federal, state, and local governments have responded by shifting their focus to investments that support alternative travel modes, rather than cars. Most cities and suburbs have good networks of bicycle lanes, and transit systems have expanded, while the size of the road network has barely budged in 20 years. High-speed rail has been built in a half-dozen corridors, and it captures a healthy percentage of travel among those cities.

Each scenario has its own set of final structuring assumptions and/or underlying theories about the future. These final assumptions are displayed in Table 5-4 in the structure of the conceptual framework that has been designed for these scenarios. These assumptions are explicitly noted in the scenario analysis tool, *Impacts 2050*, which is described in the next chapter.

Table 5-4. Key assumptions by sector by scenario.

Sectors	Momentum	Technology Triumphs	Global Chaos	Gentle Footprint
Demographic	Slow population growth. Population aging. Life expectancy not increasing. Fewer children per household Immigration slowing. Hispanic population growth from U.S. born.	High population growth. Longer life span and better general health; birth rate increases. Delaying marriage with "virtual living." More flexibility in living arrangements. Adult children forming new households. Increasing tech worker demand. Increasing international migration to and from U.S.	Population declines. Shorter life span due to negative effects on health and poor environment. Fewer children per household due to poor economy. Larger, multigenerational households. Declining household incomes. Decreasing immigration with border controls and deportations.	Slow population growth. Fewer children. Longer life span. Healthier lifestyles and better environment. Increasing immigration. Environmental tech business requiring workers; back-to-basics farming requiring migrant labor.
Employment	Total labor force growing due to population growth. Labor force participation rate declining due to population structure. Male and female participation rates narrowing.	Labor force participation increasing due to booming economy. Later retirement with people working from home through technology. Benefits of technology not equally shared. Economic growth favoring educated. Higher income inequality.	Low economic growth, less employment. Fewer job opportunities. Higher unemployment among women and young adults. Higher income inequality. High earners continuing to prosper. Poor economy affecting low earners. People delaying retirement due to financial necessity.	Employment sectors shifting to low-impact jobs—technology and farming increasing. Healthier people staying in workforce longer. Greater economic equality as benefits of tech more equally shared.
Land Use	Baby Boomers aging in place, mainly suburbs. Younger adults moving to urbanized areas.	Tech bringing ability to work from anywhere. Economic activity diffusing from population centers, lower densities.	Less relocation activities, opportunities dwindling regardless of geographic location. Less value on undeveloped land.	Greater density. Greater value placed on undeveloped land.
Transportation Supply	Federal and state transportation revenues and funding declining. Growing cost burden on states without increasing fuel tax. Little private investment. Increasing reliance on tolling.	Strong economy encouraging private-sector investments in infrastructure. Increasing federal and state transportation budgets. Greater private and public investment in roads and transit.	Little investment of new capacity of any kind.	Carbon tax surplus funding infrastructure. Little investment in new road capacity. More investment in public transit.
Travel Behavior	Young people delaying auto ownership. Work travel declining. More older people driving. Technology substituting for some travel Fuel prices rising, vehicle efficiency keeping pace.	Higher incomes leading to less car-sharing. Moving to suburbs/rural areas leads to higher car ownership. Technology leading to greater public transport efficiency. Self-driving vehicles leading to more auto VMT.	Fuel prices increasing due to global instability. More car-sharing. Less car ownership. More walking and biking. Fewer work trips. Less discretionary travel.	Increasing fuel prices encouraging alternative energy sources. Travel more expensive, VMT declining. More car-sharing. Car ownership declining due to better public transit systems. Higher-density, improved bicycle lanes.

CHAPTER 6

Scenario Planning Tool: *Impacts 2050*

Chapter 6 Takeaways

- *Impacts 2050* is a strategic modeling tool.
- Four scenarios are predefined in the tool, but many other scenarios can be tested.
- The underlying SD model contains 700 variables in five sectors: socio-demographics, travel behavior, land use, employment, and transport supply.
- Model simulation starts at 2000 and runs through 2050 in half-yearly increments.

"Everything must be made as simple as possible. But not simpler."

Albert Einstein,
theoretical physicist

Impacts 2050 is a menu-driven spreadsheet model that state and regional transportation decision makers can use to play out the many ways that changing socio-demographic factors in a region may impact travel demand over time. The tool is designed to be a strategic model:

> Strategic models are an emerging trend in long-range planning, where there is an awareness that one cannot actually forecast the future, but that many scenario possibilities need to be studied so that a policy or investment strategy that minimizes risk, or moves towards some desired goal(s), can be followed.

Like other types of strategic models, *Impacts 2050* has been designed to produce qualitatively accurate representations of how different variable relationships will evolve over time, rather than numerically precise forecasts for one particular sector. Being qualitatively accurate means the relationships are in the right direction and make intuitive sense.

6.1 Overview of the SD Model

Impacts 2050 is powered by an SD model that simulates a regional population over time starting from a base of the 2000 Census and spanning a period of 50 years. The model depicts five sectors: (1) socio-demographics, (2) travel behavior, (e) land use, (4) employment, and (5) transportation supply. Model results include the travel demand effects of the changing population, which were modified by feedback from the employment, land use, and transportation supply sectors. For example, population increase could increase congestion, which if not alleviated could lead to some people relocating within the region over the longer term, and eventually to a change in the location of employment and/or mode choice.

Like other SD modeling tools, *Impacts 2050* enables exploratory modeling of changes in these sectors due to socio-demographic changes, the interplay among them, and external factors that are intertwined with socio-demographics, such as attitudes and technology. The latter was accomplished through predefining our four scenarios in the tool. These represent "what if" conditions that moderate the outcome of the business-as-usual scenario, Momentum, and the tool is set up to enable a user to modify the scenario inputs in order to test many different hypotheses about the future (i.e., different scenarios)—not just the four scenarios developed by the research team.

A distinguishing feature of our SD model is an emphasis on dynamics that can result from the relationships pertaining to travel demand that will likely change over time, requiring changes in these relationships over time. Figure 6-1 depicts that there can be substantial time delays in

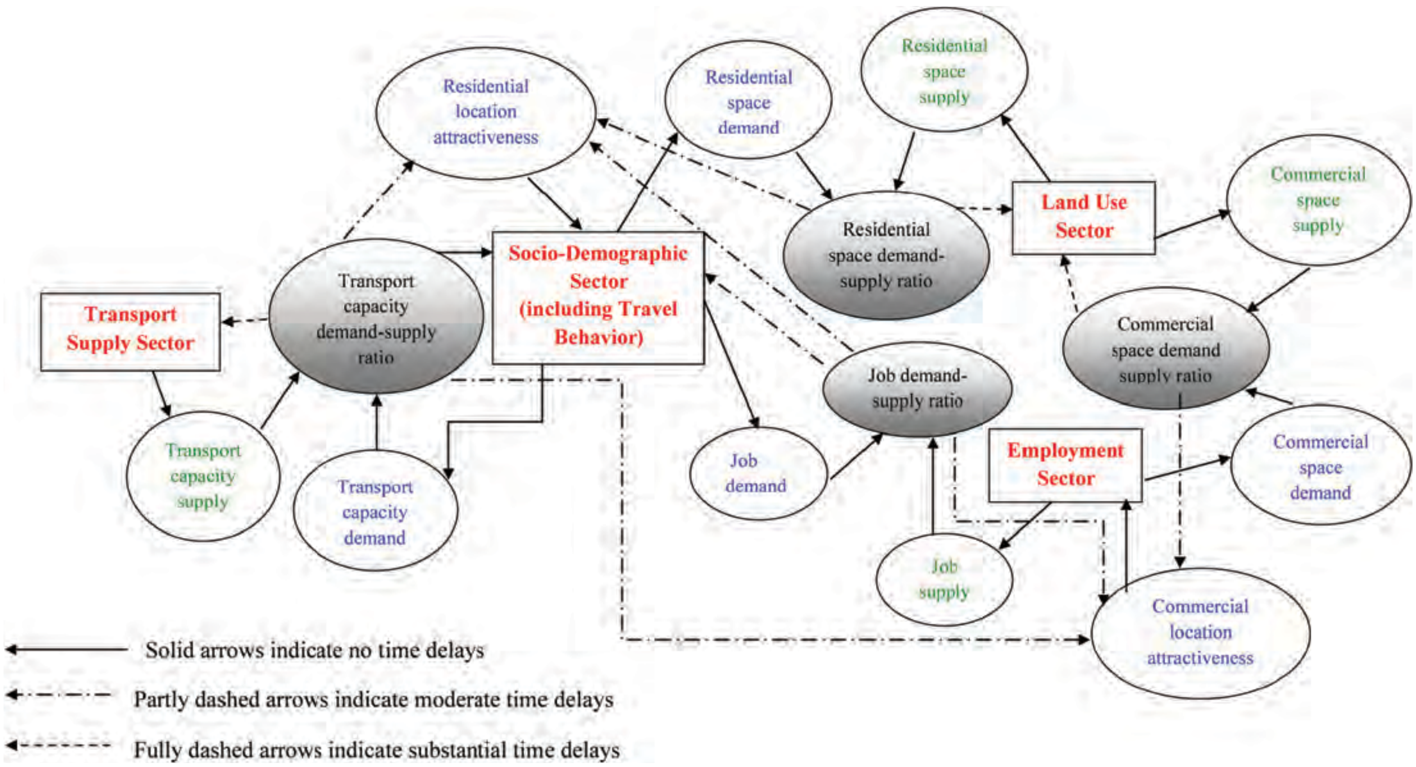


Figure 6-1. Overall relationship between the SD model sectors.

the system, such as those related to supplying new transportation infrastructure or new housing and commercial infrastructure. Even decisions to change residence or business locations can take some time to occur, so one cannot adjust immediately to changes in prices, congestion, job availability, etc. The SD methodology is specifically designed to reflect these types of dynamic phenomena. Figure 6-1 shows the main feedback relationships between the sectors.

Underneath this conceptual representation are many endogenous and exogenous variables—the model and scenario variables, respectively.

- Model variables affect and are affected by the rest of the system. There are two types of these variables: (1) those that define the current state or base conditions, and (2) those that define the transitions or rates of change in its state.
- Scenario variables are outside variables that affect but are not affected by the behavior of the system. In our SD model, these are the variables that distinguish the four scenarios.

Figure 6-2 presents the model variables that comprise *Impacts 2050*. The most detailed sector is the socio-demographic sector, which will evolve the population over time. The other three sectors—transport supply, land use, and employment—are modeled in a more aggregate manner. These sectors are not the primary focus of the model, but it is important that they be represented, as they have a crucial influence on the evolution of the population and travel within a region. Detailed documentation for each of the sectors can be found in Appendix B.

The overall design of our SD model was informed by other strategic land use/transportation models—specifically the DELTA, GreenSTEP, UrbanSIM, and Dynamic Urban Model.

- DELTA (Development, Transition, Location, Employment, and Area-quality), developed by David Simmonds Consultancy, is designed to operate in iteration with a local transport

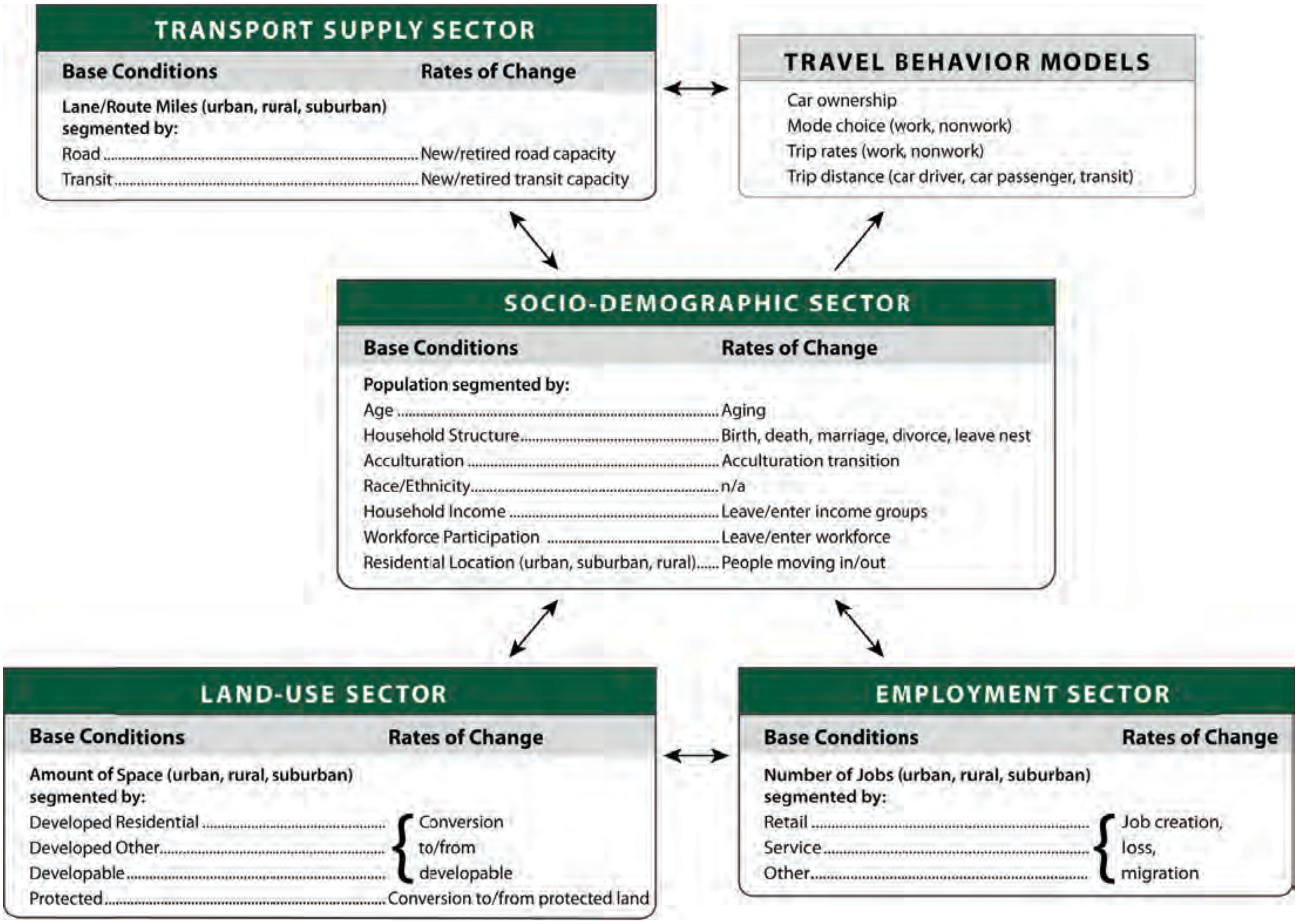


Figure 6-2. **Impacts 2050 *model structure.***

model. DELTA operates in one-year steps, with interaction with the local transport model typically occurring every two or five years, depending on the run times of the transport model.

- The GreenSTEP model (Greenhouse gas Statewide Emissions Planning), developed by Brian Gregor, forecasts greenhouse gas (GHG) emissions from the transport sector for the state of Oregon DOT.
- UrbanSIM is a simulation model for integrated planning and analysis of urban development. It was developed by Paul Waddell at the University of Washington (now at UC Berkeley), and is available as a public domain software package intended for MPO use.
- The Dynamic Urban Model (DUM) was developed by John Swanson of Steer Davies Gleave (SDG) to simulate the interaction between transport, land use, population, and economic activity in an urban area.

The heart of the SD model is the socio-demographic sector. To predict changes in this sector over time, *Impacts 2050* first profiles the base-year population across a range of attributes that are associated with travel behavior. It then evolves this population over time, simulating transitions from one category in each of these attributes to another category. Generally, the SD model segments a region's population by age, household structure, income, race/ethnicity, acculturation, residence location, area type, and work status. The model then "evolves" this population

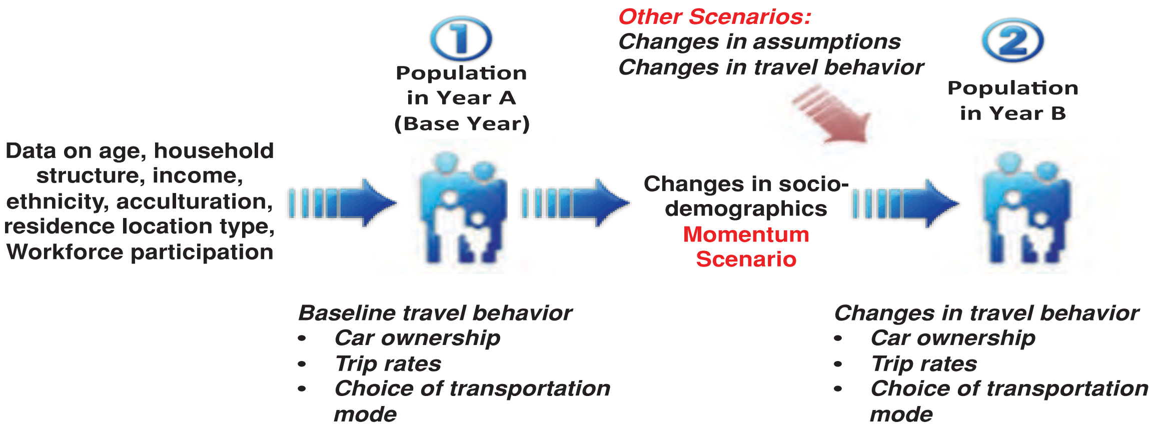


***Figure 6-3. Evolving the population over time in travel:* Impacts 2050.**

over time, simulating the population's transitions from one category in each of these segments to another category over time (e.g., aging the population into different categories: 0–15, 16–29, 30–44, 45–59, 60–74, 75 and older). The evolution of the population over time affects travel behavior, which is indicated in terms of car ownership, trip rates and distance, and mode choice. The presence of other sectors enables the incorporation of feedback loops that represent the dynamics of the transportation system. The model contains more than 700 variables representing five sectors (socio-demographics, travel behavior, land use, employment, and transport supply) that are linked by mathematical formulas. The model simulation starts with base values for the year 2000 and runs through 2050.

The impacts on travel behavior are calculated in terms of car ownership, trip rates, and choice of transportation mode. Changes in expected transitions can be tested as scenario variables. This process is illustrated in Figure 6-3.

6.2 Scenarios in *Impacts 2050*

The four scenarios are integrated into *Impacts 2050* through their underlying assumptions. The scenario assumptions are the attitudes, policies, or other phenomena that were used to develop and differentiate the scenarios. A problem is that the language of the scenarios—which is very broad and qualitative—does not translate directly into the language of the model. To help with this process, we introduced a separate conceptual layer called "scenario variables," which is illustrated in Figure 6.4.

The scenario variables represent classes of assumptions, such as "attitudes toward having children" or "environmental conditions," that affect clusters of model variables. Each scenario will affect the scenario variables differently; for example, under Gentle Footprint, people will choose on average to have fewer children. The scenario variables can then be translated directly into model variables, such as fertility rates. Scenario variables can affect more than one model variable, and particular model variables may be affected by a number of different scenario variables. Note that the scenario variables are not a functional part of the model; their role is to help calibrate the model for different scenarios, design new scenarios, and communicate the connection between the scenarios and the model.

Impacts 2050 contains default programs that run each of the scenarios. The assumptions are clearly indicated for each scenario. When the model is run for given scenarios, the results highlight their distinct futures. There are key differences in population structure, workforce

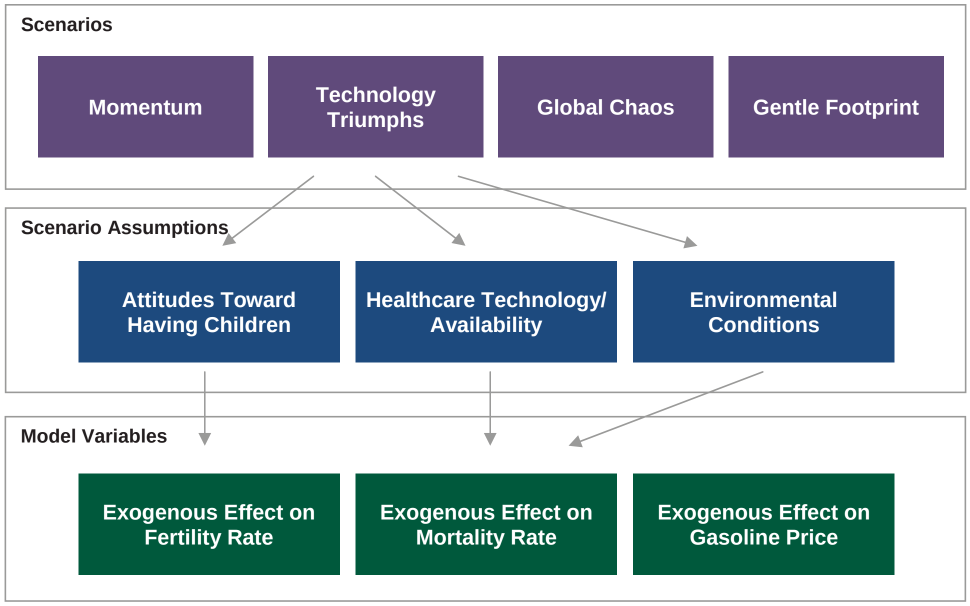


Figure 6-4. Using the technology triumph scenario as an example, conceptual representation of interaction among scenarios, assumptions, and model variables.

participation, immigration, and travel behavior across the scenarios. For example, auto VMT per capita in 2050 is much lower under the Global Chaos and Gentle Footprint scenarios than in the other two scenarios. This is due to differing assumptions. In Gentle Footprint, the lower VMT per capita is by choice, whereas in Global Chaos it is due to poor economic conditions and lack of opportunities. With the same reasoning, car-sharing and walk/bike modes are much higher under the Global Chaos and Gentle Footprint scenarios than in the Momentum and Technology Triumphs scenarios.

An innovative feature of *Impacts 2050* is that users can modify the default structures to create alternatives to these four scenarios. The assumptions can be changed, and new scenarios can be run, by modifying the parameters indicated for model variables.

6.3 Regional Settings for Model Testing

A goal of this project was to develop a tool that state and local transportation agencies can use to understand how socio-demographics will impact travel behavior in the long-term future, and to examine how the illustrative scenarios developed in this project could play out in their regional jurisdictions. So, it was important to identify a set of metropolitan areas that could serve as test sites during tool construction. The research team did not focus on metro areas that were specifically illustrative of the four scenarios, since the objective was to apply and test the scenarios in the different regional settings. The following relevant characteristics were important for differentiating the regional settings:

- Population growth trend: population change over last 50 years, net growth rate.
- Nature of growth: domestic versus international migration.
- Spatial distribution: land area, density.
- Economic base: socioeconomic status, income disparity, unemployment rate.
- Diversity: household structures, age, racial/ethnic composition.

- Transportation system orientation: highway versus transit supply, congestion levels, commute mode share.
- Location: major region of the country, as this tends to reflect era of development as well as various socio-demographic traits, such as age, household type, educational attainment, wealth, and housing.

In addition, the team thought it was important to distinguish among the five U.S. Census regions in defining the base sampling frame: Northeast, Southeast, Midwest, Southwest, and Pacific West. Each of these areas has a distinctly different character that would be reflected in the attributes listed above (see Table 6-1). With these criteria in mind, the following metro areas were selected:

- Southeast: Atlanta, GA
- Northeast: Boston, MA
- Midwest: Detroit, MI
- Southwest: Houston, TX
- Pacific West: Puget Sound (or Seattle, WA, as short-hand)

Impacts 2050 has embedded data for these five metropolitan regions. The simulation model used to compute the scenario indicators uses a custom database for each region. Four sets of data must be specified to define the year 2000 base conditions for the simulated region: demographic, land use, employment, and transportation supply. Data have already been entered into *Impacts 2050* for the five regions. For any other region, these data must be input (as is fully explained in the *User Guide*). For this reason, the team has ensured that the input data will be publicly available from the U.S. Bureau of the Census and the Federal Transit Administration.

Table 6-1. Summary of the characteristics of selected metro regions.

Characteristics	Boston	Atlanta	Detroit	Houston	Seattle
Population growth since 1960	77%	443%	16%	382%	219%
Net growth rate	5.03%	9.69%	3.5%	13.5%	8.16%
Population growth in center city	–7%	–13%	–57%	125%	11%
Population in center city	13%	8%	17%	35%	18%
Metropolitan statistical area land area	3,506	8,377	3,914	8,928	5,894
Population density	1,298	654	1,099	666	583
Average household size	2.50	2.68	2.53	2.83	2.49
Households with children	31%	38%	33%	41%	32%
Home ownership	62%	66%	71%	63%	62%
College degree	42%	34%	27%	28%	37%
White	75%	51%	68%	40%	68%
Hispanic	9%	10%	4%	35%	9%
Median age	38.5	34.9	39.1	33.2	36.8
Unemployment	7%	9%	13%	7%	7%
Median income	$69.9k	$57.5k	$52.4k	$55.2k	$65.4k
Population in poverty	19%	20%	24%	21%	17%
Transit commuting	12%	3%	2%	2%	8%
Auto commuting	69%	77%	84%	79%	70%
Roadway congestion index	1.09	1.27	1.14	1.15	1.08
Daily VMT per capita	23.4	27.9	25.6	33.3	22.1

6.4 Running *Impacts 2050* for the Test Regions

A set of quantitative indicators is built into *Impacts 2050* (See Table 5-1 for the scenario framework, including the key indicators used in the scenario development.) The indicators are the results of the model simulations related to the scenarios. They were developed to provide an overview of "what might happen in the future" (i.e., travel impacts) and "why it might be happening" (i.e., socio-demographic trends). The *Impacts 2050* output is presented in both table and graphic form. Figure 6-5 illustrates graphic output directly from *Impacts 2050.*

Tables 6-2 through 6-5 compare the results of 2050 projections for the five regions with 2010 Census estimates for a subset of these indicators. When compared with 2010, 2050 looks different from today for most regions under the various scenarios. These results support our scenario approach, which was to develop coherent pictures of the future that move off in different directions.

The Momentum scenario is our business-as-usual case. It simulates today's population in a region through time to 2050, considering relationships among model variables and feedback

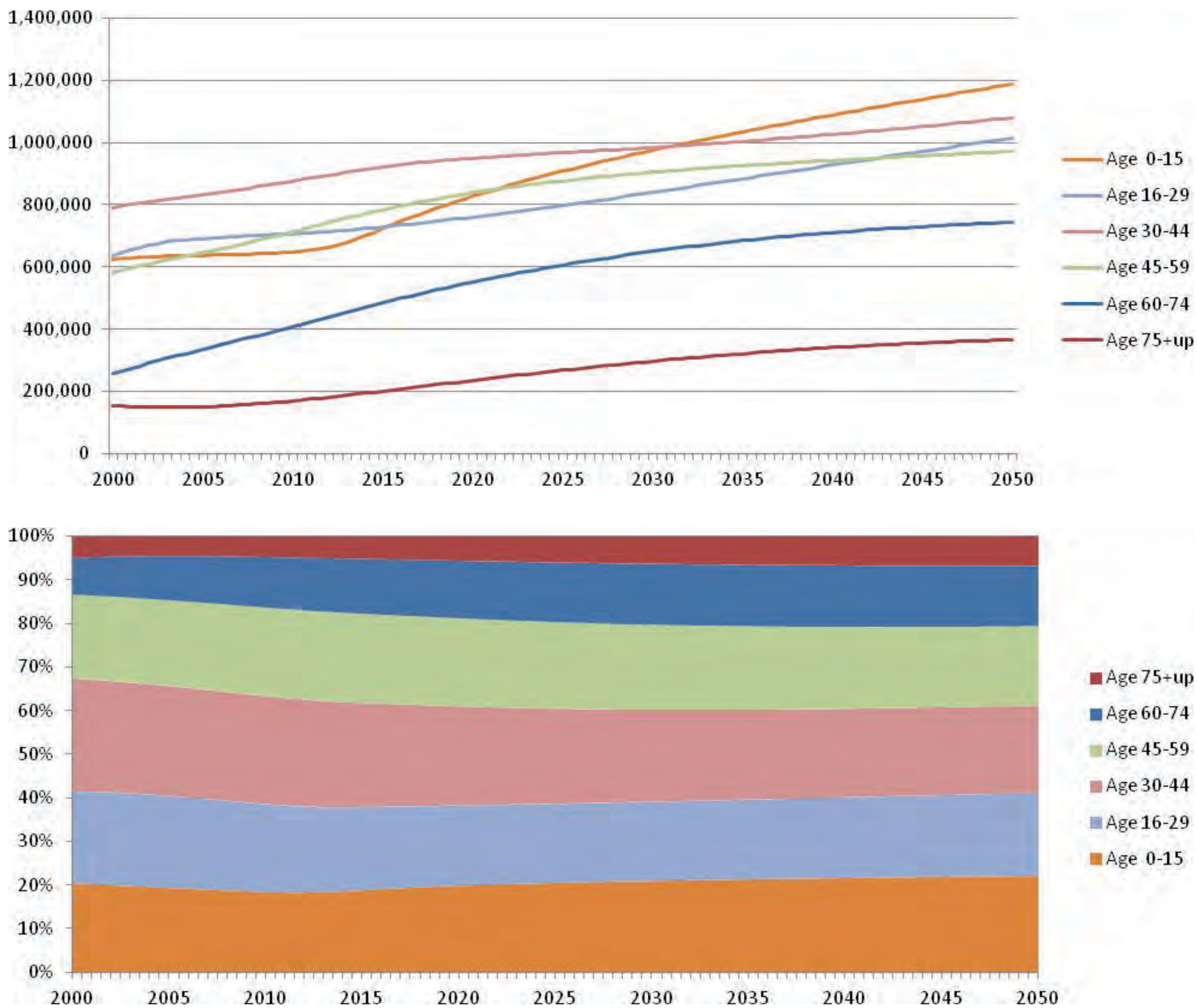


Figure 6-5. Outputs from* Impacts 2050*, population by age group (Seattle momentum scenario).

Table 6-2. 2010 statistics and 2050 projections in Atlanta by scenario.

Indicators	2010 Statistics	Atlanta 2050 Projection			
		Momentum	Tech Triumphs	Global Chaos	Gentle Footprint
Auto VMT per capita	11,115	10,251	11,461	5,451	4,167
Percent noncar owning	2.5%	3.0%	2.5%	5.2%	4.1%
Percent car-sharing	22%	22%	17%	34%	29%
Average car occupancy	1.6	1.6	1.5	1.8	1.8
Transit mode share	2%	2%	2%	2%	3%
Walk/bike mode share	11%	11%	10%	19%	22%
Work trips per capita	0.5	0.5	0.5	0.4	0.3
Nonwork trips per capita	2.9	3.0	2.9	1.7	1.7
Population	5,262,023	8,225,550	7,205,888	5,694,525	7,910,911
Percent under 16	22%	23%	20%	17%	15%
Percent over age 60	14%	19%	23%	19%	27%
Percent over age 75	4%	6%	9%	4%	9%
Percent Hispanic	8%	12%	11%	11%	13%
Percent low income	32%	33%	28%	51%	36%
Percent high income	19%	27%	32%	17%	26%
Percent foreign-born	16%	13%	11%	11%	24%
Percent in workforce	47%	39%	46%	43%	48%

Table 6-3. 2010 statistics and 2050 projections in Boston by scenario.

Indicators	2010 Statistics	Boston 2050 Projection			
		Momentum	Tech Triumphs	Global Chaos	Gentle Footprint
Auto VMT per capita	9,874	8,709	9,741	4,445	3,293
Percent noncar owning	4.6%	5.0%	4.3%	8.2%	7.2%
Percent car-sharing	24%	23%	19%	36%	30%
Average car occupancy	1.6	1.7	1.6	1.9	1.8
Transit mode share	3%	3%	3%	4%	6%
Walk/bike mode share	17%	18%	17%	28%	31%
Work trips per capita	0.5	0.4	0.4	0.3	0.3
Nonwork trips per capita	2.9	3.1	3.0	1.8	1.8
Population	4,662,662	6,149,585	5,356,991	4,242,692	6,227,814
Percent under 16	18%	22%	19%	16%	14%
Percent over age 60	18%	21%	25%	21%	30%
Percent over age 75	6%	7%	10%	5%	11%
Percent Hispanic	8%	10%	10%	10%	12%
Percent low income	28%	31%	27%	48%	35%
Percent high income	23%	28%	34%	18%	27%
Percent foreign-born	19%	17%	15%	15%	31%
Percent in workforce	51%	39%	46%	43%	48%

Table 6-4. 2010 statistics and 2050 projections in Detroit by scenario.

Indicators	2010 Statistics	Detroit 2050 Projection			
		Momentum	Tech Triumphs	Global Chaos	Gentle Footprint
Auto VMT per capita	10,126	9,580	10,586	4,886	3,775
Percent noncar owning	3.0%	3.3%	2.8%	5.4%	4.5%
Percent car-sharing	31%	30%	25%	45%	38%
Average car occupancy	1.6	1.6	1.6	1.9	1.8
Transit mode share	1%	1%	1%	2%	3%
Walk/bike mode share	11%	12%	11%	20%	23%
Work trips per capita	0.4	0.4	0.4	0.3	0.3
Nonwork trips per capita	3.6	3.7	3.6	2.2	2.2
Population	4,372,010	5,245,748	4,663,877	3,764,011	5,251,724
Percent under 16	20%	22%	19%	17%	15%
Percent over age 60	18%	20%	25%	20%	28%
Percent over age 75	6%	7%	10%	5%	10%
Percent Hispanic	3%	5%	4%	4%	5%
Percent low income	26%	31%	27%	49%	35%
Percent high income	20%	28%	34%	18%	27%
Percent foreign-born	11%	12%	10%	10%	24%
Percent in workforce	44%	39%	46%	42%	47%

Table 6-5. 2010 statistics and 2050 projections in Houston by scenario.

Indicators	2010 Statistics	Houston 2050 Projection			
		Momentum	Tech Triumphs	Global Chaos	Gentle Footprint
Auto VMT per capita	9,560	9,072	10,171	4,859	3,720
Percent noncar owning	3.7%	4.2%	3.6%	6.5%	5.5%
Percent car-sharing	30%	30%	25%	43%	37%
Average car occupancy	1.7	1.7	1.6	1.9	1.8
Transit mode share	2%	2%	2%	2%	3%
Walk/bike mode share	11%	12%	11%	20%	22%
Work trips per capita	0.5	0.5	0.5	0.4	0.3
Nonwork trips per capita	2.7	2.8	2.7	1.6	1.6
Population	5,944,540	9,291,817	8,092,777	6,380,152	8,951,738
Percent under 16	23%	23%	21%	18%	16%
Percent over age 60	13%	19%	23%	19%	26%
Percent over age 75	4%	6%	9%	4%	9%
Percent Hispanic	34%	42%	40%	40%	45%
Percent low income	38%	35%	31%	53%	39%
Percent high income	15%	25%	31%	16%	23%
Percent foreign-born	24%	17%	15%	15%	28%
Percent in workforce	46%	40%	47%	43%	48%

loops for the different sectors. Looking at the universal changes across regions for this scenario, *Impacts 2050* results seem to indicate auto VMT per capita will drop, walk/bike mode share will increase, and people over age 60 will comprise a much larger share of the regional population. But unique changes are indicated in the five regions.

Under the Momentum scenario, Atlanta in 2050 will have about 3 million more residents (see Table 6-2). Compared with today, a greater portion of these residents will be over the age of 60 and Hispanic, and will have a higher income. There will be fewer workers. In this socio-demographic context, Atlanta will be experiencing a slight change in auto VMT, but transit and walk/bike shares will be about the same as today. The percentage of people without a vehicle will be the same as today—about 3 percent. Travel behavior in Atlanta looks the most different from today under the Global Chaos and Gentle Footprint scenarios. Under these two scenarios, auto VMT decreases substantially (by more than 50 percent). Nearly one-third of residents will carpool or car-share. The walk/bike mode share will increase from 11 percent to between 19 and 22 percent.

The socio-demographic profile of Atlanta changes the most compared with today under the Gentle Footprint scenario. Nearly one of three residents will be over the age of 60, and there will be a much smaller percentage of children. The share of Hispanics will increase from 8 to 13 percent, and the percentage of foreign-born residents will increase from 16 to 24 percent. But there will be about the same number of workers in the region as today.

In 2050 under the Momentum scenario, Boston will have about 1.5 million more residents (see Table 6-3). Demographically, Boston will look a lot like today, except for the fact that a greater portion of residents will be under the age of 16 and there will be substantially fewer workers. In this socio-demographic context, Boston will be experiencing lower auto VMT, but in most other statistics, travel behaviors will not change much.

As in Atlanta, the Global Chaos and Gentle Footprint scenarios appear to alter current travel behavior patterns most when compared with those of today. Under these two scenarios, VMT decreases substantially and car-sharing and nonmotorized travel increase by about 10 percent. The socio-demographic profile of Boston alters the most under the Gentle Footprint scenario in much the same way as Atlanta—people live longer, so there are more people over age 60 and age 75. Green businesses and increased farming activity increase the immigrant population.

Detroit, under the Momentum scenario, will have about 1 million more residents in 2050 (see Table 6-4). But the demographic makeup of Detroit will be much like that of today. The significant change will be that income inequality will grow with both more low-income and more high-income residents.

In terms of travel behavior, Detroit will retain its current auto orientation: high auto VMT per capita, high carpooling or car-sharing, and low transit and walk/bike shares. In the future under the Momentum scenario, auto VMT per capita will decrease, but by a small percentage. Carpooling or car-sharing will not decrease much, and the share of nonmotorized modes will not increase. In terms of the impact of the other scenarios on travel behavior, Global Chaos and Gentle Footprint will cut auto VMT per capita significantly, while under Tech Triumphs it will increase slightly. Car-sharing will decrease slightly under Tech Triumphs, but will increase substantially under Global Chaos and Gentle Footprint. Walking and biking also will increase under the latter two scenarios, but will stay about the same under Tech Triumphs.

The percentage of children will decrease under all three alternative scenarios, but the decrease will be greatest under Gentle Footprint. The percentage of people over age 60 will increase substantially under both Gentle Footprint and Tech Triumphs. Income inequality will be lessened under the Tech Triumphs scenario and exacerbated under Global Chaos and also to some degree under Gentle Footprint.

Houston, under the Momentum scenario, will experience a population increase of slightly more than 3 million people in 2050—about the same projected increase as for Atlanta (see Table 6-5). Compared with today, the population distribution will be older (nearly one in five people will be over age 60). The portion of people in Houston who are older than 60 will increase substantially under Tech Triumphs and will increase even more under Gentle Footprint. There is a large variation in the percentage of the population that is in the workforce under the different scenarios. Workers will decrease significantly under the Momentum scenario and less under the Global Chaos scenario, and will increase under the Tech Triumphs and Gentle Footprint scenarios.

Today, large percentages of Houston's population are Hispanic (34 percent) and immigrant (24 percent). Under the Momentum scenario, the percentage of Hispanics will increase to 42 percent, but the percentage of immigrants will decrease to 17 percent. Under the Tech Triumphs and Global Chaos scenarios, the growth in Hispanics will be lower than under the Momentum scenario and will be even higher under the Gentle Footprint scenario. In terms of the immigrant population, it will increase to 28 percent under the Gentle Footprint scenario; however, under the other two scenarios, the percentage of foreign-born residents will decrease to 15 percent.

Under the Momentum scenario, travel behavior will not change much in Houston by 2050, with only a slight projected decrease in auto VMT per capita. Under Tech Triumphs, auto VMT per capita will slightly increase and will significantly decrease under the Global Chaos and Gentle Footprint scenarios. Car-sharing and walk/bike mode shares will increase significantly under the latter two scenarios. Under Tech Triumphs, car-sharing will actually decrease relative to today and to the Momentum scenario.

Seattle, under the Momentum scenario, will experience a population increase of slightly less than 2 million persons in 2050 (see Table 6-6). Compared to today, the population distribution

Table 6-6. 2010 statistics and 2050 projections in Seattle by scenario.

Indicators	2010 Statistics	Seattle 2050 Projection			
		Momentum	Tech Triumphs	Global Chaos	Gentle Footprint
Auto VMT per capita	9,916	8,728	9,822	4,528	3,351
Percent noncar owning	5.6%	6.4%	5.4%	10.9%	8.9%
Percent car-sharing	18%	17%	14%	28%	23%
Average car occupancy	1.5	1.6	1.5	1.8	1.7
Transit mode share	4%	4%	4%	5%	7%
Walk/bike mode share	18%	20%	18%	29%	32%
Work trips / capita	0.6	0.4	0.5	0.4	0.3
Nonwork trips /capita	2.6	2.8	2.7	1.6	1.6
Population	3,522,980	5,365,107	4,632,781	3,656,502	5,299,978
Percent under 16	18%	22%	19%	17%	14%
Percent over age 60	16%	21%	25%	20%	29%
Percent over age 75	5%	7%	10%	5%	10%
Percent Hispanic	7%	9%	8%	8%	10%
Percent low income	28%	32%	27%	49%	36%
Percent high income	17%	27%	33%	17%	26%
Percent foreign-born	18%	16%	14%	14%	28%
Percent in workforce	49%	39%	46%	43%	48%

will be both older and younger. The percentage of workers will decrease by almost 10 percentage points. As in the other regions, there will be a decrease in auto VMT per capita.

In terms of the other scenarios, under Tech Triumphs auto VMT per capita is about the same as today as will be most other travel behavior patterns. The percentage of older persons increases substantially, that of children not so much. Income disparities among the regional population will decline. There will be fewer immigrants than today or compared to Momentum. The percent of the population in the workforce will be about the same as today. Global Chaos and Gentle Footprint have the same impacts as in other regions—dramatically decreasing auto VMT per capita. In Seattle, however, these two scenarios also have an influence on the percent of noncar owning households, which will increase significantly. Under Global Chaos, the poor economy leads to a significant drop in workers and a significant increase in the percent of low-income household. Under Gentle Footprint, the percent of the population in the workforce remains about the same as today but income inequality increases substantially.

Table 6-7 presents the comparison of the 2050 outcomes with 2010. We summarize this result as percentage or percentage point changes accordingly. The magnitude and direction of changes are indicated by arrows pointing up (increasing), down (decreasing), and sideways (no or small change). A data table presenting the statistical back-up for Table 6-7 is found in Appendix C.

An analyst can examine this information and attempt to understand the underlying influences that likely affect the movement in one direction versus another. Hypotheses can be tested by running with new assumptions in mind.

For example, auto VMT per capita decreases over time in 13 out of the 20 scenarios tested. Tech Triumphs deviates from this main trend in all regions. A potential reason for this deviation is increased overall economic growth as well as employment growth. Under the Momentum, Global Chaos, and Gentle Footprint scenarios, the auto VMT per capita decreases probably because of both the aging of the population (i.e., percentage of seniors goes up over time) and lower workforce participation (i.e., percentage of people who are employed goes down). These demographic changes happen in the Tech Triumphs scenario as well; however, this scenario indicates an increase in income, which leads to high car ownership and less car-sharing. The decrease in auto VMT per capita is strong in the Global Chaos and Gentle Footprint scenarios due to distinct reasons. In the Global Chaos scenario, fewer trips are made due to poor economic conditions. In Gentle Footprint, we see an increase in environmental consciousness that is associated with both a decrease in reliance on the auto and an increase in the use of alternative modes of travel.

Results are not always the same across the regions. For example, within the Global Chaos scenario, transit mode share increases by 24 percent in Atlanta, 8 percent in Boston, 21 percent in Detroit, 17 percent in Houston, and 19 percent in Seattle. One can test our assumptions about why this might be happening. For example, the relatively high transit share in Boston at the start of the modeling period leads to this outcome in the direction of the trajectory.

The next chapter discusses the value of *Impacts 2050* to state DOTs and MPOs. While many different inputs went into writing that chapter, one data set was derived from onsite demonstrations and beta tests of the poll that the research team conducted with three of the five regions for which data are included in the tool. Detailed information about these evaluative activities is provided in Appendix C. Here we present seven broad findings:

- Generally, *Impacts 2050* was favorably received in each of the demonstrations, and most participants were receptive to the tool concept.
- The perceived utility of *Impacts 2050* is initially tied to how far the transportation agencies have progressed with regard to their long-range transportation planning process; after

Table 6-7. Selected indicator trajectories (2010–2050) by scenario by metropolitan region.

	Atlanta				Boston				Detroit				Houston				Seattle			
Indicator	M	TT	GC	GF	M	TT	GC	GF	M	TT	GC	GF	M	TT	GC	GF	M	TT	GC	GF
Auto VMT per capita	→	→	↓	↓	↘	↘	↓	↓	→	→	↓	↓	→	→	↓	↓	↘	→	↓	↓
Percent non-car owning	↗	→	↑	↑	→	→	↑	↑	↗	→	↑	↑	↗	→	↑	↑	↗	→	↑	↑
Percent car-sharing	→	↘	↑	↑	→	→	↑	↑	→	↘	↑	↗	→	↘	↑	↗	→	↘	↑	↑
Average car occupancy	→	→	↗	→	→	→	↗	↗	→	→	↗	↗	→	→	↗	→	→	→	↗	↗
Transit mode share	↗	→	↗	↑	→	→	→	↑	→	→	↗	↑	↗	→	↗	↑	→	→	↗	↑
Walk/bike mode share	→	→	↑	↑	→	→	↑	↑	→	→	↑	↑	→	→	↑	↑	→	→	↑	↑
Work trips per capita	↘	→	↓	↓	↘	↘	↓	↓	↘	→	↘	↓	↘	→	↘	↓	↘	→	↓	↓
Non-work trips per capita	→	→	↓	↓	→	→	↓	↓	→	→	↓	↓	→	→	↓	↓	→	→	↓	↓
Population (millions)	↑	↑	→	↑	↑	↑	→	↑	↗	→	↘	↗	↑	↑	→	↑	↑	↑	→	↑
Percent under 16	→	→	↘	↓	↗	↗	→	↘	↗	→	↘	↓	→	↘	↘	↓	↗	→	→	↘
Percent over age 60	↑	↑	↑	↑	↗	↗	↗	↑	↗	↑	↗	↑	↑	↑	↑	↑	↑	↑	↗	↑
Percent over age 75	↑	↑	↗	↑	↗	↗	↘	↑	↗	↑	↘	↑	↑	↑	↗	↑	↑	↑	→	↑
Percent Hispanic	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↗	↗	↗	↑	↑	↑	↑	↑
Percent low income	→	↘	↑	↗	→	→	↑	↗	↗	→	↑	↑	→	↘	↑	→	↗	→	↑	↗
Percent high income	↑	↑	→	↑	↗	↗	↘	↗	↑	↑	↘	↑	↑	↑	→	↑	↑	↑	→	↑
Percent foreign born	↘	↓	↓	↑	→	→	↘	↑	↗	→	↘	↑	↓	↓	↓	↗	↘	↓	↓	↑
Percent in workforce	↘	→	→	→	↘	↘	↘	→	↘	→	→	→	↘	→	→	→	↘	→	↘	→

Note: M= Momentum, TT=Tech Triumphs, GF=Gentle Footprint, GC=Global Chaos

Legend:

↑ greater than 25% increase

↗ 10-25% increase

→ -10% to 10% change

↘ 10-25% decrease

↓ greater than 25% decrease

consideration and discussion, participants discovered other uses for *Impacts 2050* beyond its contribution to the development of their long-range plans.

- There was agreement that *Impacts 2050*'s scenario analysis function will be useful to transportation agencies. Participants welcome better ways to conduct scenario planning, and thereby reach agreement on changes from the status quo.
- Two major and important advantages of *Impacts 2050*, compared with the models currently being used for long-range planning, are (1) it runs scenarios and produces output much faster than other models, and (2) its inclusion of socio-demographic linkages with transportation and land use fills a transportation planning gap.
- A drawback to *Impacts 2050*, which could be a potential factor that deters receptivity to it, is that many transportation agencies have already invested in a wide array of modeling and forecasting tools; they are wary of adding another new tool that someone will have to manage and maintain (when some staff have not yet mastered those already being used).
- Most modelers are used to working with spatial data, so the limited spatial definition of *Impacts 2050* (urban, suburban, regional) could be seen as a drawback to its applicability.
- Two keys to *Impacts 2050*'s adoption and use are in the quality and level of detail provided through the *User Guide* and the usefulness of the *User Guide.*

In sum, the feedback received in the demonstrations indicated a need for, and interest in, *Impacts 2050* and a quality *User Guide.*

CHAPTER 7

Key Indicators and Monitoring Approach

Chapter 7 Takeaways

- Key indicators or early warning signs can indicate the likely directions of trends in key areas that affect transportation.
- Economic indicators that change before the economy as a whole changes.
- Driving forces that distinguish the four scenarios are economic growth, number of jobs, rate of job loss, rate of job creation, age structure, percentage of foreign born, number of lane miles of road, pro-environment attitudes, and existence of a carbon tax. Critical uncertainties in these variables will affect transportation trends.

"No sensible decision will be made any longer without taking into account not only the world as it is, but the world as it will be."

Isaac Asimov, author

7.1 Defining Key Indicators

One of the fundamental uses of scenarios is that, if considered plausible, they can help policy makers and other decision makers anticipate and prepare for change. One of the key recommendations from transportation planning decision makers, the potential users of *Impacts 2050*, was that it would be useful to develop a way to monitor key trends in relation to each scenario.

The scenario planning literature discusses the utility of identifying early warning signs that can indicate the directions of trends in critical parameters. For example, VMT estimates are "lagging" indicators in the sense that they inform us after travel behaviors have already changed. By contrast, "key" indicators are useful in signaling future changes in travel behavior. For example, a traffic light that turns yellow before it turns red tells us to stop in advance of the red light. Thus, a key indicator is simply an early warning sign of future events.

We can think of the early warning signs being applied in the same way that leading economic indicators are used to monitor the health of the U.S. economy. In 1995, the Bureau of Economic Analysis of the U.S. Department of Commerce created a private, nongovernmental organization to determine a monthly leading index. The Conference Board publishes a composite Leading Economic Index consisting of 10 indicators designed to predict the activity in the U.S. economy six to nine months in the future. According to Webster's Dictionary, leading economic indicators are "indicators that change before the economy as a whole changes." Drawn across sectors that influence economic health, these indicators include average weekly jobless claims for unemployment insurance, building permits for new private housing units, vendor performance (time it takes to deliver orders to industrial companies), and the Standard & Poor's 500 stock index.

Similarly, this study has attempted to consider all of the influencing sectors in *Impacts 2050* (e.g., demographics, employment, land use) when identifying early warning signs. Doing so forces the acknowledgement of shifts in trends outside of the transportation-specific domain. The purpose of this exercise is, then, to ask: Which scenarios are we moving toward, and what are the implications?

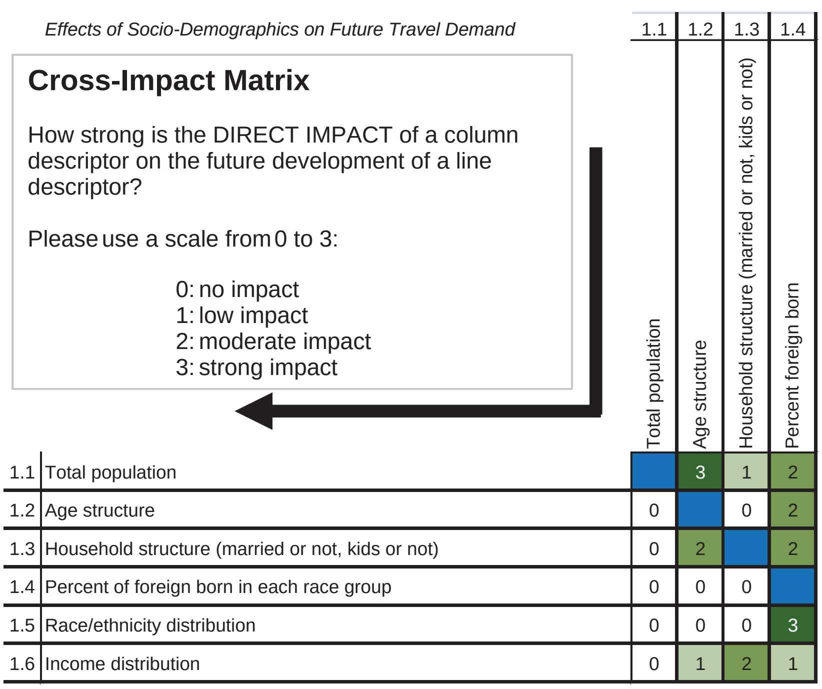
The *Impacts 2050* scenarios provide a useful platform for building contingency plans that can be tested against the "what if" projections embedded in the scenarios. For example, are contingencies robust and resilient over more than one scenario? If not, can they be adapted to cope with the challenges in the scenarios?

Specific early warning signs can be developed on the basis of the key trends set out in the scenarios, supported by appropriate data sources that are monitored regularly. For example, under the Gentle Footprint scenario, potential early warning signs could include shifts in the national environmental agenda due to public attitudes or the political momentum for a carbon tax. Under the Technology Triumphs scenario, early warning signs might be the strength of GDP growth or market penetration of self-driving vehicles. Different users of the scenarios may be more interested in one category of early warning signs than another, depending on their assumptions about critical uncertainties.

7.2 Driving Forces in the Scenarios

The research team associated early warning signs with key drivers in the scenarios. To identify the key drivers, the team conducted a cross-impact analysis among the SD model variables (Gausemeier et al. 1998), which include base-condition variables (such as age structure), rates-of-change variables (such as birth rate), and qualitative policy variables (such as introduction of a carbon tax). All of these variables are embedded in the assumptions for each scenario in *Impacts 2050*, as noted in Table 4.1 in Chapter 4.

The impacts of the different model variables on each other were recorded in a cross-impact matrix (or influence matrix), using a scale from 0 (no impact) to 3 (strong impact). In the cross-impact analysis, it is important to assess the direct—not indirect—impacts of the variables. Figure 7-1 presents an extract of the cross-impact analysis matrix; the entire matrix is presented in Appendix E. Figure 7-1 should be read from column to row (note the direction of the arrow). For example, the total population has no direct impact on age structure, so that relationship would be rated 0. By contrast, age structure has a strong direct impact on total population, so it was



		1.1 Total population	1.2 Age structure	1.3 Household structure (married or not, kids or not)	1.4 Percent foreign born
1.1	Total population		3	1	2
1.2	Age structure	0		0	2
1.3	Household structure (married or not, kids or not)	0	2		2
1.4	Percent of foreign born in each race group	0	0	0	
1.5	Race/ethnicity distribution	0	0	0	3
1.6	Income distribution	0	1	2	1

Figure 7-1. Extract of cross-impact analysis matrix.

rated 3. This exercise establishes the degree of interconnectedness of all indicators. Figure 7-1 is a matrix, so all variables are included in all columns and all rows. It should also be noted that the scores in the matrix are subjective; they are based on the judgment of the research team.

Table 7-1 presents the results of the cross-impact analysis for each model variable in terms of the passivity score (i.e., that variable being influenced by other SD model variables) and activity score (i.e., that variable influencing other SD model variables). The activity and passivity scores are the sums of the scores in the matrix. The table is sorted by activity score, which identifies the most important and least important factors.

The higher the activity index of a variable, the more it influences other variables in the model. For example, attitudes favoring clean energy and environmental protection affected a large number

Table 7-1. Results of cross-impact analysis for each SD model variable.

Variable Number	SD Model Variable Name	Activity Score	Passivity Score
5.3	Rate of economic growth	38	17
2.2	Rate of job creation	26	12
6.4	Attitudes favoring clean energy and environmental protection	26	9
6.3	Introduction of carbon tax	24	3
1.2	Age structure	22	10
1.4	Percentage foreign-born	21	7
2.1	Number of jobs	21	14
2.3	Rate of job loss	20	6
4.1	Number of lane miles for freeways, arterials, and other highways	19	16
2.4	Rate of job migration within region	16	9
5.1	Telework share	16	14
1.7	Aging rate	14	6
1.8	Workforce participation	14	32
1.1	Birth rate	14	17
3.1	Amount of space that is developed residential, developed other, developable, protected	11	27
3.3	Rate of conversion to/from protected	11	19
6.1	Price of gas	11	3
1.11	Marriage rate	10	8
3.2	Rate of conversion to/from developable	10	25
4.2	Total route miles for rail and bus transit	10	29
1.5	Race/ethnicity distribution	9	4
1.9	Population density (urban, suburban, rural shares)	9	24
1.13	Household formation rate	7	14
5.2	Online shopping share of retail sales	7	12
1.3	Household structure	6	23
1.6	Income distribution	6	22
6.2	Total miles of walk and bike paths	6	4
1.12	Divorce rate	5	5
5.4	Adoption of smartphone or mobile devices with Internet access	5	8
5.5	Market penetration of self-driving vehicles	3	4
1.1	Total population	0	14

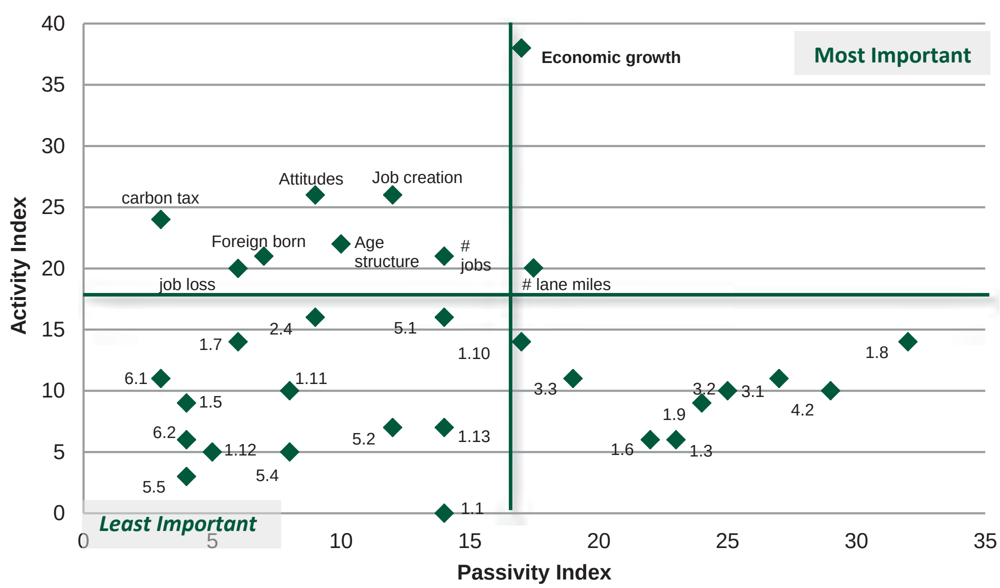
Note: Variable numbers (first column) are cross-referenced in Figure 7-2.

of other indicators, so this variable is highly influential on the other variables in the SD model and has an activity score of 26. On the other hand, the higher the passivity index, the more a variable is driven by other variables. Workforce participation is affected by many other variables, so it is considered highly passive, and has a passivity score of 32.

Variables with both high activity and high passivity indices, such as rate of economic growth, are strongly interconnected in the system, being driver and driven at the same time. While some scores could be scenario specific, this analysis was conducted in an overarching way, across all scenarios. This analysis was the basis for identifying some SD model variables as key drivers in the scenarios.

The four scenarios outline different possible paths to explain how socio-demographics may influence travel demand over the next 30–50 years. While similarities among the scenarios exist, what is important for anticipating and preparing for change are the critical uncertainties, or driving forces, that cause one path to emerge over another. To identify these uncertainties, the research team began with the information about each variable's activity or passivity. The outcome of this analysis is illustrated in Figure 7-2. Scenario drivers, depicted in the top half of Figure 7-2, are variables that "drive" or influence other variables, so are high on the activity index. The quadrants in which the most important and the least important variables are located are noted as such. (Due to the length of some variable names and limited space in the lower two quadrants of Figure 7-2, only the variable number in Figure 7-1 is referenced. For example, 6.1 in the lower left quadrant refers to the "price of gas" variable.)

The future development of these critical uncertainties will strongly affect other variables in the four scenarios. Table 7-2 presents assumptions about how each of these uncertainties will play out in the scenarios. For example, the number of jobs is shown as stable under the Momentum scenario and increasing under the Technology Triumphs and Gentle Footprint scenarios, whereas earlier in this report Table 6-7 shows that the percentage in work decreases over time under the Momentum scenario and is mostly stable with the other scenarios. As discussed in Chapter 3, workforce participation is highly influenced by structural forces in the population age distribution.



Note: Numbers are cross-referenced to the first column in Table 7-1. Key drivers are shown in text.

Figure 7-2. Key drivers as outcomes of the cross-impact analysis.

Table 7-2. How driving forces play out in the scenarios.

Driving Forces	Momentum	Technology Triumphs	Global Chaos	Gentle Footprint
Economic growth	Steady growth	Strong	Low	Moderate
Number of jobs	Stable	Increasing	Decreasing	Increasing
Rate of job loss	Low	Zero	High	Low
Rate of job creation	Stable	High	Low	High
Age structure	Population growth, increase in older people	Population growth, more young people	Slower population growth, fewer older and younger people	Population growth, fewer young people
Percentage foreign-born	Immigration stable	Immigration declines	Immigration declines	Immigration increasing
Total number of lane miles	Constrained due to funding	Private-sector funds	No new capacity	Carbon tax funds
Pro-environment attitudes	Gradual shift to high priority	Low priority	Low in priority	Shifts quickly to high priority
Carbon tax	Gradual introduction	No	No	Yes

7.3 Monitoring Key Indicators or Early Warning Signs

Economic growth is both a highly active and a highly passive scenario variable. So while it is a driver in the scenarios, it is not recommended as an early warning sign to be monitored. The drivers related to employment (number of jobs, rate of job loss, and rate of job creation) directly impact economic growth; therefore, they are better relied upon as key indicators. Other key indicators are demographic: age structure and the percentage foreign-born. The remaining key indicators are social or policy variables: attitudes favoring clean energy and environmental protection, and the introduction of a carbon tax. Data sources for monitoring these indicators are described below. It is recommended that trends analysis be conducted for all indicators at least once every two to three years to determine if a region or regions may be moving toward one scenario versus another. A single indicator may not be a reliable measure for the trend.

7.3.1 Economic Indicators: Number of Jobs, Rate of Job Loss, Rate of Job Creation

Monthly information relating to jobs at the state or regional level is available from the BLS in the form of labor force and unemployment data from the Local Area Unemployment Statistics program and in the form of nonfarm payroll employment estimates from the Current Employment Statistics program. These data cover 372 metropolitan statistical areas and metropolitan New England city and town areas, plus eight areas in Puerto Rico.

7.3.2 Demographic Indicators: Age Structure, Percentage Foreign-Born

Demographic data are available from the American Community Survey, which is an ongoing survey of the U.S. Census Bureau. The survey captures data on age structure, aging, and origin (foreign versus native born). One-year estimates provide detailed data for areas with populations of 65,000 or more.

7.3.3 Transport Supply Indicators: Total Number of Lane Miles for Freeways, Arterials, Other Highways, and Transit

It is assumed that state and local transportation agencies will have the necessary database to monitor this indicator.

7.3.4 Social and Policy Indicators: Attitudes Favoring Clean Energy and Environmental Protection and the Introduction of a Carbon Tax

Ongoing national surveys provide insights into the trends in America's environmental attitudes, such as the Pew Research Center and Gallup. However, these survey results are rarely disseminated at the regional or state level. It is recommended that questions on environmental attitudes be added to existing local, regional, or state surveys. For trend purposes, it would be important to ensure that question wording and sampling methodology are consistent between survey iterations. The report for NCHRP Project 20-07/Task 260, *Putting Customer Research into Practice: Guidelines for Conducting, Reporting, and Using Customer Surveys Related to Highway Maintenance Operations*, provides useful guidance (Zmud 2012). The introduction of a carbon tax is a qualitative variable that is binary (yes, no). If no, it can be monitored in terms of how close a state may be to enacting low-carbon legislation.

7.4 Identifying Indicators Using *Impacts 2050*

In addition to the identified indicators, other candidates for inclusion in the indicator list may be SD model variables that show strong variation in outcomes across scenarios for a particular region. A state DOT or MPO would have to run *Impacts 2050* to determine which variables would be most informative. For the regions studied, candidate variables may be percentage of car-sharing and percentage of low-income population. For example, Table 7-3 illustrates the variation across regions and across scenarios for percentage of car-sharing. Since the trajectory of percentage of car-sharing is so different for each scenario, the monitored trend for percentage of car-sharing would be one indication of the direction in which society may be heading.

7.5 Monitoring the Future with *Impacts 2050*

Currently, the *Impacts 2050* base data are U.S. Census data from 2000. Some state DOTs or MPOs may have data at finer resolution or more recent data that can be used to calibrate the simulations in future years. The tool is calibrated to 2010 Census data. With regular use, it can

Table 7-3. Trajectory results for percentage of car-sharing from Table 6-7.

Scenario	Atlanta	Boston	Detroit	Houston	Seattle
Momentum	5–25% decrease	5–25% decrease	5–25% decrease	–5% to 5% change	5–25% decrease
Technology Triumphs	>25% decrease	>25% decrease	>25% decrease	5–25% decrease	>25% decrease
Global Chaos	>25% increase	>25% increase	>25% increase	>25% increase	>25% increase
Gentle Footprint	5–25% increase	5–25% increase	5–25% increase	5–25% increase	5–25% increase
# of Different Outcomes	4	4	4	4	4

be progressively calibrated for successive years—2015, 2020, etc., which will refine the simulated long-term outcomes and allow for monitoring the indicators over time.

Thus, transportation agencies that regularly use *Impacts 2050* will in some way be "reinventing" it. This tool was designed with reinvention in mind. Its generic character enables an agency to get it up and running quickly. It is likely and acceptable that some transportation agencies may adopt some components of *Impacts 2050* and change or reject others. It is hoped that in doing so agencies will "fix" *Impacts 2050* to better meet their needs. Reinvention was a key element in the diffusion and use of the Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) system when it was first introduced.

The primary strategic issues or decisions facing a transportation agency provide the focus for implementing *Impacts 2050.* With this new information *Impacts 2050* provides, transportation agencies must be prepared to implement change, as is discussed in the next chapter.

CHAPTER 8

Relevance and Value of *Impacts 2050* to Transportation Agencies

This research project has created a package of tools, *Impacts 2050*, that have been designed to assist state DOTs, MPOs, and other transportation agencies in better coping with the effects of uncertainty in their long-range planning process. At the core of the package is the *Impacts 2050* model, a spreadsheet-based, scenario-planning tool that is designed to assess the effects of various socio-demographic and other trends on long-term transportation outcomes and needs. With this tool, agencies have the capability to relatively easily define, test, and evaluate the impacts of trends on existing projections and estimates of need.

Impacts 2050 is an SD model that simultaneously accounts for the interaction of a wide range of variables on the nature and magnitude of travel demand 30, 40, and even 50 years into the future. Implicit in its structure is the interaction among key sectors—population, employment, land-use patterns, and transportation supply—that are known to be highly interdependent, and influenced by economic, technological, financial, and policy developments.

Accompanying *Impacts 2050* is a set of scenarios, strategically designed to represent dramatically different planning futures. In contrast to a baseline Momentum scenario, which reflects continuation of existing trends, are three scenarios that depict radically different futures: a high-tech scenario (Technology Triumphs), in which technology greatly enhances transportation and economic productivity; an economic hardship scenario (Global Chaos) that depicts flat or no economic growth, widespread joblessness, and reduced quality of life; and an environmental consciousness scenario (Gentle Footprint) that places limiting harm to the physical environment as a societal priority.

Impacts 2050 was used to project the impacts of each scenario on 2050 transportation conditions in several metropolitan areas to quantitatively illustrate how existing transportation plans and policies could lead to widely different outcomes in the face of future shifts in any of the key underlying factors.

Chapter 8 Takeaways

- *Impacts 2050* can enhance capabilities of transportation agencies to address uncertainties in plans, expand analytic capabilities, and assist with educating and engaging stakeholders.
- *Impacts 2050* may aid agencies by:
  - Supporting long-range plan development.
  - Supplementing the capabilities of existing planning models.
  - Formalizing the consideration of uncertainty in the planning process.
  - Facilitating participation in the planning process.
  - Serving as a sketch-planning tool for providing quick and timely answers, and supporting sensitivity and exploratory analyses.
  - Serving as a utility program for providing data inputs to models and the planning process.

"Change is the law of life. And those who look only to the past or present are certain to miss the future."

John F. Kennedy, 35th President of the United States

The goal of both *Impacts 2050* and the scenarios is to enhance the capability of transportation agencies to address uncertainties in their plans, expand their analytic capabilities, and assist them in educating and engaging stakeholders on the importance of sensitizing plans and expectations to potentially radical changes in historical trends. The travel forecasting models many transportation agencies use are categorically different from the design and intent of *Impacts 2050.*

Not surprisingly, those future conditions are strongly defined by past trends. If those conditions change—as the result of one key factor changing substantially, or multiple factors interacting more subtly—the implications for the reality of the original forecasts may be dramatic. While *Impacts 2050* is not intended to replace these traditional models, it is meant to (1) show how significant these uncertainties can be, (2) foster broader awareness of and the importance of uncertainty, and (3) set the stage for more meaningful dialogue and creative thinking in terms of mitigating strategies or planning scenarios.

8.1 Demands of the Long-Range Planning Process

Both state DOTs and MPOs are required under federal law as a condition of funding to engage in a comprehensive long-range planning process. While the makeup, authority, and responsibilities between these two types of agencies have important differences, common to both is the requirement for a long-range plan that projects conditions, needs, and programs over a horizon of at least 20 years into the future, and a routine update process that occurs roughly every four years. The update is a major process, involving many players—staff, elected officials, stakeholders, and the public—during which:

- Previous goals and objectives are reviewed for attainment and continued relevance,
- New projections of population and employment are received in conjunction with development plans,
- Transportation needs are evaluated through use of transportation planning models, and
- New transportation projects and programs are evaluated in response to the growth trends and projected needs.

Specific projects and programs recommended for funding and implementation must come from this comprehensive process. These recommended projects must not only demonstrate cost-effectiveness in meeting projected demand, but satisfy other evaluation criteria as well. These criteria are largely linked to the adopted goals that frame the plan, which themselves are significantly guided by the "planning factors" established under MAP-21. These factors are intended to ensure that transportation investments are supportive of critical social, economic, and environmental goals that are served by transportation. As outlined under the latest revision of the MAP-21 (USC 2012), these planning factors include (emphasis added):

- Support the *economic vitality* of the metropolitan area, especially by enabling global competitiveness, productivity, and efficiency.
- Increase the *safety* of the transportation system for motorized and nonmotorized users.
- Increase the *security* of the transportation system for motorized and nonmotorized users.
- Increase the *accessibility and mobility* of people and freight.
- Protect and enhance the *environment*, promote energy conservation, improve the quality of life, and promote *consistency between transportation* improvements and state and local planned growth and economic *development patterns.*
- Enhance the *integration and connectivity* of the transportation system, across and between modes, for people and freight.
- Promote efficient *system management* and operation.
- Emphasize the *preservation* of the existing transportation system.

The goals and objectives in state DOT and MPO transportation plans must embody these planning factors. Increasingly, these agencies are being required to measure the performance of their project and plan recommendations in achieving these goals and in selecting projects. This obviously places more weight on the respective planning and decision-making process to adopt achievable long-term goals and select projects that are most likely to achieve them.

The challenge for state DOTs and MPOs is that they neither directly control many of the factors that define the assumptions that make up the long-range plans, nor have complete control over the prioritization of projects. For example:

- Residential and employment growth assumptions are largely the result of both local development plans and exogenous forecasts.
- The location of growth and the design of the development are largely controlled by local jurisdictions with planning and zoning authority.
- Project priorities are heavily influenced by the political process, which reflects support for local plans and priorities—often in exception to or without full consideration of regional or state priorities.

Since the state DOTs or MPOs are not in control of these key underlying elements, it is difficult to foster broader thinking about and support for alternative ways to potentially manage growth, supply efficient transportation, and achieve key economic, social, and environmental goals. To a reasonable extent, part of the challenge is being able to illustrate the potential effects of alternative approaches, or how the area might grow very differently based on exogenous trends in the economy, technology, funding levels, environmental initiatives, etc.

Several strategies have been devised and tested for intervening in this set of relationships to try to raise the discussion level to consider a broader array of factors, actions, and outcomes. Among these strategies are "visioning" exercises and scenario planning. While the two are very similar and often intertwined, the nature of visioning is frequently fairly broad and qualitative, while scenario planning generally is more specific as to assumptions and employs tools to quantify probable outcomes.

With visioning, participants are generally asked to look at a broad set of possibilities and not be constrained by historical experience or practical constraints, such as funding, existing conditions (facilities, development, zoning), or adopted regulations. Visioning may be the way DOTs or MPOs obtain input to their long-range plans.

In comparison, scenario planning is more focused, tied down to a fairly specific set of alternative growth, land-use, and transportation investment "futures" that may represent a synthesis of the ideas ("visions") that come out of a visioning exercise or may be composed by a specially convened group of individuals who hold decision-making power in the planning process. The goal is to represent an array of possible approaches and try to characterize the expected outcomes across a range of important indicators. Because generally no one scenario will appear superior across all criteria, the scenario exercise serves to compare the alternatives with each other in a manner that highlights their impacts as tradeoffs. The participants then weigh the tradeoffs in developing recommendations for the preferred scenario.

While exercises such as these have been employed by many DOTs and MPOs, their results have not been seen as uniformly meaningful or productive in attracting desired attention to key issues. One important reason for this may lie in the tools and information used to support scenario planning, which may be limited in terms of:

- Their ability to accommodate or accurately estimate the impact of highly relevant strategies, such as the relationship between compact mixed land-use and travel behavior, especially in reducing auto ownership and VMT, and increasing use of transit and nonmotorized modes.
- Dexterity/flexibility in entering assumptions and manipulating conditions.
- Visual communication of problem setting, alternatives, and impacts.
- Extensive computational time that prevents real-time use.

Admittedly, the challenges of scenario planning extend far beyond simply being able to "model" a provocative set of scenarios. Lack of any direct authority over local planning and land-use decisions means that many of the key variables that would be essential to proper scenario planning are, for practical purposes, fixed, which greatly constrains the range of important options. However, it is reasonable to believe that one way to objectively visit and challenge this constraint is to provide credible evidence as to the impacts of future changes on transportation, economic development, and other key societal goals.

8.2 Value and Potential Use of *Impacts 2050*

In light of these responsibilities associated with the long-range planning process, and the gaps presented by the suite of existing planning tools, it was of direct interest to ascertain whether and how the *Impacts 2050* model and prepackaged scenarios may be of use in the process. To address this question, input was obtained from a number of sources, including planners and planning officials who participated in the demonstration workshops, those who agreed to pilot test the model, and members of the project panel with extensive state DOT experience and familiarity.

Clearly, the long-range planning *process* pursued by states and MPOs is about more than production of an official long-range *plan* every four years. While updating the plan is a major task for states and MPOs that can consume as much as two years of intense activity, much of the ongoing daily work of these agencies is concerned with planning for the future and attempting to balance current needs with making responsible, cost-effective, and sustainable long-term decisions. Questions are routinely raised about the potential consequences of a new trend (e.g., fuel prices, travel tendencies of Millennials); policies to respond to a trend (e.g., tolling to enhance revenues); or the potential impact of a major new transportation investment.

Viewed in this manner, activities and responsibilities related to long-range planning are continuous in most transportation agencies, and also involve a wide variety of functions that frequently stretch the agency's capabilities. Based on feedback from the state DOT and MPO audiences, the needs associated with these gaps that may be aided by *Impacts 2050* fall into the following general categories:

- Supporting long-range plan development.
- Supplementing the capabilities of existing planning models.
- Formalizing the consideration of uncertainty in the planning process.
- Facilitating participation in the planning and decision-making processes.
- Serving as a sketch-planning tool for providing quick and timely answers, as well as supporting sensitivity and exploratory analyses.
- Serving as a "utility" program for providing data inputs to models and the planning process.

The following is a summary of those needs and possible applications offered by those who pilot tested the model.

8.2.1 Supporting Long-Range Plan Development

As earlier noted, the development of the actual long-range plan—or, more properly, its periodic update—is a major activity for any DOT or MPO. Goals and objectives must be revisited and revised in light of past performance, future trends, and new regulatory or funding requirements; new forecasts are run; and new priorities are established. This process involves many players, inside and outside of the agency. Staff must perform research and assemble key information on past performance and future trends (incorporation of member forecasts, national trends), and must communicate policy objectives. And at each step, there is active involvement of stakeholders—governing boards, elected officials, technical committees, interest groups, and the general public—to provide their ideas and recommendations, review staff materials and suggestions, and eventually help craft the new plan. This plan development process could benefit from new tools in many ways, specifically the features of the *Impacts 2050* methods, both in expanding the set of issues that can be examined, as well as in ways of communicating with participants.

While long-range plan development is a participatory process, the inclusiveness may come at the expense of objectivity and sustainability. Member jurisdictions will understandably advocate for their own visions and priorities, and so development of the respective regional or statewide plan will be something of a compromise between local versus regional/statewide objectives, and between near-term and long-term outcomes, and will not necessarily reflect an optimal plan for allocating resources. While this process is largely the result of institutional factors, the inability of the planning tools to effectively depict the tradeoffs among different future land-use and investment scenarios greatly diminishes the opportunity to interject valuable objectivity into the decision-making process.

8.2.2 Supplementing Travel Forecasting

Existing travel forecasting modeling tools have several characteristics that limit the potential of the long-range planning process to pursue a wider and potentially more enlightened set of conclusions. First, most conventional trip-based models were not designed to address the types of planning or policy questions that have become increasingly important, such as those related to the interplay between land use, transportation investments, and travel behavior. Because *Impacts 2050* incorporates this interplay and other key relationships as part of its basic structure (even in a limited manner), it offers agencies greater opportunity to explore scenarios with a wider range of important factors.

Second, almost all existing transportation models—including the newer activity- and tour-based models—tend to be highly detailed and complex, and require substantial time and effort to set up and return results. This tends to limit the number of variations that can be considered when investigating alternatives, and eliminates the opportunity for real-time interaction with participants. The *Impacts 2050* model is quite the opposite of this conventional experience: it is a strategic planning model designed to respond quickly to planning questions, thus sustaining the interest stimulating the creative participation of stakeholders in the planning process.

Third, existing travel forecasting models have the characteristic of striving to be accurate (or presumed to be accurate) in projecting outcomes of key variables—ridership, volumes, VMT—for a very specific set of future conditions. Unfortunately, if any of those conditions changes, the original forecasts become highly questionable. The responding states and MPOs saw great value in being able to address these uncertainties in a relatively easy and demonstrable way. *Impacts 2050* makes it possible to test the stability of long-term forecasts in the face of potential changes in socio-demographic composition, rates of growth and its geographic distribution, and perhaps even locational and modal preferences.

8.2.3 Formalizing Treatment of Uncertainty

Because *Impacts 2050* enables its users to quickly and easily explore the effects of variations in long-term trends on future travel outcomes, it encourages consideration of uncertainty in the planning and forecasting process. In so doing, the tool provides a way to sensitize forecasts and also temper expectations of stakeholders regarding the likelihood that a particular growth scenario will materialize, and help understand the risks associated with a particular policy approach or set of investments. Correspondingly, by offering an improved lens for viewing the future, *Impacts 2050* provides a mechanism to begin to consider supporting or corrective strategies that may help better ensure the desired future outcome.

In addition to incorporating *Impacts 2050*'s capabilities more formally into the travel forecasting process, some less formal methods would also be beneficial. One such step would be identifying a set of key indicators that reflect key trends and committing to tracking those indicators. Example indicators were presented in the preceding chapter. By monitoring these indicators and observing key changes in direction, the agency is made more aware of how market conditions and needs may be shifting, and has the opportunity to explore what the effects may be on adopted plans. This information process not only can support in-house planning activities, but also can be used to educate and inform key stakeholders—board members, elected officials, and members of the public. Regular newsletters, periodic announcements, or articles in news media can help with the dissemination of such information toward a more informed constituency.

8.2.4 Facilitating Stakeholder Involvement

Some of the volunteers who pilot tested the model saw a particular value in an enhanced capability to communicate and interact with decision makers and the public. These interactions would be at large and small (and formal and informal) levels, ranging from defining and testing alternative scenarios in regional/statewide plans to supporting dialogue at community meetings. Most testers saw a role for the *Impacts 2050* model and scenarios in visioning and scenario-planning activities as a way both to profile a broader set of options (with quantitative results) and to educate and engage the stakeholders in creating and identifying with the scenarios. They felt that this could help alter their past experience with scenario planning as minimally effective in changing perspectives. At a less formal level, great potential was seen in *Impacts 2050*'s capacity to respond to questions received at random times from a variety of sources (officials, the public), where having a quick and defensible answer could either help support a desired effect or diffuse/deter an undesired effect or action.

8.2.5 Serving as a Sketch-Planning Tool

There are many occasions where agency staff must perform analysis in advance of a formal study, or tweak the results from an existing study to better understand the range of potential outcomes and the sensitivity of the results to changes in key variables. For this purpose, *Impacts 2050* was seen as a potentially valuable tool for internal applications to help guide early scoping decisions on complicated problems, or simply to educate people participating in the analysis on the nature of the particular issue and effectiveness of actions being considered. The primary strengths of the model that encourage this use are the variables and relationships contained in its structure, the ease of varying assumptions on these variables, and the speed with which results are received. Obviously, this capability is similar to the value seen in having the tool available for use in public meetings or planning sessions.

8.2.6 Preparing and Manipulating Data

A number of pilot testers suggested that *Impacts 2050* may have considerable value as a mechanism for preparing data for use in other mainline models, such as either travel forecasting tools or integrated transportation/land-use models. One tester sees the tool as a means for generating small area "margins" (subgroup population characteristics, such as people by age, households with/without young children) when developing synthetic populations for activity or tour-based travel models. The ability afforded by *Impacts 2050* to experiment with different rates of change in key variables (and the margins) over time is also seen as extremely valuable.

Most of the pilot testers saw strategic value in what was viewed as *Impacts 2050*'s cornerstone feature: its inherent capability to integrate socio-demographics with land use, economics, and the transportation system with travel behavior. One tester saw use of the tool to (1) develop scenarios to control the boundaries of the land-use model and (2) show the relationship between land scarcity and how it is affecting the population dynamics (since with land-use models, there is no feedback on real-world socio-demographic variables, like employment). *Impacts 2050* was also seen as a way to investigate and guide the manipulation of data to reflect demographic characteristics in relation to land-use issues.

8.3 Value of Prepackaged Scenarios

While it is widely acknowledged that uncertainty is ever present in forecasting, decisions must regularly be made with the best information at hand. However, there is a natural tendency to see the future through the eyes of current experience and historical trends. An important question guiding this study and model development is whether having tools that give better information on where future trends may lead can help agencies do a better job at planning or managing their transportation systems, as well as understanding what other collateral actions may be necessary to ensure the success of those plans.

As one mechanism to gauge the potential impact of the *Impacts 2050* tools on transportation agencies, a national Internet survey was conducted involving members of the AASHTO's Standing Committee on Planning. The survey consisted of presenting respondents with descriptions of the four scenarios (detailed in the previous chapter), and then asking for their response to two types of questions:

- How likely they thought each of the scenarios was of actually occurring, along with a brief explanation of their reasoning behind their answer.
- What impact, if any, would such a scenario have on their agency, its policies and practices, and its operations.

Responses received represented a good cross section with regard to geographic region, urban versus rural character, and other key characteristics. A summary and interpretation of the survey responses are offered below.

In terms of the projected likelihood of each scenario occurring, Table 8-1 below shows that most respondents (almost 80 percent) felt that the Momentum scenario was likely to happen, while the fewest (16.7 percent) felt that the Global Chaos scenario would happen. Meanwhile, about one-third (37 percent and 34 percent, respectively), felt that the Technology Triumphs and Gentle Footprint scenarios had some reasonable chance of occurring.

Respondents were also asked to indicate what they thought the impact of the given scenario would be—positive or negative—on their goals and priorities. Table 8-2 tabulates these responses.

The most notable findings here were:

Momentum (75 percent likely, 25 percent unlikely or no response)

While most respondents believed that the Momentum scenario was highly likely to happen, only one-third thought that its impacts would be positive for their agency, while 41.7 percent thought the predominant effect would be negative. Of those believing the effect would be positive, they believed that those trends were within the expected realm of experience and could be managed. They saw hope in advancing technology and an apparent leveling off of VMT growth as factors that would give agencies time to develop an appropriate response and identify necessary funding. Those believing the primary effect to be negative felt that revenues would not keep up with demand, and would limit the ability to diversify programs and offerings beyond highways. Those seeing neither positive nor negative consequences took the position of believing this would be business as usual and that funding and programs would adapt.

Table 8-1. Projected likelihood by scenario.

Response	Momentum		Technology Triumphs		Global Chaos		Gentle Footprint	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Very likely	5	20.8%	1	4.2%	0	0.0%	1	4.2%
Quite likely	13	54.2%	8	33.3%	4	16.7%	7	29.2%
Hardly likely	4	16.7%	12	50.0%	10	41.7%	15	62.5%
Not likely	0	0.0%	1	4.2%	6	25.0%	1	4.2%
No response	2	8.3%	2	8.3%	4	16.7%	0	0.0%
Total	24	100%	24	100%	24	100%	24	100%

Technology Triumphs (37.5 percent likely, 62.5 percent unlikely or no response)

Only about half as many respondents felt that the Technology Triumphs scenario was as likely to happen as Momentum, but virtually all of those respondents felt that the impacts would be positive. This group felt rather uniformly that technological advances would positively affect the economy and transportation—that travel would be faster, cheaper, safer, and more efficient than ever, and that there would be an increasing number of opportunities to use technology to replace personal travel. With less personal travel and demand, hope was expressed that there might be more resources to invest in improving freight systems. There was also the sense that a healthy economy might produce innovative sources of funding.

Among the roughly two-thirds who felt that the scenario was unlikely or were unsure, most felt that there would be no impact on their agency or goals, slightly fewer felt there would positive impacts, and only a small number thought the effects might be negative. Among those seeing the effects as potentially negative, some who represented rural states felt that they might not equally share in the gains from technology, while others felt that an era of technological innovation might also introduce new needs and services that the agencies were not trained to deal with and for which funding had not been identified.

Global Chaos (16.7 percent likely, 83.3 percent unlikely or no response)

This was the most difficult scenario for respondents to envision as a potential reality. Those few who did pointed to the recent economic meltdown with worldwide impacts, conflict in the Middle East, and lack of political leadership as reasons to believe this scenario could happen. Those in the majority who felt it was unlikely or had no opinion felt that government, industry,

Table 8-2. Expected impact on agency's goals and priorities by scenario.

Response	Momentum		Technology Triumphs		Global Chaos		Gentle Footprint	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Positive	8	33.3%	14	58.3%	0	0.0%	10	41.7%
Both positive & negative	0	0.0%	0	0.0%	0	0.0%	4	16.7%
Negative	10	41.7%	3	12.5%	21	87.5%	5	20.8%
No Impact	6	25.0%	7	29.2%	2	8.3%	3	12.5%
No response	0	0.0%	0	0.0%	1	4.2%	2	8.3%
Total	24	100%	24	100%	24	100%	24	100%

and society would never allow it to happen, and would kick in investments and stimulus policies, and that technology would play a major role. Regardless of likelihood of occurrence, no respondent saw a positive impact from this scenario. The probable shortage of funding in a poor economy would likely limit the agency's ability to maintain the transportation system, let alone invest in strategic projects or diversify into other modes that might be demanded as a substitution for driving, particularly transit.

Gentle Footprint (33.4 percent likely, 66.6 percent unlikely or no response)

Slightly less than the percentage of respondents who felt that the Technology Triumphs scenario was likely felt that the Gentle Footprint scenario was likely. Those believing it was likely pointed to growing concerns about and action toward global warming, and also pointed to trends among Millennials to forego car ownership to live in urban areas where they can walk or take transit. They saw the impact on their agency as having to diversify more extensively into other transportation options, though with potentially limited funding to do so. Those believing it unlikely tended to feel that some of these trends were likely to happen, but not at the rate implied by the scenario. Rural states generally felt they would be affected more than urban areas, but had some concern that their economies depended upon highways, and any change away from that focus would not be positive.

It was not part of the strategy in this survey to inquire about *Impacts 2050* as a way of responding to the implications of the four scenarios, since they had not been as thoroughly exposed to the model as the participants in the onsite demonstrations or the beta tests. Nevertheless, it was revealing to observe the respondents' perspectives on the uncertainty associated with the scenarios and how their agency would address them. The most common response was that none of the scenarios was likely to come to fruition, because they represented such extreme cases, and that the current process of creating long-range plans with 20-year horizons—with reassessment and update every four years—would be sufficient to make the necessary adjustments and stay on course.

8.4 Strategic Responses

The four scenarios were purposely designed to encourage transportation agencies to think outside the box—and consider what they might do if the future took a sudden and decidedly different turn from the trajectory defined by the previous 50 years. But are planners or their constituents able to cope with such uncertainty?

Viewing the results of the survey, it is reasonable to conclude that nothing so severe as what is suggested by the "extreme" scenarios would ever fully happen. However, the agencies responding offered little as to what they *would* do if such trends began to manifest. Most of them thought that their biggest challenge would be finding enough funding. Also, most believed that the conventional long-range planning process, with a 20-year horizon and a 4-year update, would also provide them with an adequate mechanism to monitor and respond to change.

There is nothing inherently wrong with the current long-range planning requirement and its recommended time frames. The 20-year horizon and periodic updates make great sense as a way of balancing long-term goals and perspectives with near-term needs and realities. The real question is whether the benefits of the existing process are being fully exploited in addressing future needs, goals, options, and uncertainties, or whether the process has become comfortable with building off historic trends—i.e., maintaining momentum and avoiding the potential conflict of change. There seems to be ample evidence that the latter may be the case, which further raises the argument for new tools that can add new dimensionality to the existing process.

Clearly, a solid trend has been in place in the United States since World War II, exhibiting a steady increase in not only VMT alone, but also VMT per capita, with little perturbation from 1945 through 2005. During that time, annual VMT grew from 250 billion miles a year to more than 3 trillion miles—more than a factor of 10—while population merely doubled. This means that VMT per capita grew from 4.9 miles per day to 27.9 miles per day—an increase of almost 470 percent. The trends behind this steady increase are well documented: aided by major transportation investment in highways, households and employers have steadily moved out of central cities to low-density suburban subdivisions, office parks, and shopping centers. Only private vehicles can provide mobility in such settings, so continuation of these trends has led to increasingly longer trips and more vehicle miles—not just for work travel, which accounts for less than 20 percent of household travel, but more significantly for nonwork travel, which has grown at a much higher rate than commuting since 1970.

Planners and decision makers have been aware of these trends for decades, with a particularly defining moment occurring in the late 1990s, when a "suburban traffic crisis" was declared nationally to describe suddenly untenable traffic congestion gripping previously exempt suburban areas, with no obvious remedies in such a landscape, except for additional road capacity. Insufficient funding to address such expansion needs was identified simultaneously with recognition of substantial deferred maintenance on the existing system, suggesting unprecedented infrastructure funding needs. This combined crisis led to the passage of the first Intermodal Surface Transportation Efficiency Act in 1991, which not only raised revenues, but also placed sharp conditions on their use, including the requirement of goal-oriented, multimodal planning and the long-range planning process. While data suggest that this trend began to level off in 2005, important exogenous events have been occurring, such as the recession, joblessness, the bottoming out of the housing mortgage market, and unprecedented increases in fuel prices for which the effects on VMT have not been fully accounted.

So while this set of requirements has been in place for more than 20 years, and transportation has faced the added challenges of mitigating air pollution emissions under the 1990 Clean Air Act Amendments, the upward trend in VMT continued until only the mid-2000s. One reason that may be offered as to why major changes have not occurred in the trend is that the long-range planning process has not been able to truly encourage transportation and planning agencies and their constituents to consider a different set of future outcomes. Hence, plans are more reliably made as a function of past trends and continued similar expectations, while the agencies conducting the planning are frequently unable to encourage elected officials and the public to consider alternative future approaches and outcomes.

Much headway has been made over the past decade in considering other planning frameworks, particularly those giving more emphasis to transit investment coupled with compact mixed land use and attention to pedestrian and bicycle travel. States like Maryland with its Smart Growth and Sustainable Communities Law, and California with its climate change-driven AB-32 and SB-375 initiatives, have raised the bar in trying to encourage, through laws and incentives, greater consideration of coordinating land-use planning with transportation investments. While the benefits of these smart growth/sustainable efforts have yet to be fully demonstrated, they have been aided by tools and empirical evidence that have helped illustrate their benefits. Admittedly, such changes in outlook take time to manifest themselves in thinking and implementation, but most who have practiced in the transportation and urban planning fields know that the substantial resistance to changing traditional practices and perceptions is difficult to overcome in the short term. While modeling tools and analyses that can better capture and relate these effects are only part of the potential solution, they are nevertheless seen as a major step in the right direction to better inform participants in the planning process about the positive and negative impacts of a broader array of options.

8.5 Challenges Facing State DOTs and MPOs

This section provides some suggestions as to various ways that transportation agencies may respond to better cope with the uncertainties—even some of the less desirable certainties—of the future. *Impacts 2050* was especially designed to assist this process by providing enhanced insight into the potential impacts of major trends. However, the tool is only an aide to what must be a planning process that is better able to deal with the uncertainties of change.

Several important conclusions were drawn from studying the state DOT survey responses:

- **Insufficient funding.** Many DOTs see their principal problem or challenge as sufficient funding. Clearly, this has been a critical issue through the recent recession, and may have been given some relief through MAP-21 and passage of new transportation funding legislation in some states (e.g., Virginia and Maryland). However, the reliability and durability of these funding streams are far from predictable over the long term, so at a minimum, transportation agencies are recognizing that they need to extract as much sustainable value as they can from the resources they have. This objective can best be addressed through sound planning that places priority on investments that create the most comprehensive (meeting societal goals) and sustainable long-term benefits.
- **Tying transportation investment and policy decisions to broader goals.** To achieve the most efficient and sustainable use of resources, every effort should be made to tie transportation investment and policy decisions to broader economic, social, and environmental goals. This can be done through judicious identification and diligent use of outcome-oriented performance metrics in plans and programs. Through such a performance-based process for setting priorities—which has been underscored in the latest transportation funding act, MAP-21—the connection between transportation and societal goals is made clearer. Therefore, if decision makers and planners want to determine where to put scarce resources to get the most impact, these relationships should guide them and justify their decisions.
- **Lack of influence with regard to how transportation funds are spent.** Some state DOTs see themselves as not being in a position to greatly influence policies and preferences that determine how transportation funds will be spent. Neither DOTs nor MPOs have any direct control on the all-important planning and zoning decisions that are the domain of local jurisdictions. Therefore, both organizations must accomplish change through means of education, persuasion, and perhaps incentive. To maximize the potential for impact under this arrangement, DOTs and MPOs must have access to the best tools and information to lead the discussion, which will ideally give way to better understanding of the consequences of particular actions (or inactions), and the tradeoffs involved. The existence of such tools may also improve dialogue between the states and the MPOs, who may often disagree on how resources are allocated and what priorities are being supported in plans and programs.
- **Uncertainties in the amount and source of transportation funding.** Because transportation agencies often see adequate funding as the ultimate factor in what they can or cannot accomplish, there is ongoing concern about the uncertainties in the amount and source of transportation funding. While federal funding comes with a variety of conditions, some of which present difficulty for the agency, a lessening of the federal role is likely to mean that the states (primarily) will have to step up with either new mechanisms to generate funding or plans and programs that lessen the demand for additional funding. In either case, they will need ample tools and evidence to garner support for their actions, neither of which will be free of controversy.
- **Need for better tools to support expansion of multimodalism.** All state DOTs are required to be multimodal in their structure, plans, and priorities, and most have made substantial efforts to evolve into that role. Many agencies, especially in more rural states, will admit that they are still predominately highway agencies. To gain broader acceptance of multimodal thinking and concepts—both internally and externally—the agencies will need better tools and evidence

to support plans and policies that expand multimodalism. As a challenge, their planning models—if they exist—are very highway oriented, making it difficult to evaluate or make the case for prioritizing multimodal approaches in plans, policies, and programs. This situation may be strategically aided by introduction of tools with the capabilities of the *Impacts 2050* model and scenarios.

- **Differences between urban and rural interests.** There is a long-standing competition between urban and rural interests that greatly affects plans, priorities, and funding levels. Rural interests are often represented by agricultural or natural resource extraction industries that rely heavily on a well-maintained highway network, and may not agree with the need for transit or other costly infrastructure enhancements in the busier, higher-density urban areas. Hence, they may oppose raising revenues for such initiatives. Any of the tested "extreme" scenarios accentuates these differences and potential negative outcomes for rural areas. One approach for reconciling these differences is to create a framework that lays out the different characteristics, needs, and expected performance of these different areas, and then develops funding plans and priorities that are commensurate with those places and the benefits they provide. The capabilities of *Impacts 2050* would seem to provide assistance in quantifying these tradeoffs.
- **Moving beyond 20-year plans.** There is a need to encourage transportation agencies and their stakeholders to consider a longer-range outlook when developing their 20-year plans. While 20 years is certainly a long-term horizon, setting one's sights on only 20 years with the ability to revisit the assumptions in 4 years is argued to create a situation where long-term goals are not viewed with the same confidence and value as the near-term needs. Recommending consideration of a 50-year outlook offers to put more emphasis on considering conditions that could occur in 20 years, and stimulate greater focus on and support for plans to achieve 20-year objectives.

8.6 Response Mechanisms for Meeting an Uncertain Future

From these observations, a set of response mechanisms has been outlined below to provide potential guidance to transportation agencies in better meeting the needs of an uncertain future. *Impacts 2050* can be used to carry out each of these mechanisms.

8.6.1 Establish an Indicator Monitoring System

- Pick the indicators and associate them with trends of concern; articulate the relationship(s) tied to the indicators.
- Find the data to populate indicators; set up a procedure for routine update.
- Establish a departmental function to monitor, analyze, and report on these indicators.
- Hire and train staff with appropriate skills (economics, demographics, geographic information systems, statistical analysis, and market research) to explicitly support this function.

8.6.2 Stimulate Wider Awareness and Dialogue about Possible Futures and Potential Responses

- Prepare an annual or biennial report on trends and conditions—e.g., what key trends are happening, how big are the changes, how do we compare with other areas, what are the possible implications?
- Prepare periodic topic reports addressing particular trends and their possible explanations—e.g., pedestrian safety.
- Encourage feedback, either by inviting visits to a Web site or by conducting periodic Web surveys.

- Present these findings to agency leadership and governing boards, and encourage discussion as to their nature and implications.
- Investigate alternative trends and outcomes.

8.6.3 Increase Stakeholder Participation and Buy-in

- Perform scenario planning and visioning exercises supported by credible tools and data to highlight the particular issues/trends or to portray alternative responses and outcomes.
- Encourage members of agency boards, elected officials (particularly lawmakers), stakeholders, and other decision makers to participate in the planning and discussion process.
- Elicit and test recommended actions from participants to increase understanding of the issues and ownership of the viable solutions.

8.6.4 Recognize the Need for Organization Growth and Change

- Encourage multimodal approaches to all transportation problems, striving for cooperative and creative thinking across modes.
- Engage sister agencies (transportation, planning, environment, economic development, community development, education, criminal justice) in the planning process.
- Develop the ethic of first seeing transportation as a means for accomplishing social, economic, and environmental goals before focusing on modal performance optimization.
- Attempt to identify the best long-term sustainable approaches to a transportation problem that look beyond transportation capacity.

8.6.5 Provide Financing and Political Support

- Adopt a performance-based planning and programming process that uses multimodal sustainability as the key prioritization criterion (net accessibility benefits over the long term), and find a way to account for the long-term benefit/cost stream.
- Select projects based on these criteria, and then report progress and success annually (Maryland and other states are doing this as part of their annual capital program).
- Be aggressive about ensuring that decision makers—especially legislators who review budget requests—are involved in this deliberate process, and support changes that must be made to policies or funding practices.

CHAPTER 9

Opportunities for Improved Decision Making

Chapter 9 Takeaways

- What is important in today's environment is asking the right questions.
- *Impact 2050* is designed to alter how transportation agencies think about the *possibilities* of addressing uncertainty and not just deriving the *answer* to a problem that can be precisely defined.
- Reinvention was a design principle built into this research. This recognizes that it is possible to adopt some components of an innovation and change or reject others.
- Transportation decision makers must shift from planning strategically to thinking strategically. In this view, formulating and implementing policy become iterative processes and decision making is ongoing and interactive.

"The world moves into the future as a result of decisions not as a result of plans."

Kenneth Boulding, systems scientist

In Chapter 2, we posited the question of why transportation agencies would want to go through all the trouble of using our new tool, based on a complicated SD model, to explore emerging trends and create possible futures. The reason to us is simple: to increase the chance of making better decisions. But our study delivers more than a new tool. Our goal is to encourage a new way of thinking about alternative solutions to long-range transportation plans for an uncertain future world—a world that is increasingly more complex and dynamic than the world transportation agencies planned for in the past. Chapter 3 presents eight trends that highlight a range of uncertainties transportation agencies face in their long-range planning, from a changing workforce to the implications of a hyperlinked society.

In developing *Impacts 2050*, this study team needed to address some of the limitations of the more traditional approaches to anticipating the implications of future demographic changes. The learning that took place has made it clear that the traditional approaches are no longer sufficient to address the accelerating rate of change and increased complexities of the 21st century. Taking full advantage of the products of this study will require individuals who are skilled in the old ways of transportation planning to accept additional ways of thinking, which are more aligned with the 21st-century types of problems and environments. In addition, they need to accept that these new ways of thinking about alternative solutions to long-range transportation plans will sometimes be introduced by individuals junior to themselves, who are more likely to be aware of their potential value.

9.1 Addressing the Dynamic Complexity of the 21st Century

What is meant by an accelerating rate of change and increased complexity, and how real is it? Almost everyone would accept that today and for some time in the future transportation agencies can count on:

- Increased customer/citizen and market/community diversity,
- A more transparent world—significantly increased information and knowledge available to customers/citizens,

- Increasingly more rapid technological change, and
- A fiscally constrained operating environment.

Agencies can also expect that:

- They will have less time to respond to market/constituency requests,
- They will be less able to forecast market conditions and constituency needs,
- The places they normally go to get money and things done will be under pressure to change, and
- The ability to find, much less talk to, mass markets through a single communication medium where they control the message content will continue to decrease.

Based on these changing conditions, the approach and the need for change are best described by revising a very important point made in 1960 by John Tukey when he said:

> Far better an approximate answer to the right question, which is often vague; than the exact answer to the wrong question, which can always be made precise.

While this quote has remained relevant for 50 years, due to changing 21st-century conditions we felt the need to update Tukey's wisdom with the following revisions.

> Far better a system of inquiry that engages decision makers and information providers to ensure the appropriate data not only are collected but are also organized in manner that the data can be transformed into relevant answers to the right questions in a timely manner at a cost that decision makers will value. Thus we can avoid processes that imply a precise answer, in some cases, to the wrong question.

Long-range planning traditionally uses forecasts generated from travel demand forecast models. These models focus on quantitative accuracy in input data and model parameters. Output is in the format of point estimates for specific years. Running the model and analyzing results is time-intensive. Our solution, *Impacts 2050*, facilitates analytical reasoning, rather than the computation of a precise number. The focus is on including a wide range of model relationships and on "qualitative accuracy." Running the model is relatively quick and easy, therefore allowing a user (from a planner to a forecaster to a decision maker) to iteratively change model parameters and inputs to gauge the impact on travel behavior. What becomes important in this environment is asking the right questions.

9.2 Changing One's Mindset to Handle Complex and Dynamic Problems

In Chapter 4, we provided the rationale for our study's solution to the problem of long-range planning in an uncertain world. Our solution reflects an emerging trend in long-range planning, where there is an awareness that one cannot actually forecast the future, but that many scenario possibilities need to be studied, so that a policy or investment strategy that minimizes risk or moves toward some desired goal(s) can be followed. Chapter 5 presents four plausible future scenarios, but with our tool, we invite users to develop their own scenarios. Our scenarios were designed to encourage transportation agencies to consider what they would do if the future took a decidedly different direction over the next 50 years compared with its historical trajectory.

From a systems thinking perspective, a joint scenario/modeling approach can replace the traditional process of transportation forecasts, feeding long-range plans with an organic decision—a support system that can pump a free flow of contextual data and knowledge into a series of dialogues that take place continuously across the planning functions of transportation agencies.

A distinction between two metaphors helps illustrate the importance of these differences. The industrial-age mechanistic mindset encouraged us to think about managing enterprises as if they were made up of replaceable parts—like pieces in jigsaw puzzles. The metaphor fit reasonably well for that era. When you start a puzzle, you know how many pieces you're supposed to have, and the chances are they are all there. Each of the parts will interact with only a small portion of the other parts. If you have trouble deciding how to put the pieces together, you have a picture on the box to remind you there is one single solution to the problem. And, though some puzzles are more complex than others, the underlying process of putting them together is always the same. But today's business challenges are more complex than that. Transportation agencies operate in a world of complex problems compounded by an accelerating rate of change. It is an environment that consists of constantly changing processes, relationships, and interacting components—more like a DNA molecule than a jigsaw puzzle. Depending on how the pieces come together and what is occurring in the containing environment of the molecule, we can end up with a final result different from what we had any reason to expect.

Impacts 2050 was designed to facilitate a change in the way transportation agencies think about the future—to focus more on the *possibilities* of addressing the uncertainty of complex and dynamic problems than on deriving *the answer* to a problem that can be precisely defined.

Impacts 2050 allows transportation planners to engage in a decision-making process that allows them to consider alternative strategies based on an assessment of the impact of alternative future scenarios. Chapters 6 and 7 provide building blocks of the tool and the information that can be derived from it. These products were built not only to provide estimates of future needs but also to enable users to develop a deeper understanding of the dynamics and interaction of socio-demographic and other influencing factors, rather than providing exact forecasts and predictions that are limited by what is known at the time the model is run. This approach allows the planning team to think about and consider alternatives to the projected estimates, rather than being limited to focus on the implications of the outcome of traditional planning models.

9.3 Reinventing the Model to Meet the Requirements of an Uncertain Environment

The basic elements of *Impacts 2050* have been designed so they can be modified to adjust to the differences that distinguish one transportation problem for another. Data have already been entered into the tool for the Atlanta, Boston, Detroit, Houston, and Seattle regions. The study team used publicly available data. But because a region or state may have more reliable or accurate measures than we provided, flexibility was built into the tool so that the underlying data can be improved. The four scenarios are predefined in the tool. But a user can create new scenarios by altering the scenario parameters. Easy instructions direct a region other than our five (or a state) to set up the model for itself. "Reinvention" was a design principle built into our approach. The concept of reinvention recognizes that an innovation is often really a bundle of components; it is possible to adopt some components and change or reject others.

This approach is reflective of the work of Everett Rogers in his original work in the diffusion of the Census Bureau's geographic systems that served as a precursor to the TIGER system. Rogers and his colleagues identified their findings as reinvention. They defined this important finding as follows:

> Reinvention is the degree to which an innovation is changed by the adopter in the process of adoption and implementation after its original development. Reinvention may involve both the innovation as a tool and in its use. Thus, the same technological innovation may be put to a different use than originally intended; alternatively, a different innovation may be used to solve the same problem. In addition, the intended or potential consequences of an innovation may be changed through reinvention.

9.4 Doing Better

The current practice of long-term planning relies on point prediction in an uncertain future. The predictions are updated at certain intervals (every 10, 15, 20 years) in order to correct course. As consumers of forecasts, decision makers face the problem of interpreting the findings they receive. Through our study, we offer a tool and suggest an alternative approach to cope with this uncertainty and to make better decisions. Using the tool requires a change in thinking, in which the output of the forecast is a less important ingredient to a long-range plan than the process of interacting with the model to produce many different possible future scenarios. Chapter 8 provides implications of the use of the tool for transportation agencies and key indicators that can be monitored as early warning signs of change. The premise is that transportation decision makers shift from planning strategically to thinking strategically. In this view, and with the support of *Impacts 2050*, formulating policy and implementing policy become iterative processes, and decision making is ongoing and interactive.

9.5 Getting the Research into Practice

This project has been unique and ambitious in terms of its scope: to identify an approach for assessing the impacts of socio-demographic changes on future travel demand and to develop an associated tool to simulate regional changes in population demographics over time, with feedback from employment, land use, and transportation supply. While the breadth of the relationships modeled in the tool approaches the most ambitious of integrated regional transportation models, we have captured the detailed spatial aspects of such models in approximate relationships. This is to be able to simulate the trends and feedbacks in response to a wide range of different user inputs and assumptions, over an extended period of time. Further, we have built the tool into a spreadsheet-based format that is designed for use by both technical and nontechnical users. That it came close to accomplishing our ambitious goals was evidenced by the positive responses in the initial demonstration of the tool for five different U.S. regions, as discussed in this report.

But with a project of this scope, it is inevitable that many further improvements will be made. Potential improvements have been identified from our initial pilot users for this project, as well as feedback from other potential users in regional and state agencies other than our five pilot sites.

Below are some recommendations for further development of the tool:

1. **Improving the tool's usability.** Building a fairly complex model into a relatively simple and familiar user interface is a challenge. While using the tool, we have identified a number of ways that the functionality, stability, and ease of use could be improved. Some examples are:
   - Improve the code and installation process to ensure that the tool will run correctly on a wide range of computing systems (including Apple computers), under a wide range of user configurations of those systems. The code would also anticipate a wider variety of user errors in installing and using the tool and would prevent or correct those errors.
   - Make it simpler to create, arrange, and catalog a wide variety of different user scenarios within the tool. One approach for this is to store the inputs and results for each new scenario within the same version of the spreadsheet (rather than saving each one as a new version). Each new scenario would then be added to a menu list, so that the user can select it as the starting point, to either rerun it or modify it to create a new scenario.
   - Include more functionality for creating and saving custom reports in the form of tables and graphs.
   - Such changes will require a great deal of expertise in programming Visual Basic macros for Excel.

2. **Refining the transition rates within the demographic sector.** The socio-demographic transition rates within the model are based on analysis of the most appropriate available data, including the Panel Survey on Income Dynamics (PSID) and various types of Census data. Yet, there were only small samples sizes for estimating some of these rates, particularly those for immigrant and minority households. Very recently, a new wave of PSID data from 2011 has become available that would increase the useful sample size for analysis, so it would be worthwhile to update this analysis at some point. Detailed analysis of Census micro-data from 2000, the Public Use Micro-data Sample, and the subsequent American Community Survey could also be useful, although the sampling error in repeated cross-sections must be considered carefully in such analysis.
3. **Conducting sensitivity testing.** The use of model sensitivity testing is common with traditional models. In *Impacts 2050*, we generally can assess model sensitivity by changing parameters in the model spreadsheet. However, users in specific regions may ultimately find it useful to document a range of sensitivity tests comparing the sensitivity of selected dependent variables on a different independent set of variables for (1) comparison within the same scenario, (2) between different scenarios, and (3) between different metro areas for the same scenario.
4. **Convening a TRB Subcommittee to the Travel Model Improvement Program subgroup centered on the model/scenario planning process.** The group would monitor the use of *Impacts 2050*, identify helpful modifications made by users that would benefit other users, and promote the new planning process at conferences and other events. The group could actively support model enhancements, including continued funding for updating data sources, such as the PSID.

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APPENDIX A

Scenario Narratives

A.1 Momentum Scenario

Momentum Scenario Synopsis

The current state of the country in 2050 would still be recognizable to any transportation planner who had worked in the year 2010. Change has been incremental based primarily on population dynamics, and we have not experienced any major shifts from prevailing demographic, economic, or technology trends. Nor have there been major policy shifts. America has become "grayer" as the Baby Boom generation has aged and "browner" as the white population has slower growth rate than every other racial group. Likewise, the U.S. labor force has grown older and more diverse. We see an overall increase in VMT, but a decline in per capita VMT. Baby Boomers have continued their reliance on the auto as their primary travel mode, but young adults have declining driver's licensing rates, auto ownership, and auto usage. They also rely more on technology to substitute for travel when possible, but telework is not prevalent due to the fact that most young adults access the Internet via mobile devices. Road congestion has decreased only somewhat. Federal gas taxes have risen a few times, but not enough to keep up with the increases in fuel economy. As a result, with less federal funding, many states have had to increase their own funding streams if they want to maintain their existing road network.

Population Growth Population growth in the first half of the 21st century was slow relative to the second half of the 20th century, but the growth rate is still higher than other developed countries. Population growth was driven largely by relatively high fertility rates among Hispanic women (both native and foreign born) and by continuing immigration in younger age groups. Also, while the U.S. population has aged, it has also experienced an extended life span. There has been a significant increase in the population age 65 and older, as the Baby Boom generation has entered and passed through this age category.

Health While people are living a little longer, life expectancy is not increasing; the obesity epidemic has led to an increase in related conditions, such as diabetes. So while people are living an extra year or two, their quality of life is often not particularly high.

Economic Growth	The economy, after recovering from the Great Recession of 2008, has been fairly reliable—not growing enormously, but not sputtering either.
Labor Force	America's labor force growth rate is declining relative to the second half of the 20th century, mostly because of structural changes in the labor force. As the Baby Boom generation moved from middle age, with high participation rates, to the older age groups with significantly lower participation rates, the overall labor force participation rate declined. Over the past 40 years, the United States has also experienced declining labor participation rates for young adults. Still, incomes and inflation have moved at a fairly steady pace, so we have not experienced major increases in poverty or wealth.
Family Arrangements	The gap in labor force participation has narrowed between men and women over the past 40 years. Over the year, women have comprised a majority of Baby Boomers who have delayed retirement. Women have had increasingly higher education attainment than men, so have stayed in school longer, delaying their entry into the labor force. With the difficulties young adult males have faced in employment, we have seen slow rates of household formation, creating more single households and more multigenerational, large households. But the average household size has remained about the same as 2010.
Immigration	The United States continues to attract immigrants, both legal and illegal, since our country's economic position is still better than many countries. Some portion of the immigrant population is drawn by the increase in low-wage health service or retail trade jobs, and others seek higher-skilled, information sector work. In the past 40 years, Hispanics have accounted for a majority of the total growth of the labor force.
Technology Advances	The technological revolution wrought by cellular and smart phones continues, and the speed and volume of data have increased exponentially. No major breakthroughs or new devices have come to market, but the quality and quantity of access are much higher. High-speed data access is essentially a utility now, not unlike electricity, gas, or water. Most people access the Internet via mobile devices. Only some people with broadband connections can work remotely, but more socializing takes place virtually than ever before.
Urbanization	The effect of technology has untethered decisions about where to live from the workplace, at least for many white-collar employees. Some have preferred urban lifestyles, with higher densities and shopping and entertainment within easy reach. Others have moved to the outskirts, where schools remain better than in cities and housing prices are more affordable. Baby Boomers have tended to age almost in place, and have continued to drive and own cars. Young adults have tended to locate in high-density, pedestrian-friendly neighborhoods of the center city and inner suburbs, as they continue to be attracted by the densities of jobs available as well as by access to alternative transportation modes. The cost of car ownership as a percentage of income has continued to make owning a car, versus sharing one, less desirable to younger persons. The net effect has been that urban and inner suburban growth has continued to outpace growth in the outer suburbs. Overall about 85 percent of Americans live in urban or suburban areas. The rural share of the U.S. population has declined considerably.

Energy and Sustainability

Energy and transportation technologies have not changed very much in the past few decades. Oil prices have continued their cyclical journey upward—occasional spikes followed by retreats. While there are more electric vehicles, extended-range electric vehicles, and hybrids on the road now than when they were first introduced, they are still a niche market. Most of those buyers have a strong environmental bent, but no manufacturer has introduced a model with mainstream appeal that would overcome the larger price tag. With creeping versus rocketing gas prices, most buyers do not think it's worth it, especially when the average car gets over 50 miles per gallon thanks to the 2025 Corporate Average Fuel Economy (CAFE) standards.

Vehicle Technology

Most vehicles today are safer to drive, due to advanced driver assistance systems, such as lane-keeping sensors, which have been good for older people who have continued to buy, own, and drive automobiles. But the hype around autonomous vehicles proved to be overblown. Insurance commissioners were reluctant to allow self-driving vehicles, and the high prices meant that there has been no popular pressure to legalize them.

Travel Behavior

Travel demand and funding have changed a bit more. Commute travel has decreased somewhat, thanks to technology and declining labor participation. However, workers in low-wage service-sector jobs, many of whom are Hispanics, have not been able to rely on technology to substitute for travel. So they continue to drive and carpool in older vehicles and use public transit to travel to work. People are also still on the roads a fair amount for shopping and personal business, but congestion levels are manageable.

Transportation Finance

Federal gas taxes have risen a few times, but not enough to keep up with the increases in fuel economy. As a result, with less federal funding, many states have had to increase their own funding streams if they want to maintain their existing road network. (Not many new roads are being built these days.) Pressure from the states led the federal government to lift restrictions on tolling interstate highways, so most highways now have some type of paid express lane, or all lanes are tolled.

A.2 Technology Triumphs Scenario

Technology Triumphs Scenario Synopsis

Technology has saved us from ourselves. While the United States faced some difficult challenges in the 2010s, many of these have been mitigated by innovations through 2050 that helped us live longer, reduce our carbon footprint, connect our world, and travel more easily and safely. Autonomous vehicles have changed how people travel, and data-intensive communications technology has significantly affected how much people travel. Commute travel has declined, since a high proportion of office workers now work from home with new types of mobile devices, and schooling and health care are mostly handled online. Fewer people live near their jobs, since their physical presence is seldom required. Much socializing also takes place virtually, and many weekly necessities are delivered to peoples' doors. The travel that does take place tends to be faster, cheaper, and more convenient than ever.

Technology Advances Personal devices continued to evolve and gain in computing power as well as security, and competition led to both falling prices and widespread access and adoption. The reach of the *Web of Things* where just about everything (people, homes, cars, objects on the street) seamlessly interacts with smartphones and with each other is ubiquitous. High-speed data are considered a necessary utility, along with electricity, gas, and water. Computing costs have fallen, meaning that all schools are able to access virtual content and use computers in new ways in the classroom, and this, to a large extent, has reduced the achievement gap between high- and low-income students and schools. Advances in communications have also spurred healthy competition among countries. Governments have adopted cross-national common standards for data privacy to ensure that information remains protected across borders, and the standards are rigorously enforced.

Population Growth Population growth in the first half of the 21st century was on par with the growth of the 20th century.

Health Major advances in stem cell research and targeted drugs made many illnesses curable or chronic, rather than fatal. This made a huge difference in longevity; an American born today can reasonably expect to live to 90, and many people will reach 100. Most of these added years are healthy ones, and it's not uncommon for 80- and 90-year-olds to continue working, travelling, and living independently.

Economic Growth The economy, after recovering from the Great Recession of 2008, has been very strong due to a booming technology sector. The technological revolution can be considered a triumph of both the public and the private sectors. The public sector finally got serious about education and incentives. After a decade of realizing that our students were outscored in math and science by other countries, consensus emerged to shift investments to science, technology, engineering and math (STEM) education. The federal government also made more funds available for research and development, and provided promising start-ups in key areas with low-interest loans. The structure of tax incentives for targeted areas, such as clean energy, was streamlined and made permanent, so that entrepreneurs with good ideas were able to count on them being in place year after year. It would be hard to overstate the collective impacts of these revolutions on the economy, although they seem as normal as cars and telephones a century ago. But the wealth distribution favors the educated, who benefit most from technology funding, access, and use.

Labor Force America's labor force growth rate has remained steady relative to the second half of the 20th century. Baby Boomers have delayed retirement because they are healthier and because technology has enabled more people to work from home for more types of jobs. With a strong economy, the generations after Baby Boomers, Gen X'ers, and Millennials have experienced a strong job market since the 2020s.

Family Arrangements With a growing economy, family sizes are growing due to the presence of children. There are fewer multigenerational households as elderly parents have technology options for remaining in their own homes, and young people are moving into their own residences because they can afford to. Young adults are opting to delay marriage with greater social opportunities provided by "virtual" living.

Immigration

International migration to the United States has increased to the levels seen in the 1990s. While immigration is still regulated, more countries have adopted looser standards for work-based immigration, meaning that people with in-demand skills can move from country to country more freely.

Urbanization

Fewer people live near their jobs or retail or many services, since their physical presence is seldom required. We see greater movement to the rural/exurban areas, without the long commutes usually associated with such locations.

Energy and Sustainability

Energy costs have declined. Carbon sequestration was perfected, allowing many emissions to be buried harmlessly underground. Fast battery charging for electric vehicles, combined with standardization of battery sizes, meant wide adoption of electric vehicles (EVs). These two innovations have not entirely stopped the effects of climate change, but they do mean that responding to climate change has not entailed any sacrifices or economic disruption. People still use air conditioning but the added energy use produces fewer emissions than previously.

Vehicle Technology

Autonomous vehicles have had an enormous impact. With their easy availability—in most places, summoning a shared autonomous vehicle takes only a few minutes, and the transaction is billed automatically—vehicle ownership is down. Auto manufacturers are still busy churning out fleets of autonomous EVs, and many have entered the lucrative car-sharing business. Car sharing is no longer limited to environmentally minded urbanites; many suburban and even rural communities rely on it heavily. Older people who prefer not to drive have retained high mobility, and far fewer people die in automobile crashes.

Travel Behavior

Although autonomous vehicles have changed *how* people travel, data-intensive communications technology has also affected *how much* people travel. Commute travel has declined, since a high proportion of office workers now work from home. Travel for education, health, and even socializing is down as well, as people take advantage of convenient and plentiful tele-education, tele-health, and tele-shopping options. Much socializing also takes place virtually, and many weekly necessities are delivered to people's doors. The travel that does take place tends to be faster, cheaper, and more convenient than ever. This has to a large degree altered the demand for fixed public transit services. People are traveling less on all modes. Public transport service that does exist is leaner and more agile than the fixed mass transit systems that comprised America's aging infrastructure at the turn of the 21st century.

Transportation Finance

Private-sector funding of transportation infrastructure increases the quality and quantity of vehicle, transit, and nonmotorized infrastructure. Improved technology makes travel more efficient.

A.3 Global Chaos Scenario

Global Chaos Scenario Synopsis

The past few decades have challenged Americans' general optimism, and the world has become a far different and more difficult place in 2050. Several trends intersected to bring about a distressing new normal: growing financial instability at a global scale, a continuing Great Recession in the United States, the increasing and visible impact of climate change, and a reactionary sense of new isolationism. The results, which affect most of the world, are heightened insecurity (over jobs, food, and oil) and chronic conflicts (over jobs, food, and oil). Widespread unemployment means that far fewer people are on the roads and transit systems. With state and local governments collecting relatively little revenue, they have a hard time maintaining the existing infrastructure or responding to crises, like returning travel to normal after a major storm. Walking and cycling are far more popular now, but generally out of necessity rather than choice, and people with cars often make extra money on the side as gypsy cabs.

Energy and Sustainability

The United States has experienced severe shifts in weather patterns over the past 30 years as the result of unchecked carbon emissions. While the world's countries had long tried to negotiate binding and far-reaching limits on emissions, economic competition among countries in the wake of the 2008 financial crisis precluded this outcome. The United States and China refused to curtail their emissions, and by 2025 the carbon concentrations were too high to respond to mitigation measures.

Economic Growth

Pressure on the world's resources due to political instability and climate change has been significantly damaging to the global economy over the past 40 years. Demand for basic commodities, such as wheat, corn, soya, iron ore, and copper have soared, have caused sudden price rises, and have triggered overreactions and even militarized responses. Volatility of prices is the new normal, hitting both consumers and producers. Compounding the problems, speculation has exacerbated price volatility. Commodity price volatility has proved damaging for the global economy, because it has increased the risk of producing resources. This deters investment in resource production, further reducing supply and pushing up prices. Global trade is so interconnected that the United States has not been able to remain insulated from these problems. The U.S. federal government was overwhelmed with demands for basic social services, as well as public outrage that conditions had deteriorated so far and so fast. At the local level, in those areas hardest hit, keeping order is the most pressing challenge. Overall the mood combines resignation and anger, as well as disbelief that economic progress seems to belong to the distant past.

Population Growth

Population growth is declining due to the poor economy.

Health

American's health status has declined overall due to a lack of focus on health care and poor environmental conditions. While many locations are negatively affected by more powerful storms, leading to massive coastal flooding, the devastating change is in food production. Many formerly fertile areas—the American Midwest, Australia, Ukraine—are subject to extreme droughts beginning in the late 2010s. The decreasing supply of food resulted in food riots around the world, starting in developing countries but progressing to developed ones where income inequality meant that starvation is beginning to occur even in prosperous areas. As governments panic about not being able to feed their own people, several key food producers suddenly ban exports, and by 2022 regional famine in many countries, other than the United States, is widespread.

Labor Force As food prices rise, demand for other goods and services falls, leading to slow or no growth in many economic sectors. This becomes a vicious cycle, with unemployment growing just as many people lack sufficient income to feed themselves. Many older Americans are forced to delay retirement because a fiscally constrained U.S. retirement system has continually raised the retirement age and reduced social security benefits. Young adults are leaving school and entering the workforce at a younger age to support dwindling household incomes. Women are leaving the workforce to create more opportunities for their fathers, husbands, and children.

Family Arrangements Household size declines overall due to declining birth rates, even though adult children remain living with parents or elderly parents are moving in with their children.

Immigration In its wake, climate refugees begin to crowd into less affected northern countries, some of whom have ironically benefited from a warming globe in terms of agricultural production. Russia and Europe are besieged with climate refugees, and tensions with their own populations grow. The United States and many European countries begin tightening their borders in response, but demand remains high and illegal immigration continues.

Technology Advances In the poor economy, people have not been able to purchase the latest smartphones or other personal technology devices. Household members often share devices if the household can afford the prices of a service provider. There is a large market for used devices both for consumers and for businesses.

Urbanization The more enterprising of Americans begin establishing self-sufficient farms in sparsely populated areas, but many do not have the financial means to leave the cities, where conditions are worsening. People have been stuck in place geographically for nearly a decade.

Travel Behavior Widespread unemployment means that far fewer people are on the roads and transit systems. They have neither jobs to go to nor disposable income for shopping or vacations. Walking and cycling are far more popular now, but generally out of necessity rather than choice, and people with cars often make extra money on the side as gypsy cabs. Ironically, many urbanites would welcome congestion as a sign of much-needed economic activity, but the highways are largely empty.

Transportation Finance With state and local governments collecting relatively little revenue, they have a hard time maintaining the existing infrastructure or responding to crises, like returning travel to normal after a major storm, much less investing in new capacity.

A.4 Gentle Footprint Scenario

Gentle Footprint Scenario Synopsis

After droughts and "superstorms" begin plaguing the United States in the 2010s, both public consciousness and political will in the 2020s begin shifting toward taking more serious action to slow climate change. While it is too late to curb the rise in carbon concentration in the atmosphere, the United States has made surprisingly good progress in adopting a variety of means to reduce energy consumption. Many lifestyle changes that may once have been considered radical are now mainstream, particularly since the generational divide between Baby Boomers and younger generations on energy and environmental priorities has narrowed over time. Federal, state, and local governments have responded by shifting their focus to investments that support alternative modes, rather than cars. Most cities and suburbs have good networks of bicycle lanes, and transit systems have expanded, while the size of the road network has barely budged in 20 years. High-speed rail has been built in a half-dozen corridors, and it captures a healthy percentage of travel between those cities.

Energy and Sustainability With visible evidence of climate change in the form of droughts and superstorms becoming quite prevalent in the United States in the 2010s and 2020s, both public consciousness and political will have begun shifting toward taking more serious action to slow climate change. The younger generations already had such priorities in place. While it is too late to curb the rise in carbon concentration in the atmosphere by the late 2020s, the U.S. has made surprisingly good progress in adopting a variety of means to reduce energy consumption in the past 20 years. Much of the transformation has begun with legislation in the 2020s to introduce carbon taxes that affected all sectors of the economy: transportation, energy, manufacturing, and communications. The tax is structured to phase in gradually and increase in predictable increments in the future. This has provided both producers and consumers several years to prepare for cost increases, which have lessened what may have been a deleterious economic impact. It also has taken setting the price of emitting carbon out of the hands of legislators and has put it into the hands of technocrats, thus alleviating political pressure not to increase the tax.

Population Growth Population growth in the first half of the 21st century is slow relative to the second half of the 20th century.

Health Many households have experimented with growing at least some of their own food, and schools so frequently teach gardening and nutrition that it's hard to find a curriculum without it. At the supermarkets, food miles and calories share space on the same information panel. As people eat better and walk more, obesity has declined, and life expectancy has increased.

Economic Growth To the surprise of some, far from becoming a drain on the economy, the carbon tax has unleashed a torrent of innovation (and new jobs) from the private sector.

Labor Force Labor force participation rates have not changed much in the past several decades, but the sectors of employment have changed. Many people have their own home-based or farm-based business. Fewer people seem to be participating in the "rat race." On surveys, most Americans report they prefer a job with shorter hours than one with a higher salary. Americans now live at a more relaxed pace.

Family Arrangements Americans have also been making different personal decisions, driven not only by higher prices on energy but by a different environmental ethos. Fertility rates have declined as more couples choose to minimize their environmental impact by having smaller families.

Immigration International migration has increased, as environmental technology businesses require tech workers and "back to basics" farming requires migrant labor.

Technology Advances The technological revolution wrought by cellular and later smartphones continues, and the speed and volume of data have increased. Major breakthroughs seem to be in the area of environmental technology, which has funding from surpluses of the carbon tax.

Urbanization Another shift is the trend toward more urban ways of living. As gas prices rise with the addition of the carbon tax, more and more people look for places to live where they will depend less on cars. Inner-ring suburbs, with their smaller lots and houses, have boomed, and much new development consists of row houses and small apartment buildings with modern conveniences but smaller square footage. Most households now own only one vehicle, meeting their other transportation needs on foot, bicycles, or transit.

Vehicle Technology Car companies compete to put out the most efficient vehicle possible, even surpassing the 2025 CAFE standards, and the charging stations for EVs become as common as gas stations. Older people still prefer their autos, but they opt for smaller, fuel-efficient vehicles, even if they are not necessarily safer. Energy producers invest in alternative sources, such as wind and solar. While these sources will never meet all the country's energy needs, they represent a far larger proportion than before the climate legislation passed.

Travel Behavior Most cities and suburbs have good networks of bicycle lanes, and transit systems have expanded, while the size of the road network has barely budged in 20 years. High-speed rail has been built in a half-dozen corridors, and it captures a healthy percentage of travel between those cities. Air travel has reverted to being a mode for the affluent, and airlines log fewer miles now. Some airlines have even partnered with high-speed rail to provide feeder service to their hubs, since it is less costly to move those passengers on rail.

Transportation Finance

There is a strong federal government role in transportation infrastructure funding and policy making. Federal, state, and local governments have responded by shifting their focus to investments that support alternative modes, rather than cars. There is little investment in new road capacity.

APPENDIX B

Impacts 2050 Model Structure Documentation

B.1 Demographic Sector

The stock variable is the number of people in a regional population of interest, and it is segmented into dimensions. These dimensions were selected for their strong relationship with travel behavior, based on the knowledge of the research team and Tasks 1 and 2 findings, documented in the project memoranda. Taken simultaneously, these dimensions represent the current state of a regional population at a given point in time. For all, 2000 Census data were used to derive the starting demographic estimates of marginal distributions within each region, and 2010 Census or 2005–2009 American Community Survey (ACS) data are used for validation.

- **Age cohort**: Six categories: 0–15, 16–29, 30–44, 45–59, 60–74, 75 and older. Each cohort is roughly 15 years in duration—short enough to capture the main variations in life cycle and behavior, but long enough to avoid many different cohorts.
- **Household structure**: Four categories: single without children, couples with children, single with children, and couples without children. A "couple" is defined as either married or cohabiting partners (but not, for example, two unrelated adults).
- **Acculturation group**: Three categories: foreign-born with less than 20 years in the United States, foreign born with 20 or more years in the United States, and native born. The threshold of 20 years in the United States for foreign born was selected to distinguish "acculturated" from "nonacculturated" residents.
- **Race/ethnicity**: Four categories: white/other, Asian, black, and Hispanic.
- **Workforce status**: Two categories: participating in the workforce and not participating in the workforce. This includes those who are employed or looking for employment.
- **Household income**: Three categories in 2009 dollars: lowest quartile ($0–$34,999), middle two quartiles ($35,000–$99,999), and highest quartile ($100,000 up). The middle two quartiles are grouped, as they tend to show fewer differences in behavior than the more extreme ones.
- **Residence area type**: Three categories: urban (central city), suburban, and rural areas. Our base condition for the area types in each of the regions is derived from 2000 Census data—at the tract level. For each tract comprising the metropolitan statistical area (MSA), we identified the number of jobs per square mile and the number of residents per square mile. Urban areas are defined as having at least 4,000 jobs per square mile, or at least 10,000 residents per square mile inside the tract. Suburban areas are defined as having at least 500 jobs per square mile or 1,000 residents. Rural areas are defined as having less than 500 jobs or 1,000 residents per square mile.

NOTE: These area type definitions were chosen to roughly match the Claritas PRIZM area type categories (Urban, Suburban and Second City, Town and Country) that are used for data sets, such as the National Household Travel Survey (NHTS).

Running the SD model for a specific region requires the initial distribution of the population along all these variables simultaneously. With the categories above, that requires values for $6 \times 4 \times 3 \times 4 \times 2 \times 3 \times 3 = 5{,}184$ different combinations, or "cells" in a multidimensional matrix. We have kept the number of socio-demographic stock variables and dimensions as concise as possible, to constrain the number of cells in order to facilitate rapid analyses of many scenarios. As noted in the objectives section of this report, "strategic models are fast models." Currently, the simulation of the population model runs in a matter of seconds.

We did not have access to the necessary micro-data from the Census to be able to run the multidimensional matrix for a given region (i.e., age × household structure × acculturation group × race/ethnicity × workforce status × household income × residence area type). So we applied an iterative proportional fitting (IPF) technique to derive a multidimensional matrix for each region. IPF is a procedure for adjusting a table of data cells, such that they add up to selected totals for columns and rows in the table. The data cells are referred to as the "seed" cells, and the selected totals are referred to as the "marginal totals."

First we developed a table that would serve as the "seed" cells. We used the NHTS, 2009 (for which we did have access to the necessary micro data) to develop a national multidimensional matrix. In the tool's Excel spreadsheet, in the tab "Demographic seed matrix," this simultaneous distribution of the national population is displayed.

However, to run the model for a given region, we needed to transform this national matrix into one that is representative for a specific region. We had the marginal totals for all of the socio-demographic variables in the model from the Census. These distributions can be viewed in the Excel spreadsheet, in the tab "Demographic initial values."

For example, the marginal distribution for Atlanta by age category based on the 2000 Census is shown here:

- Age 0–14 = 955,906 people
- Age 15–29 = 941,083 people
- Age 30–44 = 1,135,495 people
- Age 45–59 = 758,505 people
- Age 60–74 = 313,953 people
- Age 75+ = 143,038 people
- Total = 4,247,980 people

B.1.1 Demographic Rates of Change

The guts of the socio-demographic model are the assumptions that define how the people in a region will transition over time between the various categories of socio-demographic variables. The rates of change define how the population will transition from one "state" to another. Two of the rates are structural, as they depend only on the passing of time:

- **Ageing**: Transition from one age cohort to the next. This is completely structural and is not affected by other variables in the model (endogenous or exogenous). Our model assumption is that with 15-year cohorts, each year 1/15th of the people survive age transition to the next cohort.

NOTE: Currently, the model ages the population in the aggregate from one age cohort to the next. It does not keep track of the age distribution within any age cohort. This could be an enhancement built into model at a later date, or could be addressed by making the age cohort duration shorter—5 or 10 years instead of 15.

- **Acculturation transition**: People's race/ethnicity and birthplace (foreign or native) do not change during their lifetime. Thus, the only transition that applies to acculturation is related to how long foreign-born people have lived in the United States. Our model assumption is that each year 1/20th of foreign-born population transitions to the "greater than 20 years" category.

Rates of change other than aging and acculturation have been derived from the PSID. The very significant aspect of using the PSID data to derive the rates of change is that we were able to derive individual-level rates of change. Therefore, we were able to link specific rates of change to the individual categories comprising each socio-demographic variable. *There is no other data set from which this information can be derived.* To derive the rates of change used in the SD model, we focused on the PSID's three most recent pairs of waves—2003 versus 2005, 2005 versus 2007, and 2007 versus 2009—and tabulated the rates at which specific transitions were observed to take place over the two-year intervals, as a function of which categories the persons fit into in the prior year (age group, household type, and ethnicity). The resulting rates were divided by two (to transform from two-year intervals to rates per year), and were used to inform the rates used in the SD model. The resulting rates can be viewed in the Excel spreadsheet in the tab "Demographic transition rates."

- **Births**: Births are generated from people in the cohorts of childbearing ages (16–29, 30–44). The model does not treat males and females as separate groups, so the rates used in the model are about half of what they would be for females only. In addition to age group, there is some variation in birth rates, depending on ethnicity/acculturation group and household type (prior to the birth). For example, birth rates are highest among the "foreign born/in U.S. less than 20 years" group, and are substantially higher for those living as couples than for singles. Each new birth creates a new person for the simulation, and this person automatically enters the model into the "0–15" age cohort, the "with children" household structure, and the "not in workforce" workforce status. Household structure (single/couple), income group, and residence area type match those of the parent(s). Children of a foreign-born parent become U.S.-born/nonwhite or Hispanic ethnicity.
- **Deaths**: Deaths can occur in all age groups, although the death rates are very low for the lower age groups. No significant differences between ethnic groups or household types could be found from the PSID data, because the number of observed deaths in the sample was (fortunately) very small. However, there is evidence that seniors who are part of couples tend to live longer than those who are single, so the rates were adjusted to reflect that. There is also evidence that people in the lowest income quartile tend to have shorter life spans, and this can be reflected in the "Scenario user inputs" worksheet, in the row "Low-Income Effect on Death Rate."
- **Household structure transitions**: Some transitions in household type occur automatically in the SD model due to births and deaths. Others, however, occur because of events, such as marriage, divorce, and/or children leaving the household. These rates vary along the categories of age cohort, current household structure, and ethnicity/acculturation group. The PSID data were used to estimate the following rates:
  - **Marriage rate**: fraction per year of single people getting married or starting cohabitation.
  - **Divorce rate**: fraction per year of people in couples getting divorced or separated (we do not count both as separate events—if people are already separated, the subsequent divorce is not included in the rates).
  - **First child rate**: fraction per year of people in households that transition from 0 children to 1+ children. (This is structurally related to births in 0-child households, so does not need a separate rate.)
  - **Leave nest rate**: fraction of children/young adults who leave the household of their parents to form a new household—either as a single person or as a couple.
  - **Empty nest rate**: fraction of parents in households that transition from 1+ children to 0 children. This is the result of some "leave nest" events when the child/young adult leaves and there are no remaining children.

Note that the results of "marriage," "divorce," or "leave nest" are not purely structural in terms of whether there will be any children in the resulting household. Singles who marry or young adults who "leave the nest" may join a partner who already has children. Similarly, a "divorce" in a household with children may result in one or both parents retaining custody of children.

- **Workforce status**: The rates at which people enter and leave the workforce are derived from the PSID. (The number of people in the workforce who are employed versus unemployed is endogenous to the model, based on the size of the workforce relative to the supply of jobs, from the employment sector.) Although people most typically enter the workforce sometime in the 16–29 age group and leave in the 60–74 age group, there are many variations, since people can leave the workforce to raise children and/or become a "housewife," and they may enter the workforce again a later year.
- **Household income group**: Transitions in household income can be one of four types, each of which has a separate rate: (1) entering the low-income group from the middle-income group, (2) leaving the low-income group to the middle-income group, (3) entering the high-income group from the middle-income group, or (4) leaving the high-income group to the middle-income group. These rates are defined in terms of the percentage of people per year making each possible transition from the PSID data. In general, incomes tend to increase into the "middle years" and decrease again in the senior years, although there are many variations in that pattern due to personal or societal economic circumstances.

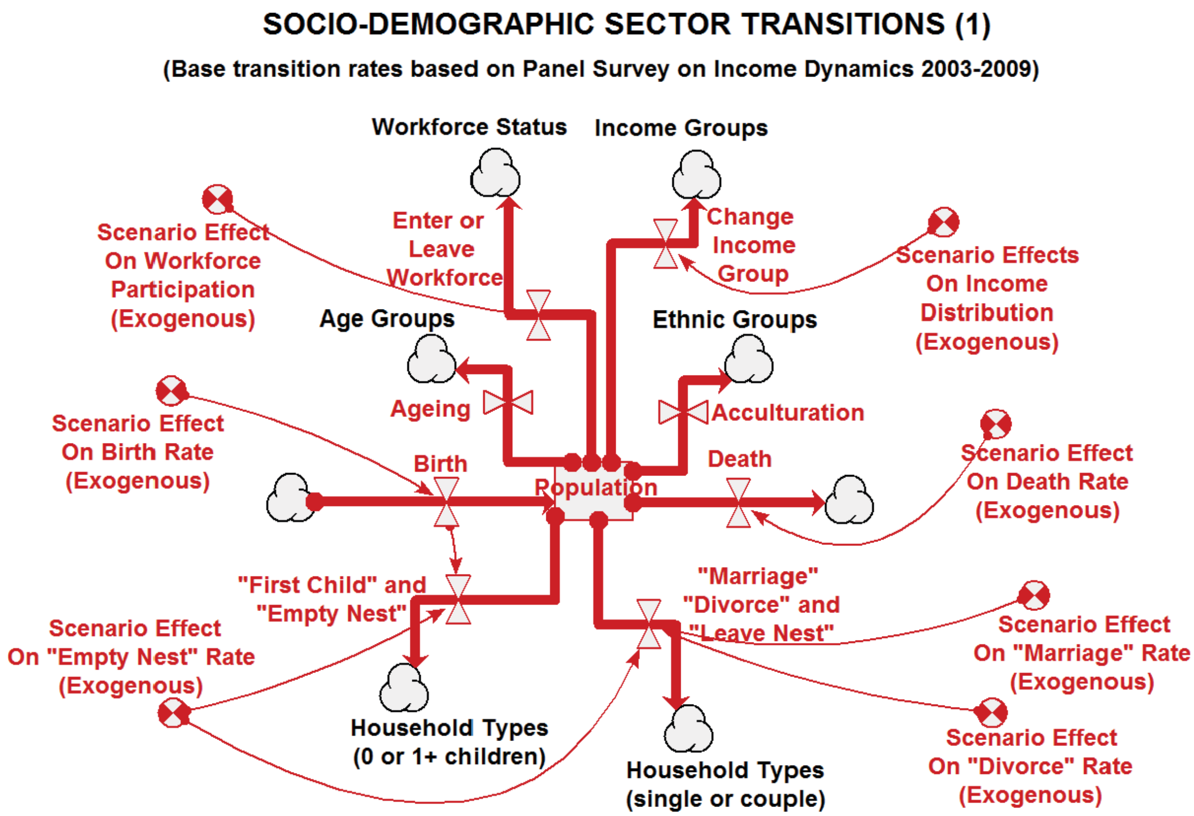
Figure B-1a shows some details of the socio-demographic transitions related to the rates of change that have been discussed thus far in the form of an SD flow diagram. Note that each rate is also affected by one or more exogenous variables that are predefined in the scenario worksheets in the SD model or that the user can set to define different future socio-demographic scenarios. Only two of the rates in Figure B-1a—birth and death—result in people entering or leaving the simulation completely. The other rates simply shift the socio-demographic categories of people.

We continue the discussion of the rates of change variables.

- **Residence location transitions**: This is an important aspect of the model because as populations change (i.e., people age) they may make different residence location decisions, such as empty nesters leaving suburban homes for condos in the urban center. These types of decisions are less "mechanistic" than most of the rates described above.
  In the model, we treat three types of location decisions (i.e., foreign migration, domestic migration, and intra-regional migration) separately, since they affect different people and may have involved different decision processes.
  - **Foreign migration**: This refers to migration to or from other countries.
  - **Domestic migration**: This refers to migration to or from other U.S. regions.
  - **Intra-regional migration**: This refers to relocation between area types in the same region.

The equations that define the various socio-demographic transition rates work somewhat differently for the different types of migration. Each has a "base migration rate" that is the fraction per year of the relevant population that tends to make a migration of the specific sort. The base rates have been derived for each region from the ACS and/or the Census. For migration within the United States (domestic) and within the region (regional), these base rates (with no modifying influences) are assumed to be symmetric between coming and going. For international (foreign) migration, however, the legal and practical processes for in-migration and out-migration are quite different, so different base rates are specified for both. The current base rates, which are in a table on the "Demographic transitions rate" tab in the spreadsheet, are as shown in Table B-1 below.

The equations for migration are in the following form: (1) a current population number, (2) a base migration rate that multiplies the current population, (3) a multiplier effect due to



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, the stock variable is population.
- The stacked triangles are "flow" variables that determine the rate of change in the stock variables over time.
- The circles represent exogenous inputs or variables computed based on other variables.
- The clouds represent places where people can transition to a new demographic state (i.e., death, birth, divorce, income group change).
- The arrows represent direct relationships that are (parts of) equations in the model.

Figure B-1a. Socio-demographic sector transitions (1).

Table B-1. Base migration rates.

Base Migration Rates (fraction/year)[a]	
Foreign In-migration	0.10
Foreign Out-migration	0.04
Domestic Migration	0.04
Regional Migration	0.04

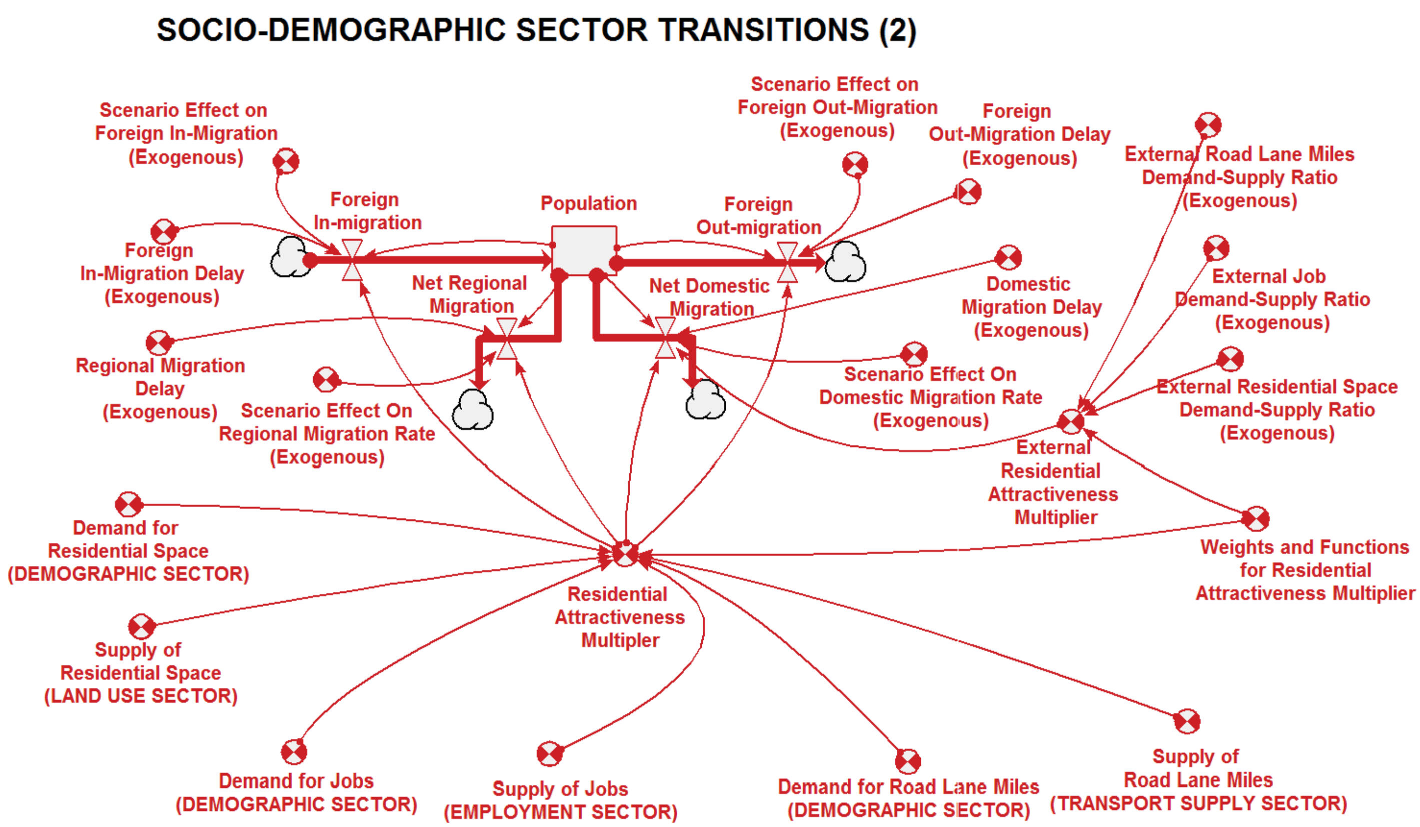
[a] Fraction/year is the fraction compared with the current relevant population.

the attractiveness of the region/area type for residents (see below for more information on this), and (4) an exogenous modifier effect that the user can define for different scenarios (relating to the scenario variable pertaining to immigration policy).

B.1.1.1 Attractiveness Function Effects on Base Residence Location Transition Rates

The main modifying effects on the base rates come from the multipliers due to residence attractiveness. This is in turn a function of relative demand and supply for jobs, residential space, and road capacity, as shown in Figure B-1b, the second part of the SD flow diagram for this sector.

The overall attractiveness function is a weighted sum of three separate values for jobs, housing, and congestion. The relative weights can vary by area type and by migration type. The values for those weights are found in the "Migration Attraction Functions—Weights on Inputs" table on the "Demographic transitions rate" tab in the Excel model. These values were derived from our team's analysis of Census and ACS data. The analysis indicates that international migration is most highly weighted toward job availability, while intra-regional migration has a heavier



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, the stock variable is population.
- The stacked triangles are "flow" variables that determine the rate of change in the stock variables over time.
- The circles represent exogenous inputs or variables computed based on other variables.
- The clouds represent sinks or sources that are outside the scope of the model.
- The arrows represent direct relationships that are (parts of) equations in the model.

Figure B-1b. Socio-demographic sector transitions (2).

weight on housing availability and traffic congestion (especially since someone can move within the region but keep the same job).

Once the attractiveness multiplier is calculated for a given area type/migration type, its use depends on the type of migration. For intra-regional migration, the attractiveness of each pair of area types is compared with the net migration going from the one with the lowest attractiveness toward the one with the highest attractiveness. For domestic migration, the attractiveness of competing U.S. regions is exogenous to the model. The net domestic migration to/from the region is then based on the relative magnitudes of the internal and external attractiveness multipliers. For foreign in-migration and out-migration, there is no way to explicitly represent the attractiveness of other countries, so the attractiveness multiplier is used directly, without comparison with another region or area type.

The socio-demographic variables are summarized in Table B-2.

Table B-2. Socio-demographic variables: stock and rates of change.

Stock Variables	Categories	Rates of Change Variables	Transitions
Age Cohort	0–15 16–29 30–44 45–59 60–74 75+	Aging	Transition from one age cohort to the next. Structural based on cohort duration.
Household Structure	Single without Child Single with Child Couple without Child Couple with Child	Birth rate	New births enter model in "with children" category.
		Death rate	Deaths can impact both presence of children and single/couple status.
		Marriage rate Divorce rate	Marriage and divorce rates mainly affect single/couple status.
		Empty nest rate	Empty nest rate affects presence of children.
		Leave nest rate	Children leave nest to form various types of households.
Acculturation Group	Foreign born, In U.S. <20 years Foreign born, in U.S. ≥20 years U.S. born	Acculturation	For foreign born, transition from one acculturation group to the other—structural, 20 years.
Race/Ethnicity	White, other Asian Black Hispanic	N/A	At the individual level, this is structural. People are born as a particular race/ethnicity, and this does not change.
Workforce Status	In workforce Not in workforce	Enter workforce Leave workforce Rates	Transitions between the two workforce states.
Household Income	\$0–\$34,999 \$35,000–\$99,999 \$100,000+	Enter low income Leave low income Enter high income Leave high income	Transition from middle-income quartiles to/from high- or low-income brackets.
Residence Area Type	Urban Suburban Rural	Foreign in-migration Foreign out-migration Domestic in-migration Domestic out-migration Regional migration	Moving between the region and area type and (1) other countries, (2) other regions of the U.S., (3) other area types in the same region.

B.2 Travel Behavior Subsector

The models are applied separately for every combination of socio-demographic characteristics in the model. They are applied in the following order:

1. The **Car Ownership Model** splits the person into three groups, effectively adding another dimension onto the socio-demographic breakdown:
   a. *Own car*: The person lives in a household where the number of cars is equal to (or greater than) the number of driving-age adults, so that each person can drive his or her "own" vehicle.
   b. *Share car*: The person lives in a household that has one or more cars, but fewer cars than the number of driving-age adults, so that at least two adults may need to share a vehicle.
   c. *No car*: The person lives in a household that has no vehicles.
2. The **Trip Rate Models** indicate the number of trips per day made by the people in each socio-demographic/car ownership category, for two types of trips:
   a. *Work trips*: to or from work, work-related or business activities.
   b. *Nonwork trips*: all other trips.
3. The **Mode Choice Models** split the trips in each socio-demographic/car ownership/trip purpose category into four modes:
   a. Car driver.
   b. Car passenger.
   c. Transit.
   d. Walk/bike.
4. The **Trip Distance Models** give the number of miles traveled per day in each socio-demographic/car ownership/trip purpose/mode category (except for walk/bike trips, for which the model does not need a measure of distance).

The data used to estimate all models described below are the full sample of the 2009 NHTS, including all add-on subsamples. Modeling was done at the person level and at the trip level, to match how the resulting equations are applied in the SD model. The NHTS sample contains 308,901 person records (from roughly 140,000 households).

B.2.1 Car Ownership Model

- *Own car*: The person lives in a household where the number of cars is equal to (or greater than) the number of driving-age adults, so that each person can drive his or her "own" vehicle.
- *Share car*: The person lives in a household that has one or more cars, but fewer cars than the number of driving-age adults, so that at least two adults may need to share a vehicle.
- *No car*: The person lives in a household that has no vehicles.

The dependent variable is percentage share for each of these three alternatives. The independent variables are age, household structure, acculturation, ethnicity, work status, household income, residence location type, and region.

The model estimation results are shown in Table B-3. "Own car" was selected as the base category and "share car" and "no car" are interpreted relative to the base category. The model estimates that 22 percent of people were in share-car households and 6 percent in no-car households, leaving 72 percent in "own car" households. The base categories apply to the independent variables as well. The base categories are the variables not found: (1) 30–44 age group, (2) single-person households, (3) white, non-Hispanic ethnicity, (4) not employed, (5) $35–100K income, (6) living in suburban area, and (7) living outside all of the five selected MSA regions. As with the dependent variable, the other categories are interpreted relative to the base category.

Table B-3. Car ownership model coefficients.

Variables	Alternative			
	Share Car	(22% share)	No Car	(6% share)
	Coefficient	T-statistic	Coefficient	T-statistic
Constant	–1.811	–87.7	–2.599	–74.4
Age group 0–15	–0.526	–27.7	–0.838	–24.0
Age group 16–29	0.543	37.2	–0.076	–2.6
Age group 45–59	–0.131	-8.4	–0.121	–4.2
Age group 60–74	–0.405	–21.2	–0.324	–10.1
Age group 75 up	0.189	8.2	0.202	5.7
Couple in household	0.834	56.5	–1.058	–38.9
1+ children in household	–0.452	–32.5	–0.433	–12.1
Single with children	0.670	32.0	0.190	4.8
Ethnicity nonwhite or Hispanic	0.592	49.7	0.999	48.6
Born outside of U.S.	0.292	13.8	–0.309	–8.9
Born outside U.S., <20 years in U.S.	0.369	15.0	0.435	10.4
Worker	–0.597	–51.2	–1.133	–53.5
Low-income group	1.111	101.3	1.661	82.0
High-income group	–0.701	–45.2	–0.635	–14.5
Urban residence area type	0.690	49.9	1.757	85.5
Rural residence area type	–0.528	–46.1	–0.599	–24.4
Atlanta MSA region	0.106	2.9	–0.232	–3.0
Boston MSA region	0.135	3.8	–0.042	–0.7
Detroit MSA region	0.650	20.0	–0.133	–1.8
Houston MSA region	0.172	4.8	–0.213	–2.8
Seattle MSA region	–.0235	–5.1	0.362	4.6

Note: Although the sample person expansion weights were used in estimation to account for nonrepresentative sampling, the weights were first normalized to a mean of 1.0, so that the sum of weights is equal to the number of observations (to avoid inflated measures of statistical significance).

The model utility coefficients are shown, along with the related t-statistic. "Own car" has an implicit utility of 0, and separate utility functions were estimated for the other two alternatives. In general, a t-statistic of 1.9 or greater means that a coefficient estimate is statistically different from 0, with 95 percent certainty. Nearly every estimate in the table appears to be statistically significant. The coefficients can be interpreted according to their sign and relative size. For example, the largest positive coefficient for both alternatives is for the low-income group, meaning that having a lower income is the main factor related to living in a share-car or no-car household instead of an own-car household. Conversely, the high-income group coefficients are strongly negative, meaning those people are less likely to be in either of these low-/no-car households.

Children are less likely to live in low-/no-car households, while seniors age 75+ are more likely to live in low-/no-car households. People who live in households with couples (versus single adults), and those age 16–29 are more likely to share a car, but are less likely to be in a no-car household.

People in nonwhite or Hispanic ethnic groups are more likely to be in low-car households, and this effect is even stronger if they were born outside the United States, and stronger still if they have been in the United States for less than 20 years (these three effects are additive). Note that this effect is over and above the income effects that are simultaneously included in the model. A worker effect is also included simultaneously, and has strong negative coefficients, indicating that workers are more likely to have their "own car."

The urban and rural variables also have strong, expected effects, with people living in urban areas most likely to live in low-/no-car households, and those in rural areas most likely to be in "own car" households.

The region-specific effects are relatively minor, and indicate the effect of the region over and above all of the other variables in the model. This is a promising sign that the area type categorization (e.g., urban, rural) worked to capture a good deal of the land-use-related variation that exists in reality. The model goodness-of-fit measure, McFadden's Rho-squared (somewhat analogous to R-squared for regression models) is 0.198, which is a typical magnitude for this type of model.

B.2.2 Trip Rate Models

Log-linear regression models were estimated for the number of work trips and nonwork trips per person-day, with work trips classified as all trips with the purpose at either (or both) trip ends coded as work, work-related, or business, and all other trips classified as nonwork trips. The dependent variable for both models is LOG (#trips + 1), the 1 included to avoid taking the log of 0 for those with 0 trips. Note that the NHTS data include all days of the week throughout the year (i.e., including weekends and holidays), so it is truly an "average day" in the sense that multiplying by 365 would give an annual expected trip rate.

The model results are shown in Table B-4. The independent variables are the same as in the previous model, except that two new variables—"no car" and "share car"—are added, to represent the effect of car ownership on trip rates, relative to the base group, "own car." Also, the Work Trip Rate model was only estimated for people who are workers, so the age group 0–15 and worker variables were not included.

The work trip rate model contains relatively few significant effects, since the fact that somebody is a worker already explains most of the variation in the population, and the rest of the variables try to explain who tend to go to work on fewer days per week or make more work-related trips, such as non-home-based work trips. There are age effects, as workers over age 60 tend to make fewer work trips, as do, to a lesser extent, workers under age 30. Also, workers with children in the household tend to make fewer trips, either working part time, or having to stay home with sick children periodically. Nonwhite and Hispanic workers make slightly fewer work trips, but this is offset by a positive additive coefficient for those born outside the United States. Those in low-income groups and in urban areas make somewhat fewer work trips, and those in low-/no-car households make fewer trips as well, particularly those in no-car households. The only region-specific effects that are fairly strong are for fewer work trips in Boston and Detroit.

The nonwork trip rate model shows stronger effects, with the strongest negative effect being for workers, who, presumably, make fewer nonwork trips because they are busy working. There is also an age effect, with nonwork trip rates increasing with age up until age 75. People in households with children also make substantially more nonwork trips (many of those for school and/or taking children to school). There is not a strong influence of ethnicity, except that people born outside the United States tend to make fewer nonwork trips, all else being equal. Nonwork trip rates increase with income and decrease in rural areas, where distances are longer and people tend to group more activities into each trip. (One home-based trip that visits two different nonwork destinations requires three trips, whereas visiting them on two separate home-based tours would require four trips.) People in low-car, and especially no-car households, also make

Table B-4. Daily trip rate models.

Variables	Alternative			
	Work Trips		Nonwork Trips	
	Coefficient	T-statistic	Coefficient	T-statistic
Constant	0.825	155.1	1.597	310.4
Age group 0–15	n/a		–0.209	–45.0
Age group 16–29	–0.031	–6.7	–0.069	–18.4
Age group 45–59	0.0	0.1	0.018	5.1
Age group 60–74	–0.076	–12.4	0.058	12.5
Age group 75 up	–0.153	–9.3	–0.004	–0.6
Couple in household	–0.007	–1.5	–0.028	–7.6
1+ children in household	–0.040	–9.4	0.115	33.3
Single with children	–0.008	–1.0	0.010	1.8
Ethnicity nonwhite or Hispanic	–0.027	–6.1	-0.009	–2.8
Born outside of U.S.	0.035	4.6	–0.073	–12.7
Born outside U.S., <20 years in U.S.	0.020	2.3	–0.017	–2.4
Worker	n/a		–0.473	–153.3
Low-income group	–0.016	–3.6	–0.031	–10.1
High-income group	–0.008	–1.9	0.065	20.7
Urban residence area type	–0.013	–2.5	0.008	2.2
Rural residence area type	–0.001	–0.2	–0.052	–19.5
Atlanta MSA region	0.014	1.1	–0.027	–2.9
Boston MSA region	–0.084	–7.5	0.0	0.0.
Detroit MSA region	–0.077	–6.5	0.127	14.6
Houston MSA region	0.005	0.4	–0.056	–5.8
Seattle MSA region	–0.009	–0.6	–0.083	–8.0
No-car household	–0.078	–8.0	–0.110	–18.6
Share-car household	–0.021	–4.6	–0.016	–5.1

fewer nonwork trips. All of these effects are typically found in travel demand models. Again, the regional variables only explain any effects over and above other independent variables.

B.2.3 Mode Choice Models

Three separate mode choice models were estimated: one for work trips, one for nonwork trips made by people of driving age (16+), and another for children under age 16 who do not have the option of driving a car. Four modes are considered: car driver, car passenger, transit, and walk/bike. Any NHTS survey trips made by other modes, such as taxi or paratransit, were excluded from the estimation.

B.2.3.1 Work Trips

The work trip mode choice model, shown in Table B-5, was estimated on a sample of about 244,000 work trips. As before, the data were weighted using the NHTS trip expansion weights, normalized so that the mean weight is 1.0. The mode shares in the sample are 82.5 percent car driver (the base alternative), 7.6 percent car passenger, 3.3 percent transit, and 6.6 percent walk/bike.

Table B-5. Work trip mode choice model.

Variables	Alternative					
	Car Passenger		Transit		Walk/Bike	
	Coefficient	T-statistic	Coefficient	T-statistic	Coefficient	T-statistic
Constant	–3.287	–89.4	–4.190	–71.4	–2.853	-74.8
Age group 0–15	n/a		n/a		n/a	
Age group 16–29	0.638	31.1	0.079	2.2	–0.111	–4.5
Age group 45–59	–0.136	–6.2	–0.092	–2.8	–0.206	–9.5
Age group 60–74	0.003	0.1	0.154	3.1	–0.264	–7.9
Age group 75 up	–0.607	–5.4	0.109	0.7	–0.364	–3.7
Couple in household	0.275	11.5	–0.633	–17.1	–0.356	–15.0
1+ children in household	–0.053	–2.6	0.273	7.2	0.004	0.2
Single with children	0.125	3.5	–0.327	–6.0	–0.756	–17.5
Ethnicity nonwhite or Hispanic	0.107	5.0	0.243	7.1	–0.366	–14.7
Born outside of U.S.	0.176	5.0	0.199	4.3	0.035	0.9
Born outside U.S., <20 years in U.S.	–0.012	–0.3	0.256	5.3	0.195	4.5
Worker	n/a		n/a		n/a	
Low-income group	0.318	16.0	–0.199	–6.2	–0.215	–8.8
High-income group	–0.039	–1.8	0.406	11.8	0.439	21.3
Urban residence area type	–0.012	–0.5	1.366	46.5	0.982	44.4
Rural residence area type	0.198	11.2	–1.252	–23.7	–0.363	–16.4
Atlanta MSA region	0.252	4.7	–0.783	–4.9	–0.027	–0.4
Boston MSA region	–0.176	–2.8	–0.006	–0.1	–0.511	–7.3
Detroit MSA region	–0.197	–3.2	–0.957	–7.4	–0.296	–4.2
Houston MSA region	–0.095	–1.5	–0.720	–6.1	–0.334	–4.4
Seattle MSA region	–0.011	–0.1	1.026	10.9	–0.251	–2.8
No-car household	3.176	59.2	5.157	94.7	3.964	79.8
Share-car household	1.333	71.4	1.934	60.3	1.179	55.2
Fuel price (per dollar)	0.005	0.6	–0.050	–3.6	0.102	11.1

We again used the same set of variables as for the preceding models. However, we did have one additional variable—the price of gasoline.

> Note that this variable could not be used for the car ownership and trip rate models described earlier, because it is only available in NHTS for people who actually made trips.

The results in Table B-5 show that age has strong effects on work trip mode choice, with workers under age 30 more likely to go as car passengers and the older age groups over 45 are less likely to bike or walk. The age effects for transit use are not strong. Workers who are part of a couple (or live with a couple) are more likely to rideshare, but less likely to use transit or walk/bike; the same pattern is found for low-income workers (and the opposite pattern for high-income workers). Nonwhite and Hispanic workers are more likely to rideshare and use transit for the work trip, but less likely to walk; this effect is even stronger for workers born outside the United States. The effects by area type are also strong, as workers in urban areas are most likely to use transit or walk/bike for their work trip, while those in rural areas are less likely to use those modes and more likely to rideshare.

As one may expect, the most important variables are related to car ownership, with workers in no-car households more likely to use all the alternatives to driving, particularly transit. Finally, as gas price increases the walk/bike share increases somewhat, counter-intuitively, the transit share seems to decrease somewhat.

B.2.3.2 Nonwork Trips

A mode choice model with the same multinomial logit specification was estimated for nonwork trips made by people age 16+ (old enough to be a car driver). The sample is roughly 750,000 weighted trips, with 65.5 percent by car driver, 20.1 percent by car passenger, 21.0 percent by transit, and 12.3 percent by walk/bike. The model fit (McFadden Rho-squared) is 0.107, and the results are shown in Table B-6.

Table B-6. Nonwork trip mode choice model—age 16+.

Variables	Alternative					
	Car Passenger		Transit		Walk/Bike	
	Coefficient	T-statistic	Coefficient	T-statistic	Coefficient	T-statistic
Constant	–1.767	–111.4	–5.187	–104.5	–2.115	–110.6
Age group 0–15	n/a		n/a		n/a	
Age group 16–29	0.682	79.1	0.628	24.8	0.218	20.0
Age group 45–59	–0.075	–8.1	–0.020	–0.7	–0.039	–3.7
Age group 60–74	–0.013	–1.2	–0.342	–10.1	–0.311	–22.8
Age group 75 up	0.230	16.2	–0.519	–11.9	–0.625	–30.8
Couple in household	0.533	57.2	–0.347	–12.8	–0.102	–9.3
1+ children in household	–0.146	–17.6	0.018	0.6	–0.109	–10.2
Single with children	0.312	22.2	–0.318	–8.2	–0.021	–1.2
Ethnicity nonwhite or Hispanic	0.053	6.6	0.378	16.0	–0.213	–20.6
Born outside of U.S.	–0.009	–0.7	–0.050	–1.5	0.152	8.9
Born outside U.S., <20 years in U.S.	0.087	5.0	0.137	3.6	0.215	11.0
Worker	–0.523	–78.3	–0.526	–25.9	–0.248	–29.4
Low-income group	0.039	5.1	0.008	0.4	–0.031	–3.2
High-income group	0.048	5.9	0.176	5.5	0.198	19.9
Urban residence area type	–0.098	–9.5	1.501	69.9	0.780	76.5
Rural residence area type	0.075	11.0	–0.884	–22.8	–0.186	–19.9
Atlanta MSA region	–0.026	–1.0	0.402	5.2	–0.057	–1.8
Boston MSA region	0.171	7.7	0.444	9.0	0.264	10.7
Detroit MSA region	–0.131	–6.2	–0.809	–9.1	–0.163	–5.9
Houston MSA region	0.013	0.5	–0.363	–4.1	–0.089	–2.8
Seattle MSA region	0.063	2.1	0.525	6.3	0.460	14.5
No-car household	2.653	109.7	5.261	154.4	3.641	156.0
Share-car household	0.645	85.4	1.524	56.6	0.575	59.6
Fuel price (per dollar)	0.041	12.6	0.124	12.7	0.124	30.8

Again, car ownership is very important, with those in low-car and especially no-car households much more likely to choose any of the alternatives to being a car driver. It is interesting that once car ownership has been taken into account, those in high-income groups are also more likely to choose alternatives to driving. Nonwhite or Hispanic workers are more likely to rideshare or use transit, but less likely to walk/bike. Being born outside the United States does not have a strong influence, except being more likely to walk or bike, especially if living less than 20 years in the United States. Workers appear more likely to drive and less likely to use any alternatives. (This is not a tour-based model, so it is likely that some of these trips are between home and nonwork stops that car drivers make as part of work tours.)

The area type once again shows significant effects, with workers in core urban areas less likely to choose to be car passengers and more likely to go by transit and walk/bike, and those in rural areas choosing the opposite. There are a few significant region-specific effects, but they are generally much less significant than the area-type effects, suggesting that the model would also do fairly well at explaining mode choice in other regions. Finally, the fuel price variable has the expected effects, with a higher fuel price related to higher uses of all the alternatives to car driver, especially transit and walk/bike.

B.2.3.3 Children's Travel

The final mode choice model, shown in Table B-7, was estimated only for children younger than 16. (Because children under 5 do not have travel diaries in NHTS, the age group for estimation is 5–15.) This model includes about 135,000 weighted trips, with mode shares 79.6 percent for car passenger, 1.6 percent for transit, and 18.7 percent for walk/bike. Because car driver is not a valid alternative for this age group, the base alternative is car passenger, and equations were estimated for the transit and walk/bike modes. Also, many of the variables could not be included in the model, because they applied either to all cases or to no cases. Those variables are indicated by n/a (not applicable) in Table B-7. The model fit (McFadden Rho-squared) is 0.86.

As in the other mode choice models, the car ownership effects are the strongest. Nonwhite or Hispanic children are more likely to use transit or walk/bike, somewhat more so if born outside the United States. Children in low-income households are also more likely to use non-car alternatives, especially walk/bike. The area-type variables also show strong effects in the usual direction, again stronger than the region-specific effects (with the exception of Detroit, which had no transit choices in the data set). Fuel price also shows the expected effects, with higher fuel prices meaning that children are less likely to get a ride (from their parents).

B.2.4 Trip Distance Models

The final set of models, shown in Table B-8, is used to convert demand for car driver, car passenger and transit from number of trips to number of person miles travelled (PMT). For car drivers, this also gives a direct value of VMT. The SD model does not need to know miles traveled for walk or bike trips, so there is no model for those trips.

The process used to calculate VMT from the trip distance model is described next. The car ownership model splits the demographic categories further into subcategories by car ownership type. Then, within that demographic/car ownership group:

$$\begin{aligned} VMT = {} & (\textit{work trips} \times \textit{work trip car driver mode share} \times \textit{work trip car driver trip distance}) \\ & + (\textit{nonwork trips} \times \textit{nonwork trip car driver mode share} \\ & \times \textit{nonwork trip car driver trip distance}) \end{aligned}$$

Table B-7. Nonwork trip mode choice model—age under 16.

Variables	Alternative			
	Transit		Walk/Bike	
	Coefficient	T-statistic	Coefficient	T-statistic
Constant	–5.783	–54.5	–1.898	–64.3
Age group 0–15	n/a		n/a	
Age group 16–29	n/a		n/a	
Age group 45–59	n/a		n/a	
Age group 60–74	n/a		n/a	
Age group 75 up	n/a		n/a	
Couple in household	–0.235	–4.5	–0.007	–0.4
1+ children in household	n/a		n/a	
Single with children	n/a		n/a	
Ethnicity nonwhite or Hispanic	0.896	14.6	0.102	6.0
Born outside of U.S.	n/a		n/a	
Born outside U.S., <20 years in U.S.	0.271	3.3	0.107	2.9
Worker	n/a		n/a	
Low-income group	0.166	2.8	0.248	13.0
High-income group	1.067	15.7	–0.026	–1.4
Urban residence area type	1.631	31.5	0.377	17.9
Rural residence area type	–1.592	–13.0	–0.359	–20.7
Atlanta MSA region	0.960	7.8	–0.325	–5.3
Boston MSA region	–0.991	–4.4	0.325	6.4
Detroit MSA region	–20.000	n/a	–0.661	–10.9
Houston MSA region	–0.911	–4.1	–0.401	–6.5
Seattle MSA region	0.191	0.8	0.710	14.2
No-car household	3.258	47.0	1.828	49.8
Share-car household	1.112	18.0	0.387	19.5
Fuel price (per dollar)	0.090	3.9	0.089	11.7

Six different models get the six different inputs to the VMT equation. This is VMT per person per day. The same equation can be applied for car passenger miles traveled and transit passenger miles traveled.

The models were estimated using log-linear regression, with the dependent variable being the log of 1.0 plus the number of miles from the trip origin to the destination (a variable provided on the NHTS trip records). To avoid outlier effects, a small number of trips with distances greater than 100 miles were excluded.

The strongest effect in the models is the "work trip purpose" variable, which indicates that trips made for work tend to be longer than nonwork trips, particularly for car drivers. Trip distances by all modes also tend to increase with income but decrease with age. People in households with children tend to make shorter car trips (many of them chauffeur-type trips). Nonwhite and Hispanic workers tend to make longer car driver trips, while workers born outside the United States tend to make longer car passenger and transit trips.

There are strong area-type effects, with urban dwellers making shorter trips and rural dwellers making longer trips by all modes, as expected. Again, the region-specific effects are small after

Table B-8. Trip distance models.

Variables	Trip Type: Dependent = LN (Distance + 1)					
	Car Driver Trips		Car Passenger Trips		Transit Trips	
	Coefficient	T-statistic	Coefficient	T-statistic	Coefficient	T-statistic
Constant	1.538	305.8	1.884	182.0	1.959	61.4
Age group 0–15	0.218	6.6	–0.211	–36.2	–0.401	–15.9
Age group 16–29	0.044	13.4	–0.070	–11.1	–0.008	–0.5
Age group 45–59	–0.051	–17.5	–0.027	–3.8	–0.100	–5.8
Age group 60–74	–0.083	–22.0	–0.088	–10.7	–0.154	–6.8
Age group 75 up	–0.178	–30.6	–0.204	–19.7	–0.140	–4.4
Couple in household	0.042	13.3	–0.061	–8.3	0.008	0.4
1+ children in household	–0.050	–16.8	–0.059	–9.8	0.035	1.8
Single with children	0.039	7.9	–0.058	–6.7	0.047	1.9
Ethnicity nonwhite or Hispanic	.052	17.7	–0.003	–0.6	0.001	0.1
Born outside of U.S.	0.022	4.3	0.097	9.1	0.240	10.1
Born outside U.S., <20 years in U.S.	–0.008	–1.3	–0.044	–3.5	–0.239	–9.2
Worker	0.434	179.8	0.190	25.9	0.277	20.4
Low-income group	–0.074	–25.7	–0.067	–13.9	–0.119	–7.9
High-income group	0.043	15.5	0.047	10.1	0.073	3.9
Urban residence area type	–0.105	–27.8	–0.108	–17.2	–0.229	–16.7
Rural residence area type	0.229	95.4	0.295	73.7	0.270	10.0
Atlanta MSA region	0.131	15.4	0.087	6.1	0.678	13.0
Boston MSA region	0.116	14.5	–0.121	–8.8	–.0025	–0.7
Detroit MSA region	0.010	1.3	0.021	1.7	0.478	8.1
Houston MSA region	0.097	10.8	0.002	0.2	0.191	3.4
Seattle MSA region	0.150	14.6	0.108	6.6	0.061	1.3
No-car household	0.101	6.1	–0.274	–25.1	–0.294	–16.3
Share-car household	–0.026	–8.1	–0.055	–11.6	–.0171	–9.9
Fuel price (per dollar)	0.008	7.2	–0.005	–2.8	0.027	4.3

taking into consideration other variables, particularly area type. People in low-car and no-car households tend to make shorter trips by car—perhaps because it is more difficult to find a ride to farther destinations.

The fuel price effects are fairly small, and not in the expected (negative) direction for car driver or transit. This result is different from the finding in the mode choice models, and may indicate that people tend to change modes for their shorter trips, but still make the longer trips by car (in which case, overall VMT would still decrease).

B.3 Land-Use Sector

The stock variable is the amount of space (in square miles) by area type (urban, suburban, local) and by use type (residential, nonresidential, developable, and protected). This stock variable is segmented into:

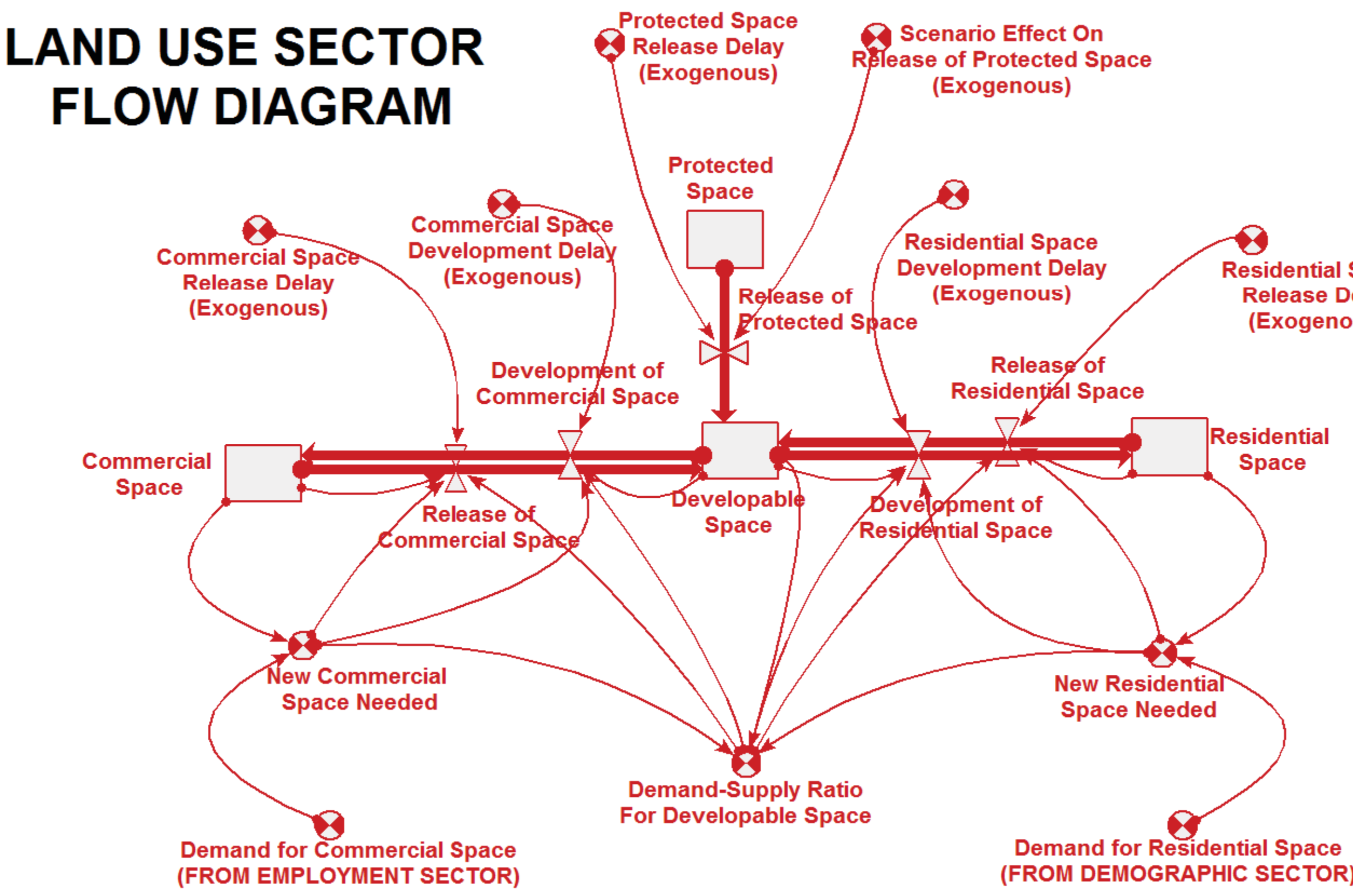
- Urban, suburban, rural residential space
- Urban, suburban, rural nonresidential space

- Urban, suburban rural developable space
- Urban, suburban, rural protected space

B.3.1 Land-Use Rates of Change

Figure B-2 presents a flow diagram for the land-use sector. The rates of change that are relevant to this sector are:

- **Development of Residential Space** and **Release of Residential Space**: Converting land from developable space to use for housing.
- **Development of Nonresidential Space**: Converting land from developable space to use for employment, industry, and other commercial uses.
- **Release of Nonresidential Space**: Converting land back to developable space—through rezoning, redevelopment, demolition, etc.
- **Release of Protected Space**: Redesignating land from protected to developable. (Note that this can be negative, which would signify the case of more land put under protection.)



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, the stock variable is the amount of space.
- The stacked triangles are "flow" variables that determine the rate of change in the stock variables over time.
- The circles represent exogenous inputs or variables computed based on other variables.
- The clouds represent sinks or sources that are outside the scope of the model.
- The arrows represent direct relationships that are (parts of) equations in the model.

Figure B-2. Land-use sector flow diagram.

The equations that comprise the rates for the first three bullets have four main components: (1) the existing stock of space in the use that would be converted out of; (2) the amount of new space needed for the relevant land use (that can be zero or negative); (3) an effect of relative demand and supply for developable land, which can moderate land prices and the amount of development undertaken by the market; and (4) the market delay time needed to create new development or release land for new development. The delay times are exogenous, and can reflect, for example, programs or tax policies to spur new housing or commercial development. By comparison, the equation for the release of protected space is based totally on exogenous scenario inputs, as it is assumed that such actions are the result of nonmarket decisions.

There are a number of things to note for the rate equations:

- The key sector inputs of demand for residential space and demand for nonresidential space come from the employment and demographic sectors, respectively. (The model does not explicitly account for land space needed for road infrastructure, as that is not likely to vary enough under the scenarios to significantly affect the land-use market—although the supply of new roads can indirectly spur the demand for land by helping to attract new residents and businesses.)
- The real estate market is modeled here as being reactive to demand, rather than predictive of what demand may be in the more distant future. Although purely speculative development is fairly rare in reality (e.g., not much construction is happening in the current recession), it would be possible to represent it in the model by including exogenous scenario variables for new development that is not dependent on market demand.

B.4 Employment Sector

The stock variable is the number of jobs (employment) by area type (urban, suburban, local) and by employment type (retail, service, other). This stock variable is segmented in the model into:

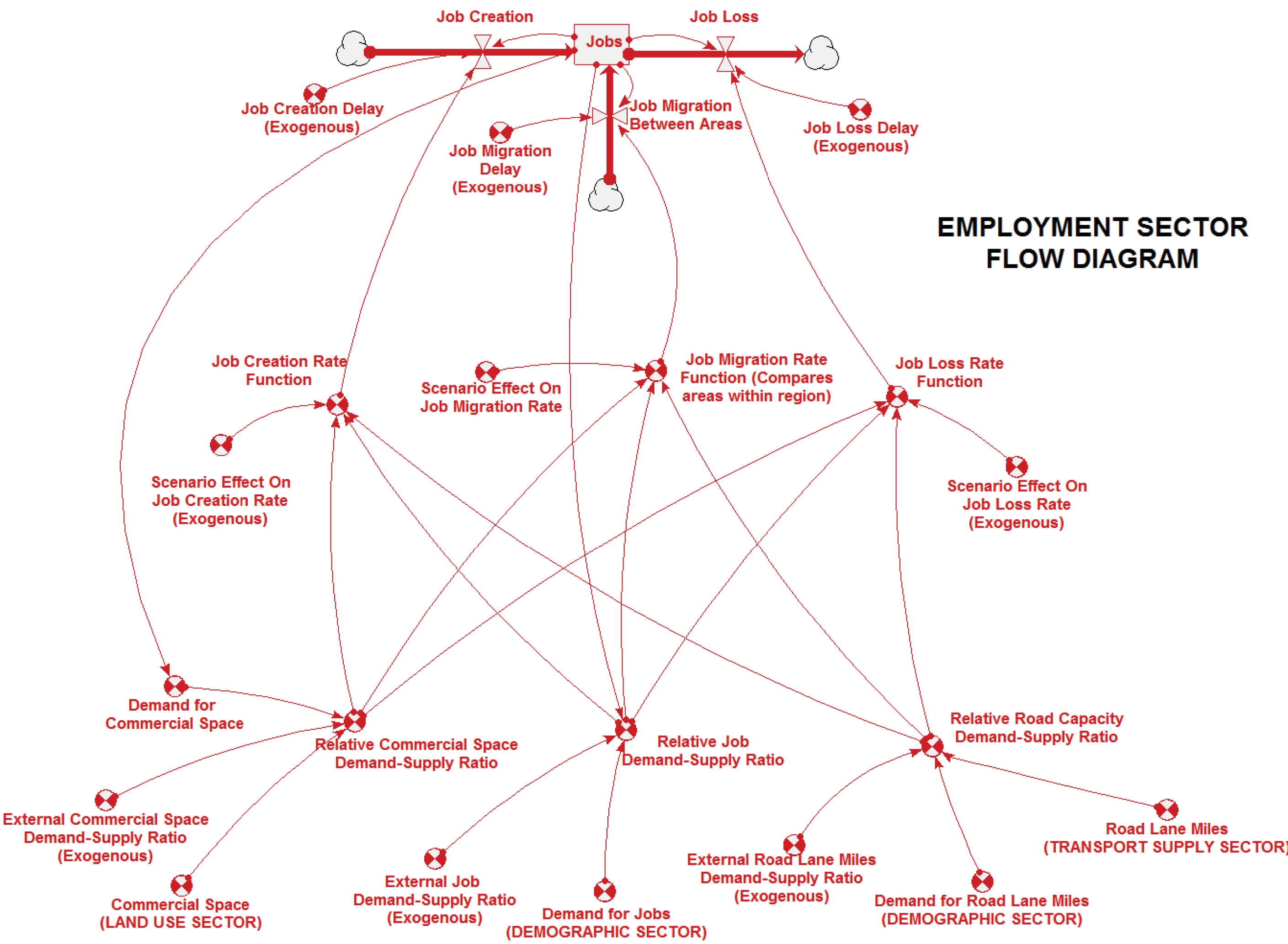
- Urban, suburban, rural retail jobs
- Urban, suburban, rural service jobs
- Urban, suburban, rural other jobs

The source data for these variables were the Longitudinal Employer-Household Dynamics data from the U.S. Census Bureau, 2002 and 2010.

B.4.1 Employment Rates of Change

Figure B-3 presents a flow diagram for the employment sector. The rates of change that are relevant to this sector are:

- **Job creation**: Jobs created in the region by companies moving to the region, new companies starting up, or existing companies adding jobs. (For the purposes of this model, it is not important to model those separately.)
- **Job loss**: Jobs lost in the region by companies leaving the region, going out of business, or downsizing.
- **Job migration**: Jobs changing location within the region, such as moving from the city center to the suburbs.



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, the stock variable is the number of jobs.
- The stacked triangles are "flow" variables that determine the rate of change in the stock variables over time.
- The circles represent exogenous inputs or variables computed based on other variables.
- The clouds represent sinks or sources outside the scope of the model.
- The arrows represent direct relationships that are (parts of) equations in the model.

Figure B-3. Employment sector flow diagram.

The equations that comprise this sector have three main components: (1) the existing stock of jobs, (2) the indicated change in the stock of jobs, and (3) the market delay time needed to reach the indicated level. The delay time is exogenous, and could reflect, for example, job creation programs or tax policies to remove barriers to creating new jobs. The rates of change in job creation, job loss, and job migration across area types is modeled from trends analysis by the team using the Longitudinal Employer-Household Dynamics data from the U.S. Census Bureau, 2002 and 2010.

The meat of the sector dynamics is in the rate functions used to determine the indicated change in the stock. Each of these in turn has four main inputs: (1) an exogenous scenario effect, reflecting, for example, the health of the economy for creating new jobs; (2) the balance of supply and demand for jobs, reflecting the availability of labor; (3) the balance of supply and demand for commercial space, reflecting the availability of land; and (4) the balance of supply and demand for road capacity, reflecting traffic congestion levels for commuting.

There are a number of things to note for each of the demand-and-supply relationships that enters the rate functions:

- While the supply of jobs and the demand for commercial space are endogenous to this sector, the other key inputs come from other model sectors, as shown in capital letters at the bottom of Figure B-3.
- The same three demand-and-supply ratios enter all of the functions, but the user can give them different weights in the different functions. For example, companies within the region may know more about traffic congestion than companies from outside the region, so that will tend to have a higher weight (relative influence) for job migration than for job creation or job loss.
- The word "relative" is used in each of the demand–supply variables because what is important to reflect is how this region is doing relative to other regions in the country, particularly for jobs coming from or going to other regions (reflected as part of job creation and job loss). Since those other regions are exogenous to the model, those external trends are exogenous scenario inputs to the model.

The attractiveness multiplier equations for this sector work in a similar way to the resident attractiveness multiplier equations described in Chapter 4. In this case, the weights vary by area type and employment type.

B.5 Transport Supply Sector

The stock variable is the number of road lane miles by area type (urban, suburban, local) and by road type (freeway, major arterial, other), and number of transit route miles by area type (urban, suburban, local) and by transit type (rail and bus). The stock variable is segmented in the model into capacity measures in terms of:

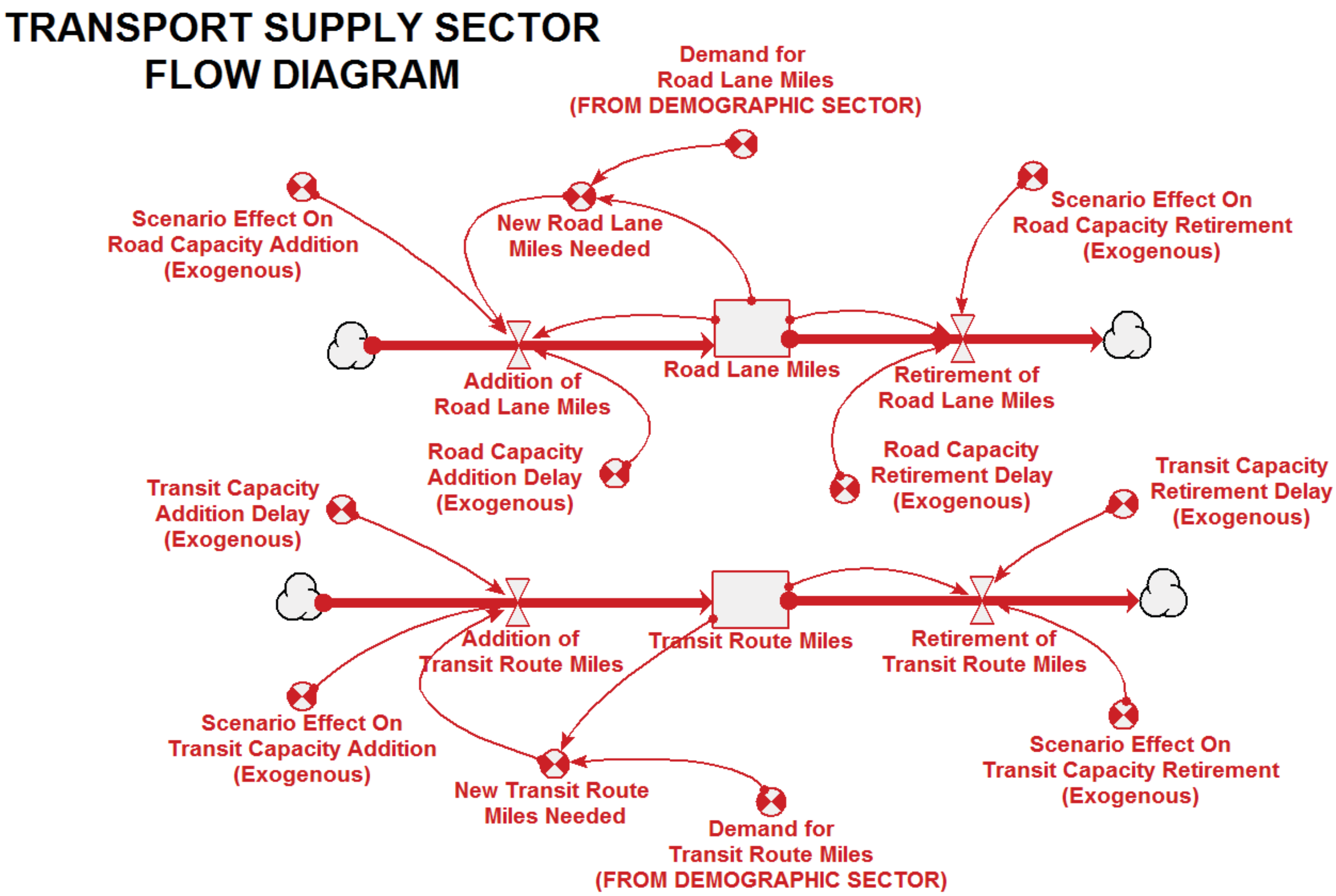
- Urban, suburban, rural freeway lane miles
- Urban, suburban, rural arterial lane miles
- Urban, suburban, rural other lane miles
- Urban, suburban, rural rail transit route miles
- Urban, suburban, rural nonrail transit route miles

The sources for these data were the National Transit Database of the FTA, 2002 and 2010.

B.5.1 Transport Sector Rates of Change

Figure B-4 presents a flow diagram for the transport sector. The rates of change that are relevant to this sector are:

- **Addition to road lane miles**: Construction of new road capacity (which could include widening of existing roads).
- **Retirement of road lane miles**: Reflects road capacity being closed or becoming unusable due to lack of maintenance.
- **Addition to transit route miles**: Opening of new transit services, or addition of routes and/or increase of frequency on existing services.
- **Retirement of transit route miles**: Reflects the closing of transit services or routes, or reduction of frequencies.



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, the stock variable is amount of road lane miles and amount of transit route miles.
- The stacked triangles are "flow" variables that determine the rate of change in the stock variables over time.
- The circles represent exogenous inputs or variables computed based on other variables.
- The clouds represent places where people can transition to a new demographic state (e.g., death, birth, divorce, income group change).
- The arrows represent direct relationships that are (parts of) equations in the model.

Figure B-4. Transport sector flow diagram.

The demand for peak-hour road supply is a function of the number and distance of work and nonwork trips by car drivers made by people living in each area type, and depending on a number of other user inputs, including the mix of road type/area type combinations used by commuters for each type of flow (e.g., suburban–urban commutes) and the peak-hour fraction of daily trips assumed for work and nonwork trips. Multiplied together, these determine the peak-hour demand for lane miles for each road type within each area type, which can be compared with the road supply to determine the extent to which the existing road supply can meet the indicated demand. Because the model does not use explicit network assignment, it approximates traffic demand growth relative to supply over time.

The rate equations for the transport sector are relatively simple, and mainly rely on user scenario inputs. This reflects the fact that transportation capital, operations, and maintenance funds mainly use public funds, with relative little influence from private market forces.

For addition of road and transit capacity, the main indicator is the amount of new capacity needed to meet passenger demand, if any, based on the demand calculations described above. The exogenous scenario inputs represent (1) the amount of that capacity that is to be provided (i.e., the government could decide to try to meet mobility demand by other means than increasing capacities); and (2) the delay before new capacity will be provided (largely a function of the availability of public funds). For retirement of existing capacity, there are again two types of exogenous inputs: (1) the fraction of existing capacity to be retired (for example, the decision to discontinue certain transit services); and (2) the rate in time at which existing capacity is to be retired. Currently, transit route miles are treated simpler than road lane miles, and the relative demand and supply for transit do not feed back to the other sectors of the model. Modeling of transit in this sector is an aspect that could be improved in a future area-specific case study.

APPENDIX C

Statistical Output

Indicator	Atlanta				Boston				Detroit				Houston				Seattle			
	M	TT	GC	GF	M	TT	GC	GF	M	TT	GC	GF	M	TT	GC	GF	M	TT	GC	GF
Auto VMT per capita	-8%	3%	-51%	-63%	-12%	-12%	-55%	-67%	-5%	5%	-52%	-63%	-5%	6%	-49%	-61%	-12%	-1%	-54%	-66%
Percent non-car owning	22%	0%	113%	68%	9%	9%	76%	54%	10%	-4%	83%	51%	12%	-4%	76%	48%	15%	-3%	96%	60%
Percent car-sharing	0%	-20%	58%	31%	-1%	-1%	51%	28%	-2%	-20%	45%	23%	0%	-18%	44%	24%	-1%	-22%	58%	31%
Average car occupancy	2%	-4%	15%	10%	6%	6%	21%	15%	3%	-3%	16%	11%	1%	-5%	14%	9%	5%	0%	19%	13%
Transit mode share	23%	7%	24%	101%	2%	2%	8%	77%	6%	-5%	21%	101%	13%	3%	17%	85%	7%	-1%	19%	73%
Walk/bike mode share	7%	-3%	79%	105%	6%	6%	60%	81%	5%	-5%	81%	107%	7%	-4%	73%	96%	9%	-2%	61%	77%
Work trips / capita	-16%	-2%	-28%	-40%	-23%	-23%	-33%	-44%	-11%	4%	-24%	-36%	-12%	3%	-24%	-37%	-21%	-7%	-32%	-43%
Non-work trips /capita	5%	1%	-39%	-40%	6%	6%	-38%	-39%	3%	0%	-40%	-41%	3%	-1%	-40%	-41%	6%	2%	-38%	-39%
Population (millions)	56%	37%	8%	50%	32%	32%	-9%	34%	20%	7%	-14%	20%	56%	36%	7%	51%	52%	32%	4%	50%
Percent under 16	5%	-8%	-21%	-30%	24%	24%	-7%	-21%	13%	-2%	-15%	-27%	0%	-12%	-24%	-33%	20%	5%	-10%	-22%
Percent over age 60	43%	74%	42%	98%	15%	15%	13%	61%	13%	37%	12%	57%	43%	72%	41%	100%	26%	52%	24%	75%
Percent over age 75	78%	166%	23%	169%	18%	18%	-19%	80%	13%	69%	-22%	72%	74%	156%	16%	164%	42%	112%	-3%	115%
Percent Hispanic	40%	30%	28%	59%	36%	36%	27%	53%	38%	30%	29%	56%	22%	17%	16%	31%	36%	28%	27%	51%
Percent low income	1%	-13%	56%	12%	9%	9%	70%	23%	18%	1%	85%	31%	-7%	-19%	40%	2%	12%	-4%	74%	25%
Percent high income	44%	74%	-10%	37%	23%	23%	-22%	18%	40%	68%	-12%	36%	70%	107%	6%	58%	57%	91%	-1%	50%
Percent foreign born	-16%	-27%	-27%	51%	-9%	-9%	-22%	65%	13%	-9%	-11%	119%	-31%	-37%	-37%	18%	-15%	-25%	-26%	51%
Percent in workforce	-16%	-1%	-9%	2%	-22%	-22%	-15%	-5%	-11%	5%	-3%	8%	-12%	2%	-5%	6%	-20%	-6%	-13%	-3%

Note: M = Momentum, TT = Technology Triumphs, GC = Global Chaos, GF = Gentle Footprint.

Legend:

- greater than 25% increase
- 10-25% increase
- -10% to 10% change
- 10-25% decrease
- greater than 25% decrease

Figure C-1. Percentage changes from 2010 to 2050 as illustrated in Table 6-7.

APPENDIX D

Method and Findings from Demonstrating and Testing *Impacts 2050*

The development of *Impacts 2050* was facilitated by testing with prospective end users through onsite demonstrations, followed by a beta test of the model. The testing led to a number of model refinements. This section briefly describes the testing, along with the key findings for each.

D.1 Onsite Demonstrations of *Impacts 2050*

The research team conducted onsite demonstrations of *Impacts 2050* with three of the five regions for which data are included in the tool: Atlanta, Houston, and Seattle. Planners, travel demand modelers, economic forecasters, and demographers from the local MPO and state DOT participated in the demonstrations, hosted by the local MPO (Table D-1).

The objective of the demonstrations was to obtain meaningful feedback from both MPOs and state DOTs in a regional setting. Specifically, participants provided insights on:

- *Impacts 2050*'s structure and source data,
- the modeled outcomes,
- how *Impacts 2050* might be used, and
- recommendations for improving *Impacts 2050.*

Participants provided their reactions to *Impacts 2050* by answering three general questions: Do you see a need for this tool? Would you use it? What challenges are you facing that you could foresee using the tool to address?

The demonstrations proved to be an appropriate venue for initial testing of the real-world value of *Impacts 2050.* The feedback contributed to refinements to ensure it is user-friendly, its purpose and intended applications are clear, and its instructions match its functionality. These refinements were made and resulted in a beta version of *Impacts 2050.* The feedback also sheds light on information that should be included in the *Impacts 2050* documentation contained in Appendix B and in the *User Guide.*

A set of seven broad findings was drawn from participant feedback during the demonstrations:

1. **Generally, *Impacts 2050* was favorably received in each of the demonstrations, and most participants were receptive to the tool concept.** One participant said, "We can always use better planning tools because we certainly aren't solving all our planning problems." Participants provided feedback that has already been incorporated into the tool. The participants in the demonstrations are eager to obtain the beta test version of *Impacts 2050*, and many noted that they will provide more substantive feedback once they are able to review the *User Guide* and "dig around" in the tool themselves.

Table D-1. ***Impacts 2050*** **demonstration schedule.**

Date	Region	Host Agency	Participating Agencies (number attending)
November 26, 2012	Atlanta	Atlanta Regional Council (ARC)	ARC (9) Georgia Department of Transportation (GA DOT) (4) Panel Member Kyle Mote (GA DOT)
February 11, 2013	Houston	Houston-Galveston Area Council (H-GAC)	H-GAC (4) Texas Department of Transportation (1) Panel Member Duncan Stewart (TxDOT, retired)
March 6, 2013	Seattle	Puget Sound Regional Council (PSRC)	PSRC (5) Washington State Department of Transportation (WSDOT) (5) Panel Member Lizbeth Martin-Mahar (WSDOT)

2. **The perceived utility of *Impacts 2050* is initially tied to where the transportation agency is with regard to its long-range transportation planning process; after consideration and discussion, participants discovered other uses for *Impacts 2050* beyond its contribution to the development of their long-range plans.** Two MPOs have produced their 2040 regional transportation plans, and the third is about two years away from producing its 2040 plan. Still, several potential and valid uses for *Impacts 2050* were suggested, including:
   - Conduct a quick manipulation of demographic characteristics in relation to land-use issues (but a mapping capability would be preferable or a useful addition).
   - Conduct sensitivity testing of land-use alternatives and their effect on demographic distributions and travel demand.
   - Conduct "what if" analyses to present alternatives to the public or to quickly respond to Board members' (or others') questions.
3. **There was agreement that *Impacts 2050*'s scenario analysis function will be useful to transportation agencies.** Participants welcome better ways to conduct scenario planning, and thereby reach agreement on changes from the status quo. Two MPOs observed that while they have conducted scenario planning as part of their transportation plans, they are not certain what it accomplished. A few participants questioned how scenario analysis would benefit or be used among planners. Still, there was general agreement that to be truly useful as a scenario analysis tool, *Impacts 2050* should include a process or framework (and examples) for its use that should be included with its dissemination and promotion.
4. **Two major and important advantages of *Impacts 2050*, compared with the models currently being used for long-range planning, are (1) it runs scenarios and produces output much faster than other models, and (2) its inclusion of socio-demographic linkages with transportation and land use fills a transportation planning gap.** Transportation agencies have many needs, including better connecting (1) with the public on ideology, alternatives, and tradeoffs; and (2) with decision makers on options and policies—especially those related to land use. Current transportation planning models (which may be accurate) are big, take a long time to run, and produce output that is too complicated to be effective in these settings. While participants in the demonstrations understood that *Impacts 2050* is not a replacement for those models, they readily recognized its advantages and the applications for its use (e.g., use the "what if" functionality of *Impacts 2050* to run and test the policy impacts within scenarios). Furthermore, most participants welcomed *Impacts 2050*'s cornerstone feature—its inherent capability to integrate socio-demographics with land-use, economics, and travel planning.

5. **A drawback to *Impacts 2050*, which could be a factor that deters its receptivity, is that many transportation agencies have already invested in a wide array of modeling and forecasting tools; they are wary of adding another new tool that someone will have to manage and maintain (when some staff have not yet mastered the tool already being used).** Once participants understood the benefits of *Impacts 2050*—particularly its speed—their interest in and receptivity to it grew. Still, this drawback should be addressed in the supplemental materials to *Impacts 2050.* For instance, information in the *User Guide* should readily explain exactly for what uses *Impacts 2050* can and cannot be used, and should also describe the level of effort and process for setting up, learning to use, and maintaining the tool (collect and prepare the data for input into *Impacts 2050*, develop the custom-relevant scenarios, validate the data, etc.). One participant suggested that the initial adoption and long-term use of *Impacts 2050* might be aided by creating a Web site through which users can download the tool, network with each other in forums as a user community, share case studies and examples on how the tool has been applied, and share modifications and/or updates to the tool. More than anything, demonstration participants opined that transportation agencies need a vision or plan and a system for integrating *Impacts 2050* into their existing planning capabilities and models already in hand. Such a Web-based user community and plan are beyond the scope of the work plan for this research effort.
6. **Most modelers are used to working with spatial data, so the limited spatial definition of *Impacts 2050* (urban, suburban, regional) could be seen as a drawback to its applicability.** This issue can be dealt with somewhat in the *User Guide*, by explaining (1) how the area-type data are built up from more detailed, tract-level data; and (2) why the amount of spatial detail is limited. Although it is not within the current project's scope, it may be useful to consider a version of *Impacts 2050* that can work at different levels of spatial detail. In one direction, a simpler, easier-to-use version of *Impacts 2050* would have no area-type definition at all, with the entire region treated as a single area. In the opposite direction would be a version that treats each Census tract as a separate area. This version would allow some visual mapping of results. Such a tool would take longer to run (maybe requiring a few minutes as opposed to a few seconds), but would still be quick relative to other models. Another potential issue is that users may focus on the results as if they are accurate spatial forecasts, moving away from the purpose of *Impacts 2050* for strategic comparison of scenarios.
7. **A key to *Impacts 2050*'s adoption and use is in the quality and level of detail provided through the *User Guide*. Users must be absolutely clear on: the tool structure, how to easily navigate within the tool, how to input and modify data and run the scenarios, and how to interpret and use the outputs.** Participants asked a number of important questions regarding the capabilities and features of *Impacts 2050.* The following is a summary of their comments and suggestions.
   - The layout and structure of *Impacts 2050* need to be clearly explained—a clear roadmap of the tool needs to be provided. The level of detail contained in *Impacts 2050* (e.g., extensive variable data, assumptions used for each of the scenarios—including the color-coding schemes) was overwhelming to participants, and they wanted to be assured they will be able to easily understand and readily use the model.
   - Some participants did not readily understand the purpose of the four scenarios, but most were receptive to the scenario concept. Still, the *User Guide*, in particular, should provide information on the scenarios and how they can be modified.
   - Some questioned whether the visual outputs of *Impacts 2050* (line graphs and stacked charts) were sufficient. A mapping capability was recommended; this would require significant resources and time to integrate, and is outside of the scope of work for this research effort.

- There were questions about whether *Impacts 2050* could be used only on the regional or MPO level, or if it could also be applied statewide. The *User Guide* should address this issue and provide recommendations on how statewide-level scenario analysis can be accomplished (i.e., the data needs and refinements users would need to make, and the steps involved in conducting the analysis).
- There were questions about the source data and level of effort required to access and prepare the data required for *Impacts 2050* for a region where data have not already been included. Instructions in the *User Guide* should cover this issue, as well as the references for the source data.

In sum, the feedback received in the demonstrations indicated a need for, and interest in, *Impacts 2050*. In each of the demonstration locations, participants made it clear that more meaningful feedback will be provided during the beta test of the tool, at which time they will be able to explore and try out *Impacts 2050* themselves. The beta test is a critical step of the tool development process.

D.2 Beta Testing of *Impacts 2050*

The refinements made based on the feedback the team received during the onsite demonstrations led to a beta version of *Impacts 2050*. About 30 people were invited to participate in a testing effort that included three items: (1) the beta version of the model, (2) a draft of the *User Guide*, and (3) a short brief describing the research effort. Testing participants included participants in the onsite demonstrations (including three panel members) and two MPOs representing two regions not included in *Impacts 2050*—Capital Area Metropolitan Planning Organization (Austin, TX) and Baltimore Metropolitan Council (Baltimore, MD). The following summarizes the feedback received on each of the testing items.

- Feedback on the research brief—Testers found the research brief to be useful, particularly the description of the scenarios, the structure of *Impacts 2050*, and the sample questions that could be answered by using the tool. Suggestions for improving *Impacts 2050* ranged from provide background on the scenario-based process and how scenarios can be manipulated, to "tease out" "what if" answers.
- Feedback on the *User Guide*—Testers appreciated the detailed instructions for using and modifying *Impacts 2050*, provided in the section describing the model structure. Furthermore, they found the *User Guide* and research brief to be complementary, supporting documents to *Impacts 2050*. With regard to improvements, they suggested adding instructions for manipulating scenario variables and including visual outputs of scenario runs, so they could follow the process and match their outputs with those in the *User Guide*.
- Feedback on *Impacts 2050*—Tester feedback on *Impacts 2050* encompassed three areas: usability, features and content, and potential use of the tool.
  - *Usability (focusing on the use, appearance, and operationality)*—Testers found *Impacts 2050* very easy to use. They appreciated its simple structure and quick processing power, and the neat organization of its inputs and outputs. Some links did not function properly (many were fixed during the test). They suggested that to improve usability, include buttons that redirect the user to the *User Guide* and return them to the start/home page on each of the pages within the tool.
  - *Features and content*—On the whole, testers appreciated *Impacts 2050*'s outputs, and a number asked about whether specific features could be included (e.g., whether the model could be run for a specific year, whether congestion could be included as a variable, and whether percentage teleworking could be shown like other mode-share

figures). Suggestions for clarifications in the model or *User Guide* included defining certain variables (e.g., children), explaining how to change the travel behavior coefficients, being a little clearer on how to input certain demographic data for regions not already included in the model, and providing tips on building Structure Query Language (SQL) statements.

– *Potential use of Impacts 2050 by transportation agencies*—MPOs with data not already in *Impacts 2050* believed they would use the tool and input the data following the instructions. While the use of scenarios in the planning process was new to some MPOs, a few shared how *Impacts 2050* could be useful to them:
  - Provide a back-of-the-envelope way for evaluating scenarios.
  - Assess "what if" events when brainstorming with policy bodies.
  - Modify scenarios and test different socio-demographic assumptions during the needs assessment phase of the regional transportation planning process.

APPENDIX E

Tool for Identifying Driving Forces in the Scenarios

Effects of Socio-Demographics on Future Travel Demand

Cross-Impact Matrix

How strong is the DIRECT IMPACT of a column descriptor on the future development of a line descriptor?

Please use a scale from 0 to 3:

0: no impact
1: low impact
2: moderate impact
3: strong impact

		1.1 Total population	1.2 Age structure	1.3 Household structure (married or not, kids or not)	1.4 Percent foreign born	1.5 Race/ethnicity distribution	1.6 Income distibution	1.7 Aging rate	1.8 Workforce participation	1.9 Population density	1.10 Birth rate	1.11 Marriage rate	1.12 Divorce rate	1.13 Household formation rate	2.1 Number of jobs	2.2 job creation	2.3 job loss	2.4 job migration	3.1 amount of space	3.2 rate of conversion to/ from developable	3.3 rate of conversion to / from protected	4.1 Number of lane miles for freeways	4.2 Total route miles for rail and bus	5.1 telework share	5.2 Online shopping	5.3 Rate of economic growth	5.4 smartphone adoption	5.5 self driving vehicles	6.1 cost of gas	6.2 walk and bike paths	6.3 carbon tax	6.4 attitudes	
1.1	Total population		3	1	2	0	0	2	0	0	3	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	14
1.2	Age structure	0		0	2	2	0	3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
1.3	Household structure (married or not, kids or not)	0	2		2	1	1	1	1	0	3	3	3	3	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	23
1.4	Percent of foreign born in each race group	0	0	0		0	0	0	0	0	1	0	0	0	1	1	2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	7
1.5	Race/ethnicity distribution	0	0	0	3		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
1.6	Income distribution	0	1	2	1	2		1	3	1	0	0	0	1	2	2	2	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	22
1.7	Aging rate	0	2	0	1	1	0		0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
1.8	Workforce participation	0	2	1	2	1	1	2		1	1	1	0	0	3	3	3	2	1	1	1	1	1	1	0	3	0	0	0	0	0	0	32
1.9	Population density (share urban, suburban, rural)	0	0	1	1	1	0	0	0		0	0	0	1	0	1	0	2	3	3	3	2	2	0	0	0	0	0	1	2	0	1	24
1.10	Birth rate	0	3	1	3	1	0	0	1	0		2	1	1	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	17
1.11	Marriage rate	0	2	0	0	0	0	0	1	0	0		1	0	1	0	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	8
1.12	Divorce rate	0	0	0	0	0	0	0	1	0	0	1		0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5
1.13	Household formation rate	0	2	0	0	0	1	1	1	0	0	2	0		1	2	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	14
2.1	Number of jobs (share retail, service, tech, agriculture, other)	0	0	0	0	0	0	0	0	0	0	0	0	0		3	3	0	0	0	0	1	1	1	0	3	0	1	0	0	0	1	14
2.2	rate of job creation	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	1	1	0	0	1	1	1	0	3	1	1	1	0	0	1	12
2.3	rate of Job loss	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	0	0	0	1	0	0	0	3	0	0	0	0	0	1	6
2.4	rate of Job migration within region	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1		1	0	0	1	1	1	0	1	0	0	0	0	0	0	9
3.1	Amount of space that is developed residential, developed other, developable, protected	0	0	0	0	0	0	0	0	1	0	0	0	1	1	2	1	2		3	3	1	1	2	1	1	1	1	0	1	2	2	27
3.2	Rate of conversion to / from developable	0	0	0	0	0	1	0	0	1	0	0	0	0	1	2	1	2	2		3	1	1	2	1	2	0	0	0	1	2	2	25
3.3	Rate of conversation to / from protected	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	2	2		1	1	2	1	2	0	0	0	1	2	2	19
4.1	Number of lane miles for freeways, arterials and other highways	0	0	0	0	0	0	0	1	0	0	0	0	0	2	2	1	1	0	0	0		0	1	2	2	0	0	0	0	2	2	16
4.2	Total route miles for rail and bus transit	0	1	0	1	0	0	1	1	2	0	0	0	0	2	2	2	1	0	0	0	2		2	2	2	0	0	2	1	3	2	29
5.1	Telework share	0	0	0	0	0	0	0	2	1	1	0	0	0	1	1	0	0	0	0	0	1	0		0	0	1	0	2	0	2	2	14
5.2	Online shopping share of retail sales	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1		0	2	0	2	0	2	1	12
5.3	Rate of economic growth	0	1	0	0	0	0	1	2	0	0	0	0	0	2	2	0	1	1	1	1	2	1	0	0		0	0	1	0	1	0	17
5.4	Adoption of smartphone or mobile devices with internet access	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1		0	0	0	1	1	8
5.5	Market penetration of self-driving vehicles	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0		0	0	0	1	4
6.1	Price of gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	3	0	3
6.2	Total miles of walk and bike paths	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1	3	4
6.3	Introduction of carbon tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		3	3
6.4	Attitudes favoring clean energy and environmental protection	0	1	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	3		9
		0	22	6	21	9	6	14	14	9	14	10	5	7	21	26	20	16	11	10	11	19	10	16	7	38	5	3	11	6	24	26	

Figure E-1. Cross-impact matrix.

APPENDIX F

Final Research Brief for NCHRP Report 750, Volume 6

Research Brief

This brief summarizes the research conducted and documented in *NCHRP Report 750: Strategic Issues Facing Transportation, Volume 6: The Effects of Socio-Demographics on Future Travel Demand.* It introduces the research need, presents how the research addresses the issues surrounding the need, discusses eight socio-demographic trends, describes *Impacts 2050* and its scenarios, and concludes with a set of strategic responses transportation agencies might take when applying the scenarios.

Research Products

- *Impacts 2050* Tool
- *Impacts 2050* User Guide
- Power Point Presentation

1. The Issue

Long-range transportation planning involves many difficult choices, especially in an era of constrained resources. Which modes of transportation should be prioritized? Which investments should be funded? And how can the outcome of the investments be predicted? These questions are difficult to answer, particularly since transportation planners must make decisions within a time horizon that extends 30 to 50 years into the future. And it is virtually inevitable that the socio-demographics of a society as diverse at the United States will shift over this time period.

A key challenge for transportation decision makers is to understand how the population might change over time, and how socio-demographic changes will affect the ways people travel and the kinds of transportation modes and infrastructure that will be needed. State DOTs and MPOs need high-quality information that will help them to act—rather than react—in a way that best meets future transportation needs.

This challenge is evident in the process for producing the required long-range plans for up to 20 years or more into the future. The beneficial outcomes of these plans are the policies and strategies that balance current needs with making responsible, cost-effective, and sustainable long-term decisions. However, state DOTs and MPOs are not always in control of the factors that define the assumptions that go into the long-range plans. These assumptions often focus on socio-demographic factors and trends; and how they may play out in the future is uncertain. The resulting plans too often are reactive to the transportation issues currently facing a region or state, instead of being proactive in adapting to future uncertainties.

2. The Solution

This research helps DOT's, MPOs, and other transportation agencies to better cope with the effects of uncertainty in their long-range planning process by increasing their awareness and understanding of socio-demographic trends and how these might affect long-range transportation conditions or needs.

Box 1. Applying the Research

This research can assist state DOTs and MPOs and other transportation decision makers by:

- Supporting long-range plan development.
- Supplementing the capabilities of existing planning models.
- Formalizing the consideration of uncertainty in the planning process.
- Facilitating participation in the planning and decision-making process.
- Serving as a sketch-planning tool for providing quick and timely answers, as well as supporting sensitivity and exploratory analysis.
- Serving as a "utility" program for providing data inputs to models and the planning process.

It also addresses a gap inherent in current planning tools and models—the inability to produce accurate long-range forecasts—by introducing the tool *Impacts 2050* to help transportation planners and decision makers apply a scenario approach.

Users of this study will be in a position to improve their long-range planning and make better related decisions (Box 1). Questions are routinely raised during the long-range planning process about the potential consequences of a new trend (e.g., fuel prices, travel tendencies of Millennials), policies to respond to such trends as tolling to enhance revenues), or about the potential impact of a major new transportation investment. *Impacts 2050* is a new tool for testing and accounting for socio-demographic trends and other related factors in projects, plans, and forecasts and examining policy or other interventions that may offset these trends.

3. Eight Socio-Demographic Trends

Eight national socio-demographic trends reflect the many changes occurring in the United States spanning population, demographics, and travel patterns and illustrate the fact that the future is difficult to predict and is shaped by many interacting factors. For each, this section presents the key socio-demographic drivers and their respective impacts on travel demand (for details on each, see *NCHRP Report 750: Strategic Issues Facing Transportation*, Volume 6, Chapter 3).

Trend 1: The Next 100 Million

The United States is growing more slowly. The 2000s marked the lowest decennial rate of population growth since the Depression.

- **Drivers**: Population growing but aging, declining fertility rates among white women, extended life span, and less immigration.
- **Impact on Travel Demand**: Overall increase in total VMT due to population growth; VMT per capita appears to be declining.

Trend 2: The Graying of America

America is becoming "grayer." The population age 65 and older will significantly increase as the Baby Boom generation enters this demographic group.

- **Drivers**: Population aging, extended life spans, "boom and bust" birth rate patterns.
- **Impact on Travel Demand**: Decreased per capita VMT, decreased in work trips, increased vehicle age, decreased auto ownership, increased carpooling, decreased transit use.

Trend 3: The Browning of America

America is becoming "browner." The white population has grown more slowly than every other race group in the second half of the 20th century.

- **Drivers**: Structural changes in population distribution by race/ethnicity, relatively high fertility rates among Hispanic women, continuing immigration in younger age groups.
- **Impact on Travel Demand**: Increase in VMT per capita, increase in auto age, greater public transit use.

Trend 4: The Changing American Workforce

America's workforce is growing older, more female, and more diverse.

- **Drivers**: Boom-and-bust birth rate patterns, population aging, female work participation patterns, female longevity, structural changes in racial/ethnic distribution of labor force, immigration.
- **Impact on Travel Demand**: Decreased VMT per capita, increased work-related VMT, lower growth in work-related VMT, increased carpooling.

Trend 5: The Blurring of City and Suburb

The differentiation between cities and suburbs is fading.

- **Drivers**: Population growth, housing starts, population aging, age structure, household structure.
- **Impact on Travel Demand**: Decreased VMT per capita, increased nonmotorized trips, increased transit trips.

Trend 6: Slow Growth in Households

The rate of new household formation has plunged since 2006, creating more single households and also more multigenerational and larger households.

- **Drivers**: Poor labor market, aging population, lifestyle choices of Millennials.
- **Impact on Travel Demand**: Decreased per capita VMT, decreased auto ownership among young people, increased carpooling, increased public transit use.

Trend 7: The Generation C

Mobile broadband will become increasingly more important and ubiquitous, creating a new Generation C.

- **Drivers**: Technology evolution, lifestyle choices, age structure.
- **Impact on Travel Demand**: Reduced VMT per capita for some trip purposes, decreased car ownership.

Trend 8: The Salience of Environmental Concerns

Generational divide over nation's energy and environment priorities is still strong but will decrease over time.

- **Drivers**: Age structure, population aging.
- **Impact on Travel Demand**: Lower car ownership, more transit and nonvehicle travel by younger generations due to elderly population shrinking.

Box 2. Sample Questions *Impacts 2050* Can Address

- What would happen if the aging of the population causes the typical retirement age to increase?
- What influence would a pandemic have on travel demand?
- How would a large shift in preference toward urban locations affect travel demand?
- How would an aggressive immigration policy influence work trip rates?
- What would happen if no new roads were built in the next 30 years but the region's population continued to grow?
- How would making telecommuting available to a majority of future employees affect travel demand?

4. *Impacts 2050*

Impacts 2050 opens a window on how future socio-demographic changes could affect regional travel demand through the year 2050, and helps policymakers plan for those possibilities.

Impacts 2050 is a menu-driven spreadsheet model that state and regional transportation decision makers can use to play out the many ways changing socio-demographic factors in a region might affect travel demand over time (Box 2). The tool helps users develop a realistic, inclusive understanding of:

- Which are the most important trends to watch for and monitor over time;
- How demographics, economics, land use, and travel behavior are likely to interact over time under a wide variety and range of scenarios; and
- Which are likely to be the most effective policy variables and intervention points in the system over time.

The tool integrates two elements:

1. A systems dynamics model that represents regional links among population, land use, employment, transport supply, and travel behavior; and
2. Scenarios representing visions of possible futures, considering basic demographic trends, globalization and immigration policy, economic growth, energy supply and demand, technology advances, transport governance and funding, land-use policies, shifting social attitudes, etc.

4.1 Using *Impacts 2050* for Long-Range Planning

Decision makers have regularly used travel demand models to assist with long-range transportation planning. Every metropolitan area has a regional plan informed by a model that looks ahead 20 to 30 years. Traditional travel demand models typically provide a forecast of future travel needs; however, in most cases they pay little attention to the level of uncertainty in the forecasts and the possible risk entailed. For example, in most forecasts for 2035, the future tends to look "just like now, only more so." Because traditional travel demand models tend to ignore uncertainties, these models can leave planners with incomplete, and often inaccurate, visions of the future on which to base policy and investment decisions.

Because *Impacts 2050* takes a different approach from traditional models, it can better account for uncertainty and minimize risk in long-range transportation planning.

Note that* Impacts 2050 *is not intended to replace existing travel demand forecast models.

4.1.1 A Strategic Model

Impacts 2050 is a strategic model. Its purpose is not so much to predict travel behavior as to realistically illustrate a *range* of future scenarios that might occur under varying sets of assumptions. Strategic models represent an emerging trend in long-range planning.

4.1.2 A Systems Dynamics Approach

Impacts 2050 uses a systems dynamics approach to understanding the fundamental relationships between social and demographic factors and travel demand, and how these relationships might change over time. The system dynamics approach also accounts for feedback within the system. For example, an increase in road supply might increase VMT, which leads to increased traffic congestion and then to road construction and expanded road supply. Alternatively, population growth might lead to increased traffic congestion, which, in the absence of road construction or other infrastructure improvements, could lead to an increase in the number of people leaving the region. Thus, the emphasis for long-range planning shifts from arriving at numerically accurate forecasts toward developing qualitatively accurate depictions of how different variable relationships will evolve over time.

4.1.3 A Fast, Path-Based Model

Impacts 2050's focus on multiple scenarios implies the need for a fast model. It is designed to run easily and quickly so that many different future scenarios can be played out. It accounts for the path taken through time into the future, unlike the traditional approach used in almost all local, regional, and statewide travel forecasting models, which focuses on a specific end state. The *Impacts 2050* approach facilitates rapid, "hands on" analysis of multiple alternative futures.

5. Scenarios Test the Impacts of Socio-Demographics on Travel Demand

The study team created four alternate future scenarios based on expert opinion that can be used to test varying impacts of socio-demographics on travel demand. The scenarios encompass four different versions of how the world (and in particular the U.S. transport system) could look in the future. Each scenario has its own set of structuring assumptions and/or underlying theory about the future, and each prioritizes certain driving forces in the future to create a different interpretation of how present-day uncertainties will move to resolution.

The scenarios from the perspective of 2050 are:

- **Momentum**—The current state of the country in 2050 would still be recognizable to a visitor from the 2000s. Change is based on population dynamics, and the United States has not experienced any major shifts in demographic, economic, or technology trends. Nor have there been major policy shifts, as the two political parties have held firm to positions, and divided government remains a feature of national politics. Travel demand and funding have changed a bit more. Commute travel has decreased somewhat, thanks to telework. People are still on the road a fair amount for shopping and personal business, but congestion levels are manageable. Federal gas taxes have risen a few times, but not enough to keep up with the increases in fuel economy. As a result, with less federal funding, many states have had to increase their own funding streams if they want to maintain their existing road network.

- **Technology Triumphs**—Technology has saved us from ourselves. While the United States faced some difficult challenges in the 2010s, many of these have been mitigated by innovations that helped us live longer, reduce our carbon footprint, connect our world, and travel more easily and safely. Autonomous vehicles have changed how people travel, and data-intensive communications technology has also affected how much people travel. Commute travel has declined, since a high proportion of office workers now work from home, and fewer people live near their jobs, since their physical presence is seldom required. Much socializing also takes place virtually, and many weekly necessities are delivered to peoples' doors. The travel that does take place tends to be faster, cheaper, and more convenient than ever.
- **Global Chaos**—The past few decades have challenged Americans' general optimism, and where they work has become a far different and more difficult place. Several trends intersected to bring about this distressing "new normal": the increasing impact of climate change, financial instability at a global scale, and a new isolationism. The results, which affect not only the United States but most of the world, are heightened insecurity, lower life spans, and chronic conflicts. Widespread unemployment means that far fewer people are on the roads and transit systems. With state and local governments collecting relatively little revenue, they have a hard time maintaining the existing infrastructure or responding to crises like returning travel to normal after a major storm. Walking and cycling are far more popular now, but generally out of necessity than choice, and people with cars often make extra money on the side as gypsy cabs.
- **Gentle Footprint**—After droughts and "superstorms" began plaguing the United States in the 2010s, both public consciousness and political will began shifting toward taking more serious action to slow climate change. While it was too late to curb the rise in carbon concentration in the atmosphere, the United States has made surprisingly good progress in adopting a variety of means to reduce energy consumption. Many lifestyle changes that might once have been considered radical are now mainstream. Federal, state, and local governments have responded by shifting their focus to investments that support these modes, rather than cars. Most cities and suburbs have good networks of bicycle lanes, and transit systems have expanded, while the size of the road network has barely budged in 20 years. High-speed rail has been built in a half-dozen corridors, and it captures a healthy percentage of travel between those cities.

The three alternative scenarios represent "what if" conditions that moderate the outcome of the Momentum population-based scenario. The scenarios are shaped by government policies, but also by other factors that cannot be reliably modeled or predicted, such as attitudes toward the environment, the development of social trends, or the rate of economic growth.

5.1 How *Impacts 2050* Works

Figure F-1 provides a simple illustration of the way *Impact 2050* models changes in a population over time.

First, *Impacts 2050* profiles a regional population in a base year according to a set of attributes that are known to have an association with travel behavior. Then, it "evolves" this population over time, simulating the population's transitions from one category in each of these variables to another category. The model defines the impacts on travel behavior in terms of car ownership, trip rates, and choice of transportation mode. Changes in expected transitions may be tested as policy or scenario variables.

Impacts 2050 models the following changes in five sectors:

- **Socio-demographics**: Changes in population demographics (age and household structures, acculturation and employment status, household income, and area type of residence location).
- **Travel behavior**: Changes in car ownership, work and nonwork trip rates, work and nonwork mode choice (car, transit, bike, walk).
- **Employment**: Changes in the number of jobs by retail, service, and other categories in urban, suburban, and rural area types.

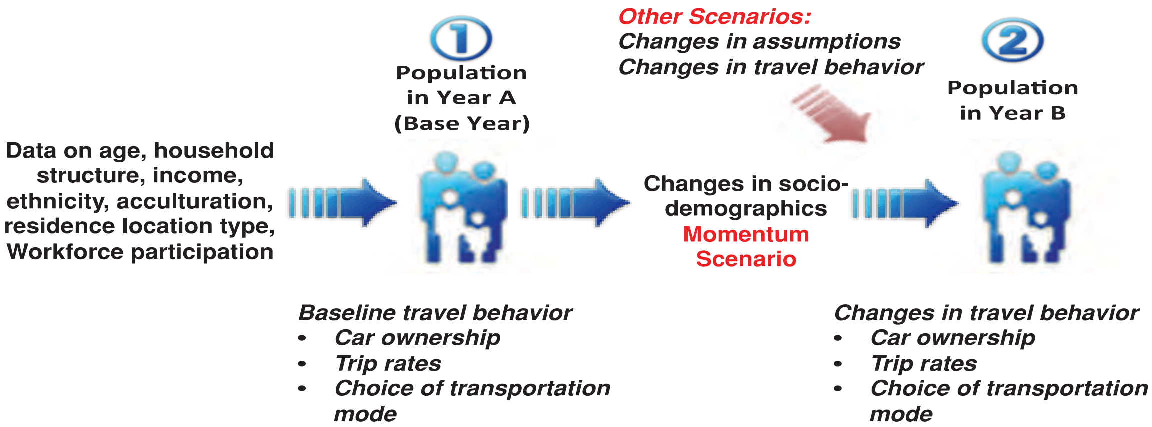


Figure F-1. **Impacts 2050—*evolving the population over time in travel.***

- **Land use**: Changes in the amounts of commercial, housing, developable, and protected space in urban, suburban, and rural area types.
- **Transport supply**: Changes in the amounts of freeway, arterial capacity, and regional transit service (bus, rail) in urban, suburban, and rural area types.

In *Impacts 2050*, the socio-demographics and travel behavior sectors are given the most emphasis. However, the land use, employment, and transport supply sectors are also important because they have a crucial influence on the evolution of the population, residence and household location decisions, and travel within a region. *Impacts 2050* also accounts for time delays that can occur within the inter-relationships between sectors. For example, an increase in traffic congestion might lead to a decision to supply new transportation infrastructure, but only after a significant delay. Even decisions to change residence or business locations can take some time to occur, and so cannot adjust immediately to changes in prices, congestion, job availability, etc.

6. Applying the Scenario Outcomes: Strategic Responses

The four scenarios were intentionally designed to encourage transportation agencies to think outside the box—and consider what they might do if the future took a sudden and decidedly different turn from the trajectory defined by the previous 50 years. It is certainly reasonable to assume that transportation agencies using *Impacts 2050* might end up with many different scenarios about the future.

What next? What are some of the strategic responses a transportation agency might take to better cope with future uncertainties? *Impacts 2050* was especially designed to assist this process by providing enhanced insight into the potential impacts of major trends. However, the tool is only an aide to what must be a planning process that is better able to deal with the uncertainties of change.

The following set of response mechanisms provides potential guidance to transportation agencies in applying scenario outcomes to better meet the needs of an uncertain future.

- Establish an indicator monitoring system.
- Stimulate wider awareness and dialogue about possible futures and potential responses.
- Increase stakeholder participation and buy-in.
- Recognize the need for organization growth and change.
- Provide financing and political support.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation