

**NCHRP REPORT 750 VOLUME 6:
STRATEGIC ISSUES FACING TRANSPORTATION—
THE EFFECTS OF SOCIO-DEMOGRAPHICS
ON FUTURE TRAVEL DEMAND**

FINAL IMPACTS 2050 USER GUIDE V 1.10

Prepared for
NCHRP
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Contents

CONTENTS	1
LIST OF FIGURES AND TABLES	III
INTRODUCTION	1
1.1 What is <i>Impacts 2050</i> ?	1
1.2 What is <i>Impacts 2050</i> designed to do?	1
1.3 How does <i>Impacts 2050</i> work?	2
1.4 Structure of this Guide	4
INSTALLING AND NAVIGATING <i>IMPACTS 2050</i>	5
2.1 Installing <i>Impacts 2050</i>	5
2.2 Navigating <i>Impacts 2050</i>	5
DEFINING BASE DATA FOR THE REGION	7
3.1 Demographic Data	8
3.2 Employment Data	9
3.3 Land-use Data	10
3.4 Transport Supply	11
DEFINING THE MODEL SCENARIOS	13
4.1 Momentum Scenario	14
4.2 Tech Triumphs Scenario	14
4.3 Gentle Footprint Scenario	16
4.4 Global Chaos Scenario	17
4.5 Specifying a Custom Scenario	18
RUNNING THE TOOL	21
OTHER PARTS OF THE MODEL	23
6.1 Demographic Transition Rates	23
6.2 Demographic Seed Matrix	24
6.3 Travel Behavior Models	25
ANALYZING THE MODEL OUTPUT	27
7.1 Simulation Reports	27
7.2 Simulation Results	30
<i>IMPACTS 2050</i> MODEL STRUCTURE DOCUMENTATION	31
A.1 Demographic Sector	31
A.1.1 Demographic Rates of Change	33
A.2 Travel Behavior Subsector	39
A.2.1 Car Ownership	39
A.2.2 Trip Rates	41
A.2.3 Mode Choice Models	43
A.2.4 Trip Distance Models	47

A.3 Land Use Sector	49
A.3.1 Land Use Rates of Change.....	49
A.4 Employment Sector	51
A.4.1 Employment Rates of Change	51
A.5 Transport Supply Sector	54
A.5.1 Transport Sector Rates of Change	54

List of Figures and Tables

Figure 1-1: Impacts 2050—Evolving the Population over Time in Travel.....	2
Figure 1-2: Travel Impacts 2050 Model Structure	3
Figure 2-1: Main Menu Navigation Options.....	6
Figure 4-1: Example of changes in the Momentum Scenario (before)	19
Figure 4-2: Example of changes in the Momentum Scenario (after).....	20
Figure 5-1: Running the Scenario Analysis Tool	21
Figure 7-1: Custom Plot: Births by Income Group over Simulation Period.....	30
Figure A-1a: Socio-demographic Sector Transitions (1).....	35
Figure A-1b: Socio-demographic Sector Transitions (1).....	37
Figure A-2: Land Use Sector Flow Diagram.....	50
Figure A-3: Employment Sector Flow Diagram	53
Figure A-4: Transport Sector Flow Diagram.....	55
Table 3-1: Base Demographic Data	8
Table 7-1: Summary of Table of Population and Travel Behavior.....	27
Table 7-2: Summary of Predefined Plots	28
Table A-1: Socio-demographic Variables: Stock and Rates of Change	38
Table A-2: Car Ownership Model Coefficients	40
Table A-3: Daily Trip Rate Models	42
Table A-4: Work Trip Mode Choice Model	43
Table A-5: Non-Work Trip Mode Choice Model – age 16+.....	45
Table A-6: Non-Work Trip Mode Choice Model – Age under 16	46
Table A-7: Trip Distance Models	47

CHAPTER 1

Introduction

1.1 What is *Impacts 2050*?

The *Impacts 2050* demographic scenario-analysis tool is a menu-driven spreadsheet model that state and regional transportation decision makers can use to investigate how socio-demographic factors in a region might impact travel demand over time. This model can be used to investigate what could happen under logically consistent demographic, economic, and development scenarios. It is not a forecasting model, as it focuses on breadth of scope and flexibility of assumptions, rather than on short-term accuracy and spatial detail.

Impacts 2050 integrates two elements:

1. A system dynamics model that represents regional links between population, land use, employment, transport supply, and travel behavior; and
2. Scenarios representing visions of possible futures.

1.2 What is *Impacts 2050* designed to do?

Impacts 2050 is a strategic model. Rather than produce detailed forecasts of travel behavior, it illustrates a range of future scenarios that could occur in a given region under a range of different assumptions. *Thus, the tool is intended to complement—not replace—existing travel demand forecast models in a given region.*

Because *Impacts 2050* is designed to be run with multiple scenarios, it is fast and easy to run. Furthermore, it predicts the path taken over time into the future, rather than making forecasts for a single end state. This approach allows rapid, “hands-on” analysis of multiple alternative futures.

Impacts 2050 is designed to address a wide range of “what if” questions that a region may confront.

- Socio-demographic questions, e.g.: What happens if the birth rate increases?
- Travel behavior questions, e.g.: What happens if the price of fuel doubles?
- Employment questions, e.g.: What if technological changes lead to increased job creation rates?
- Land-use questions, e.g.: What if there was a large shift in preference toward urban locations?
- Transport supply questions, e.g.: What would happen if no new roads were built in the next 30 years, but population growth continues?

This scenario-analysis tool can address such a wide range of questions by integrating the socio-demographic, land use, employment, transport supply, and travel behavior sectors in a system dynamics approach. This approach accounts for the relationships among these sectors over time, and for the impact of feedbacks within the system. For example, population increase could increase traffic congestion, which if not alleviated, could lead to more employers and/or workers leaving the region over the longer term.

As a tool for long-range planning, *Impacts 2050* emphasizes producing qualitatively accurate representations of how different variable relationships will evolve over time, rather than numerically accurate forecasts for one particular sector.

The scenario-analysis tool incorporates a detailed treatment of the socio-demographic and transportation sectors, but is not intended to provide detailed spatial forecasts, with the spatial dimension being represented by three aggregate area types.

1.3 How does *Impacts 2050* work?

Impacts 2050 uses a system dynamics approach to understand the relationships between population socio-economic characteristics and travel demand, and how these might change over time.

The heart of the model is the socio-demographic sector. It is modeled in the greatest detail, as understanding the impact of changes in this sector on travel demand is the main objective of this study. 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 of each of these attributes to another category. The impacts on travel behavior are calculated in terms of car ownership, trip rates, and choice of transportation mode. Changes in transition rates can be tested as scenario variables. This process is illustrated in Figure 1-1.

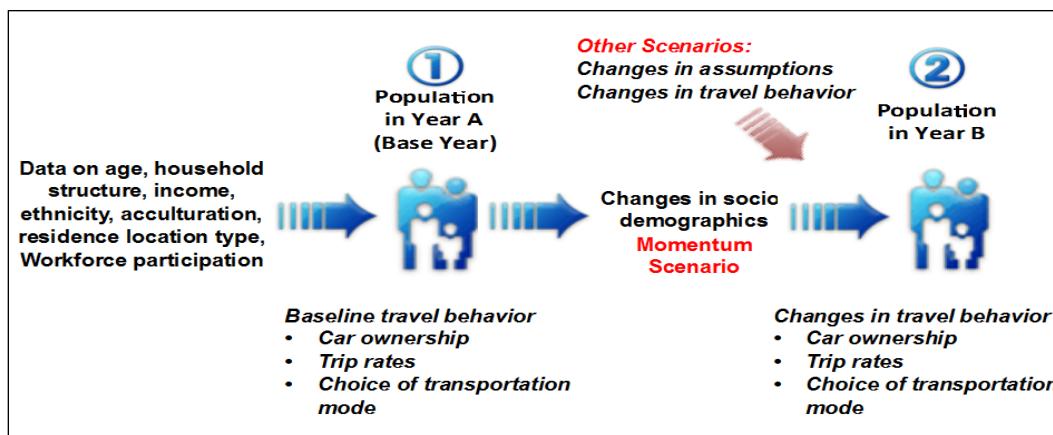


Figure 1-1: Impacts 2050—Evolving the Population over Time in Travel

Impacts 2050 models the following changes in five sectors:

- Socio-demographics: changes in age and household structures, race/ethnicity, 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 driver, car passenger, transit, walk/bike).
- Employment: changes in the number of jobs by retail, service, and other categories in urban, suburban, and rural area types.
- 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.

For each of these sectors, information is assembled to define the base conditions. Then, changes are simulated from each year to the next using the specified rates of change, including any scenario-specific inputs. The inter-relationship among the five sectors is illustrated in Figure 1-2.

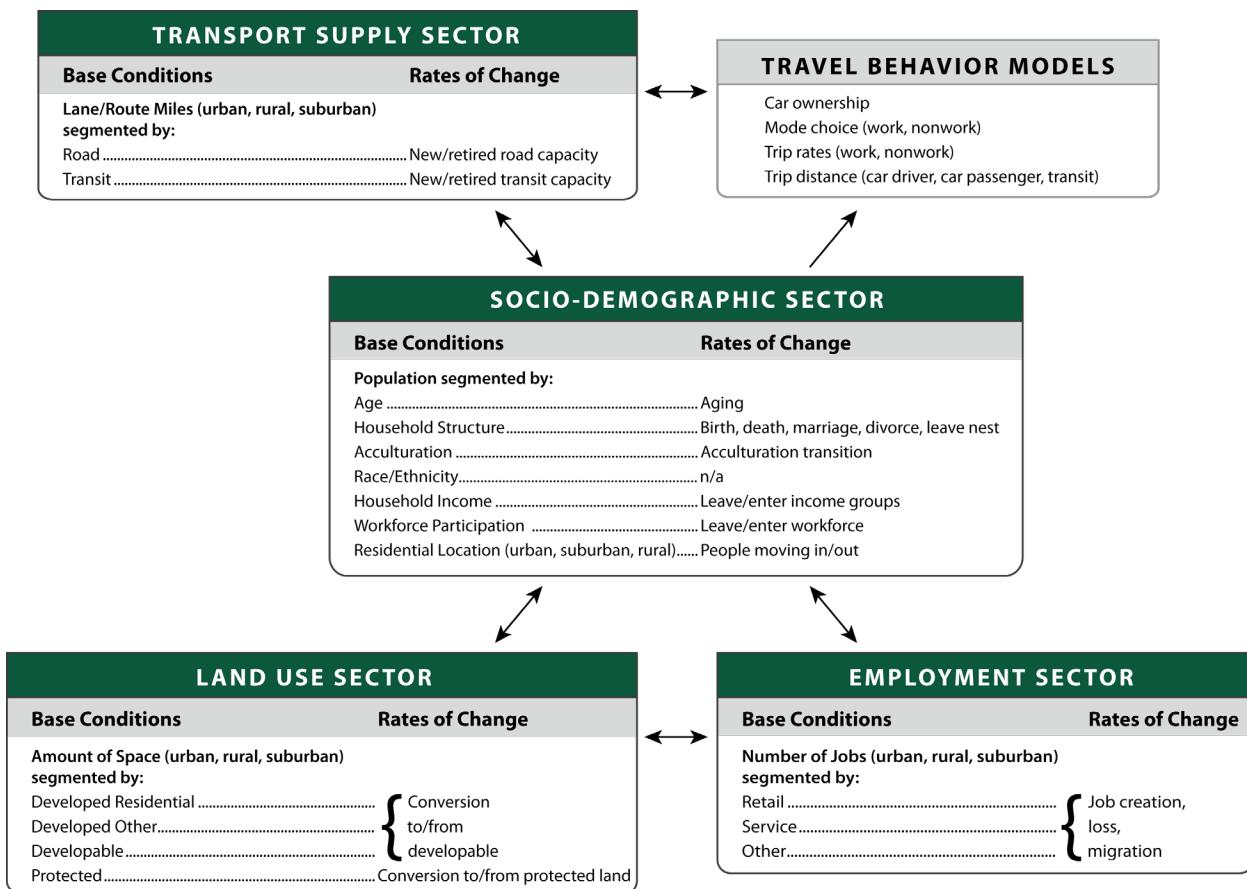


Figure 1-2: Travel Impacts 2050 Model Structure

In system dynamics terminology, *stocks* are defined for each sector. Initially stocks define the *base conditions*, and then they change over time according to the rates of change and inter-relationships among the sectors represented in the model. The stocks represented in the model are population, number of lane/route miles, amount of space, and number of jobs. As described further below, the year 2000 base values for the Demographic sector are based on the year 2000 Census, while corresponding data from the 2010 Census and recent American Community Survey (ACS) are also included to compare to the year 2010 simulation results and help to calibrate the model. Year 2000 base values for the Employment sector are based on 2002 Longitudinal Employer-Household Dynamics (LEHD) data from the U.S. Census Bureau, and corresponding 2010 LEHD data are included as well. The transition rates in the Demographic sector have been calculated from the Panel Study of Income Dynamics 2003–2009 (PSID).

The Travel Behavior models represent a submodel of the socio-demographic sector, rather than a separate sector. This submodel predicts the levels of demand for transport, given the distribution of population across the segments represented in the socio-demographic sector. (Travel demand is calculated as a derived demand based mainly on socio-economic factors, but does not have its own physical stock variables.)

1.4 Structure of this Guide

Chapter 2 explains how to install and navigate the tool.

Chapter 3 describes how to specify the base data for the region for the 2000 base year, which the model uses as the starting point for simulating the future. For the Atlanta, Boston, Detroit, Houston, and Seattle metropolitan regions, base data have already been input.

Chapter 4 explains how the model scenario can be specified. Four pre-specified scenarios are available, and this chapter briefly summarizes how each of the four scenarios has been specified. The chapter also explains how users can easily create their own scenario using one of the four pre-specified scenarios as a starting point.

Chapter 5 explains how to run the scenario-analysis tool, and how to run it to make a series of related scenario runs.

Chapter 6 describes three components of the model that the user would not modify for most scenario runs, specifically demographic transition rates derived from analysis of the PSID data, the demographic seed matrix taken from analysis of 2009 National Household Travel Survey (NHTS) data, and the travel behavior models estimated from the 2009 NHTS data.

Chapter 7 explains how the model output can be analyzed. It describes the detailed simulation output produced for half-year intervals from 2000 through 2050, as well as the summary output that is automatically generated, and how custom plots can be created from the simulation variables.

CHAPTER 2

Installing and Navigating *Impacts 2050*

2.1 Installing *Impacts 2050*

Impacts 2050 is delivered in a zip file containing two components:

- **NCHRP_Impacts_2050_V1.10.xlsm**: The spreadsheet scenario-analysis tool.
- **NCHRP_Impacts_2050_V1.10.pro**: The simulation model.

To install the tool, and open it for the first time, the user simply needs to:

1. Copy the “**NCHRP_Impacts_2050_V1.10.pro**” file to the same directory location as the spreadsheet.
2. Rename the “**NCHRP_Impacts_2050_V1.10.pro**” file as “**NCHRP_Impacts_2050_V1.10.exe**”. (The file is delivered using the .pro extension, as many computer systems will not accept or download files with the .exe extension.)
3. Open the spreadsheet. If prompted by Excel, select “Enable Content” or “Enable Macros,” so that the imbedded macros can run.

When the tool is run, Excel calls the .exe file, which runs the simulation model for each half-year interval through 2050. The simulation results are output to a .csv file, which is then read back in by the tool ready for analysis.

2.2 Navigating *Impacts 2050*

The tool has been set up so all sheets can easily be navigated via the “Main Menu” sheet, which will appear when the spreadsheet is opened. The navigation options are illustrated in Figure 2-1.

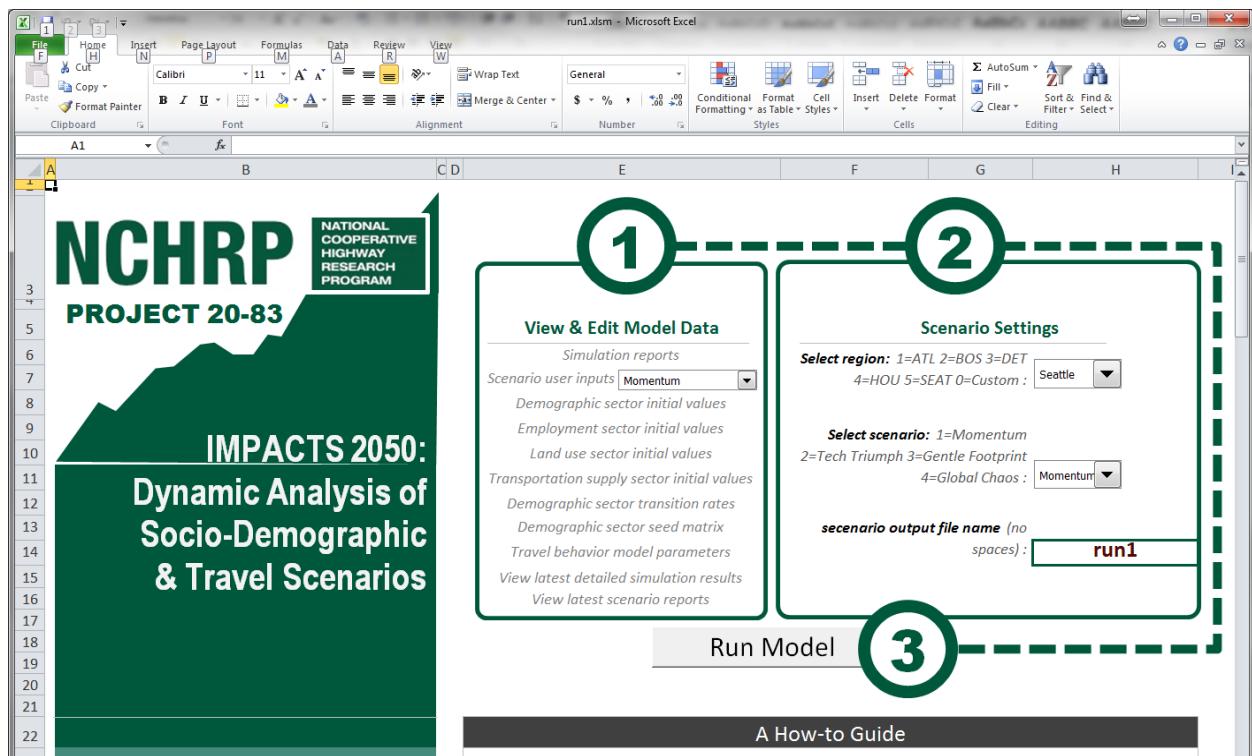


Figure 2-1: Main Menu Navigation Options

The user can navigate to all sheets in the workbook by clicking on the links given in box ①. To navigate to a scenario user input sheet, simply select one of the four scenarios from the drop-down box, and the tool will jump to the relevant scenario sheet..

To navigate back to the Main Menu sheet, simply click on the “Return to Main Menu” button highlighted in red at the top left of the other sheets.

CHAPTER 3

Defining Base Data for the Region

Four sets of data must be specified to define the year 2000 base conditions for the simulation region:

- Demographic data
- Employment data
- Land-use data
- Transport supply data

Data have already been entered into *Impacts 2050* for the Atlanta, Boston, Detroit, Houston, and Seattle regions for year 2000. More recent Census data are available for 2010. However, 2000 was selected as the base year in place of 2010, so that the 2010 Census data could be used to help validate and calibrate the model trajectory after 2000.

For setting up the model for any other region, termed a “custom” region in *Impacts 2050*, the subsections in this chapter describe the sheets in the spreadsheet where inputs need to be made for each of each of these four sets of data. The subsections describe the demographic, employment, land use, and transport supply data that the user needs to define the base 2000 conditions for a custom region.

The region to which the model is applied can be a metropolitan planning organization region or an entire state. To run the model at the state level, the user simply needs to assemble the required base data at the state level.



USER TIPS

Once the base year data for a custom region have been defined, the user should save the spreadsheet with a different name before making runs for different scenarios.

In the following sheets, cells that are highlighted in yellow are base year region-specific values that users need to specify to start the simulation with appropriate year 2000 values for a specific region.

The other cells that are highlighted in orange are the basic structural parameters of the model. Although the values in these orange cells can be changed by the user, it is recommended not to change them, unless the user has a good working understanding of the model and wishes to test the effects of making different structural assumptions.

3.1 Demographic Data

The demographic data are specified on the “Demographic initial values” sheet. The stock variable is total population in the region, which is broken down separately across a number of different dimensions.

Base year region-specific inputs

To define the base demographic data for the region, the user needs to enter the following information into the cells highlighted in yellow in columns B-G, with the column depending on which region the user plans to simulate.

Table 3-1: Base Demographic Data

Dimension	Units	Categories
Age	Persons	0–15, 16–29, 30–44, 45–59, 60–74, 75+
Household type	Persons	Single without children, couples without children, single with children, couples with children
Acculturation group/race	Persons	Combination of (a) foreign born <20 years in U.S., foreign born 20+ years in U.S., native born, and (b) Hispanic, Black, Asian, White/other
Household income band	Persons, bands in 2009 US\$	\$0–\$34,999, \$35,000–\$99,999, \$100,000 up
Employment status	Persons	In workforce (including those looking for employment), not in workforce
Area type	Persons	Urban, suburban, rural

For each of these dimensions, the number of people in the different categories should sum across categories to give the same total population figure.

For the five pre-defined regions, 2000 base data for these dimensions have been defined from 2000 U.S. Census data. A “couple” is defined as either married or co-habiting partners (but not, for example, two nonrelated adults). Year 2010 values from more recent Census and ACS data are also provided on this sheet for the 5 pre-defined regions, to help with model calibration and validation.

The area type information is defined at the Census tract level, with the tract-specific data aggregated to the three different area types. For each tract, the number of jobs per square mile and the number of residents per square mile are calculated. The area types are then defined as follows:

- Urban tracts have at least 4,000 jobs/mile² or 10,000 residents/mile² inside the tract.
- Suburban tracts are tracts that do not qualify as urban, and have at least 500 jobs/mile² or 1,000 residents/mile² inside the tract.
- Tracts that do not qualify as urban or suburban are classified as rural tracts.

More detailed information on the socio-demographic sector is provided in Appendix A.

3.2 Employment Data

The employment data for the region is specified on the “Employment initial values” sheet. The stock variable is number of jobs, which should sum to a number close to the total number of people in the workforce given on the ‘Demographic initial values’ sheet. Note that the workforce totals include people looking for employment.

Base year region-specific inputs

To specific inputs for a “custom” region, the user needs to enter the job totals into cells B4:B12, highlighted in yellow, for the nine combinations of area type (urban, suburban, rural) and employment type (retail, service, and other).

The source for these data for the five example regions is the Longitudinal Employer-Household Dynamics (LEHD) data from the U.S. Census Bureau, 2002. (An exception is the Boston region, as LEHD data is not yet available for the State of Massachusetts. In that case, county-level employment totals were used along with population density to split tracts into the area types.)

Other inputs

In cells B15:G23 are base commute patterns, specifying the fraction of residents in each area type who work in each area type (e.g., 95 percent of employed urban area residents also work in the urban area). These base values are adjusted during the simulation to take account of changes in job demand and supply in the different area types.

In cells B26:B28, the user can modify the employment sector delays, which specify the length of time it takes for the stock of jobs to adjust during the model simulation in response to changes in inputs from the other sectors. Three delay values are specified:

- **Job creation:** jobs created in the region by new companies moving to the region, new companies starting up, and existing companies adding jobs.
- **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—e.g., moving from urban to suburban areas.

In general, these delays do not need to be modified by the user, because the user can specify multipliers on these rates using rows 44–46 of each of the scenario pages. (The “rates” are inversely proportional to the delays, so a higher multiplier on the scenario sheet will give a shorter delay.) One exception: the user can effectively “turn off” the dynamics of the employment sector by specifying very long delays (e.g., 10,000 years) on this sheet.

Cells B33:D41 contain the weights on the employment attraction functions used for each of the nine employment categories. The weights specify the relative attractiveness of job demand/supply index, commercial space demand/supply index, and road mile demand/supply index on the attractiveness of the nine employment types. The weights should always sum to one across each row.

Cells B45:D65 contain the values of the attractiveness functions for the job demand/supply index, commercial space demand/supply index, and road mile demand/supply index. The graph plotted to the right of these cells illustrates the shape of the attractiveness functions.

As mentioned above, the values for the employment attractiveness function are highlighted in orange, meaning that these are structural relationships in the model, and can be left as they are unless the user wishes to test the effect of using different functions.

Appendix A provides more detail on how these attractiveness functions are specified, and presents a flow diagram illustrating how the employment sector operates.

3.3 Land-use Data

The land-use data are specified on the “Land-use initial values” sheet. The stock variable is land use in square miles.

Base year region-specific inputs

If the user wishes to use a new custom region, the area in square miles for the 12 combinations of area type (urban, suburban, rural) and use-type (residential, nonresidential, developable and protected) must be specified in cells B4:B15. The definition of urban, suburban, and rural is the same as defined in Section 3.1, above.

For the five example areas, the values were calculated using the base year population and employment figures, along with the assumed land required per household and per job (see below). More detailed parcel data and other geographic information system-based land-use information could be used to obtain more accurate estimates of these values, but that was not done for this project, as it would typically require local expertise and data on land uses in the region.

Other inputs

Cells B18:B22 are the base values for the land-use sector delays, which form exogenous inputs to the model. In general, these delays do not need to be modified by the user, although it is possible to do so in order to test different response times for this sector. The user can effectively “turn off” the dynamics of the land-use sector by specifying very long delays (e.g., 10,000 years) on this sheet.

The base densities of housing developments areas are given in cells B26:E28, for different household types in each of the three area types. Similarly, the densities of different nonresidential development types in each of the three area types are specified in cells B32:D34. The most typical way of changing these for a particular scenario are to use rows 49 and 50 of the scenario sheets, which allow scenario-specific multipliers to be applied to these base densities.

Finally, the fractions of developable land available for residential and nonresidential development are specified for each of the three area types in cells B38:C40. Note that each row may sum to more than one, as some land has multiple allowed uses.

Appendix A provides more detail on how the land-use sector is modeled, including a flow diagram illustrating how the sector is modeled, the interactions with other sectors, and how the user-defined inputs operate.

3.4 Transport Supply

The transport supply data are specified on the “Transp. supply initial values” sheet. The stock variable is lane miles for highway and route miles for transit.

Base year region-specific inputs

If the user wishes to use a new custom region, the number of lane miles for freeways, arterials, and other highways in urban, suburban, and rural areas must be specified in cells B4:B12, and the total route miles for the rail and bus transit modes must be specified in B13:B14.

To generate the lane miles inputs, data on total centerline miles have been assembled, which are converted into lane miles by multiplying by the average number of lanes per highway type. Users can input the centerline mile totals for their region into cells L4:L12; if they wish to modify the average number of lanes per highway type, these data can be edited in cells J4:J12. The lane miles values in cells B4:B12 will then be automatically calculated as the product of these two columns. (Otherwise, if the user has direct data on lane miles, the data can be input directly into cells B4:B12.)

The source for these data for the five example regions was the National Transit Database of the Federal Transit Administration, 2002. Local expertise and data could likely provide more accurate values for these regions than what was provided for this initial version, as there are no recent national-level data that provide the accuracy that a local user might desire.

Note that the road supply is much more important for the operation of Impacts 2050 than the transit supply, as currently in the model the relative demand and supply for transit do not have any feedback effects on the other sectors, while the relative demand and supply for road capacity can affect the attractiveness for new employers and new residents.

Optional inputs

In cells B17:B20, the user can modify the delays in years for road and transit capacity to be added and retired, which are exogenous inputs to the model. Rather than changing these values, the user can specify scenario-specific multipliers on these rates using rows 54–57 on each of the scenario input sheets. (The “rates” are inversely proportional to the delays, so a higher multiplier on the scenario sheet will give a shorter delay.) The user can effectively “turn off” the dynamics of the transport supply sector by specifying very long delays (e.g., 10,000 years) on this sheet.

Cells B24:D26 allow the user to modify the average road capacities in vehicles/hour per lane for the nine possible road and area type combinations.

Similarly, cells B30:C32 allow the user to modify the average transit capacities in passengers per hour per route for bus and rail for the three different area types.

Cells B35 and B36 give one-way peak-hour fractions for work and nonwork trips, respectively, to translate the daily demand from the travel demand models to morning peak-hour demand. The relative peak-hour road supply and demand are used to determine the effects of road congestion.

Finally, cells B40-J51 give the fraction of trip distances that are driven on roads for each road type/area type combination, given the type of trip (commute or non-work) and the area types where the person lives (and works, for commute trips). For example, it is assumed that suburban-to-urban commutes are 10 percent on urban freeways, 10 percent on urban arterials, 10 on urban other, 20 percent on suburban freeways, etc. (The fractions should sum to 1.0 across the nine columns in each row.) As the model does

not use explicit networks or traffic assignment, these fractions give the approximate usage of different types of roads in different area types for different types of trips, so that we can get a general comparison of road demand versus supply.

Appendix A provides more detail on how the rates of change in the transport sector are modeled, including a flow diagram that illustrates how the sector is modeled, including interactions with the other sectors, and how the user-defined inputs operate.

CHAPTER 4

Defining the Model Scenarios

Impacts 2050 is intended to be a scenario-analysis tool, and so has been set up so that different scenarios can be easily specified and tested. The following four scenarios have been pre-specified; any of them can be used as a starting point for making a particular scenario run.

- Momentum scenario
- Tech Triumphs scenario
- Gentle Footprint scenario
- Global Chaos scenario

To make modifications relative to the default values for each scenario, the user simply edits the *scenario multipliers*, which are applied as modifiers to the base rates. For example, a multiplier of 0.5 means using half of the base rate, a multiplier of 1 means using the base rate without adjustment, and a multiplier of 2 means doubling the base rate.



USER TIPS

To help highlight which scenario multipliers have been changed, the cells containing the scenario multipliers change color as the values are changed.

The cells turn increasingly **green** for scenario multiplier values above one (higher rates), and increasingly **red** for scenario multiplier values below one (lower rates).

Yellow shading indicates no change from the base rates.

Scenario multipliers can be specified at five-year intervals from 2000 through 2050. The simulation is run for half-year increments, and so for half-year points other than those where scenario rates are specified, values are determined by interpolating linearly between the rates defined at the five-year points on either side. (For example, the rate for 2013 is 3/5 x the rate for 2015 plus 2/5 the rate for 2010.)

The four pre-specified scenarios are described in the following sections, which also explain how the scenarios have been specified as modifiers to the base rates and variables in the model. The explanations should assist users who wish to set up alternative scenarios, or investigate the sensitivity of the simulation results for their region to the set of default assumptions made to specify each of the scenarios.

4.1 Momentum Scenario

The momentum scenario is described as follows. 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 roads 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.

The “Momentum Scenario” sheet shows how the study team has specified this scenario in terms of the transition rates and variables used in the model. To specify the momentum scenario, the base transition rates and variables are used without modification, as this scenario represents a continuation of current trends, except for four changes to the 2005 rates to take account of the recent economic downturn:

- A 20 percent increase in the rate at which individuals leave the workforce, and a 10 percent reduction in the rate at which individuals enter the workforce; and
- 50 percent increases in the rate at which individuals enter the lowest income group, and leave the highest income group.

The modifications are specified for 2005 only. Therefore, these scenario multipliers are assumed to return to the base rates by 2010, and thereafter remain fixed at the base rates through 2050. These modifications to the 2005 scenario multipliers to take account of the recent economic downturn have also been applied for the other three scenarios. However, as described below, these scenarios represent other changes to the scenario multipliers that come into play after 2010.

4.2 Tech Triumphs Scenario

The Tech Triumphs scenario is described as follows. 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 Americans live longer, reduce their carbon footprint, connect their 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 people’s doors. The travel that does take place tends to be faster, cheaper, and more convenient than ever.

The “Tech Triumphs Scenario” sheet shows how the study team has converted the 10 scenario variables into modifications to the model variables specified via the scenario multipliers. The scenario multipliers incorporate the following changes from 2010 onward:

Socio-demographic sector

- *Death rate* reduces due to longer lifespan and better general health due to health care technology, good environmental conditions.
- *Birth rate* increases due to increased optimism about the future.
- *Marriage rate* reduces as individuals opt to delay marriage due to “virtual” living.

- *Divorce rate* increases due to increased choices and flexibility in living arrangements.
- *Empty nest rate* increases as increased opportunities allow young people to move out.
- *Leave workforce rate* reduces because working from home allows people to delay retirement.
- *Enter lowest income group rate* reduces because of high rate of economic growth.
- *Enter highest income group rate* increases because of high rate of economic growth.
- *Foreign in-migration rate* reduces as desire to relocate to the United States falls as workers find jobs in their home countries.
- *Foreign out-migration rate* increases due to increase in demand for technology workers and open immigration policies.
- *Domestic migration rate* and *intra-regional migration rate* both reduce as technology allows people to work from anywhere and economic activity diffuses from population centers.
- *Death rates, birth rates, marriage rates, divorce rates, empty nest rates and space per household rates* by income group are all assumed to remain at base levels, under the assumption that the benefits of technology favor those with higher incomes, and so current levels of inequality persist.

Travel behavior subsector

- *Fuel/energy price* reduces due to improved energy technology and efficiency.
- *Shared car fraction* reduces due to high income growth.
- *No car fraction* reduces because move to suburbs leads to higher car ownership.

Employment sector

- *Job creation rate* increases and job loss rate reduces because growing economy helps businesses and jobs.
- *Job move rate* increases because technology allows people to work from anywhere, leading to a diffusion of activity away from population centers.

Land-use sector

- *Residential space* per household increases due to lower densities.

Transport supply sector

- *Road vehicle capacity per lane* increases because intelligent vehicles can use the road space more efficiently.
- *Transit passenger capacity per route* increases because technology leads to greater transport efficiency.

4.3 Gentle Footprint Scenario

The Gentle Footprint scenario is described as follows. After droughts and “super storms” 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 public transit, walk, and bicycle 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 “Gentle Footprint Scenario” sheet shows how the study team has converted the 10 scenario variables into modifications to the model variables specified via the scenario multipliers.

Socio-demographic sector

- *Death rate* reduces due to longer lifespan and better general health due to healthier lifestyles, good environmental conditions.
- *Birth rate* reduces because concern about the environment leads to smaller household sizes.
- *Enter lowest income group rate* increases, and *enter highest income group* reduces. Together, these two effects work to increase the proportion of the population in the lowest income group, hence, representing increasing economic equality.
- *Foreign in-migration rate* increases because environmental technology businesses require technology workers, and “back to basics farming” requires migrant labor.

Travel behavior subsector

- *Fuel/energy prices* are raised to encourage use of alternative energy sources.
- *Shared car fraction* increases because car sharing is encouraged.
- *No car fraction* increases because better public transit options are available.
- *Work trip rate* and *nonwork trip rate* are both reduced because travel becomes more expensive.
- *Car passenger mode share* increases because cars are used more efficiently.
- *Transit mode share* increases because better public transit systems are available.
- *Walk/bike mode share* increases due to higher land-use densities, improved bicycle lane network.
- *Car trip distance* decreases because car use is reduced.

Land-use sector

- *Residential space per household* and *nonresidential space per job* both reduce due to increased densities.
- *Land protection* increases because a greater value is placed on undeveloped land.

Transport supply sector

- *Road capacity addition* reduces because investment in new road capacity is reduced.
- *Transit capacity addition* increases due to increased investment in public transit.

4.4 Global Chaos Scenario

The Global Chaos scenario is described as follows. The past few decades have challenged Americans' general optimism, and the world 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 also 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 rather than choice, and people with cars often make extra money on the side as gypsy cabs.

The "Global Chaos Scenario" sheet shows how the study team has converted the 10 scenario variables into modifications to the model variables specified via the scenario multipliers.

Socio-demographic sector

- *Death rate* increases due to lack of focus on health care and poor environmental conditions.
- *Birth rate* reduces because of reduced optimism about economic conditions.
- *Marriage rate* reduces because of reduced optimism about economic conditions.
- *Empty nest rate* reduces because economic chaos results in adult children living with their parents.
- *Leave workforce rate* reduces due to later retirement.
- *Enter workforce rate* reduces due to poor economic conditions, with bigger reductions from 2030 than the reductions to the leave workforce rates.
- *Leave lowest income group rate* reduces, and *enter lowest income group* increases, as people shift into the lowest income group due to poor economic conditions.
- Similarly, *leave highest income group rate* increases, and *enter higher income group* reduces, as people shift out of the highest income group due to poor economic conditions.
- *Foreign in-migration rate* decreases due to increased border controls and stricter visa restrictions.
- *Foreign out-migration rate* increases due to stricter visa restrictions and increased deportation.
- *Domestic migration* reduces because there is less relocation activity as opportunities dwindle irrespective of location.
- *Low-income impact on death rate* increases because the increase in death rates is even higher for lower-income groups.
- All other income variations on birth, death, marriage, divorce, leave empty nest, and space per household rates remain at base year rates—i.e., base year levels of difference with income group persist.

Travel behavior subsector

- *Fuel/energy price* increases because of global supply instability.
- *Shared car fraction* increases of lower availability of affordable fuel and vehicles.
- *No car fraction* increases because poor economic conditions lead to a fall in car ownership.
- *No car fraction* increases because poor economic conditions lead to a fall in car ownership.

- *Work trip rate* falls due to lower employment rates.
- *Non-work trip rate* falls due to depressed economy.
- *Car passenger share* increases due to lower vehicle availability.
- *Walk/bike share* increases following reductions in car ownership.

Employment sector

- *Job creation rate* reduces due to low economic growth.
- *Job loss rate* increases due to low economic growth.
- *Job move rate* reduces due to reduced job opportunities.

Land-use sector

- *Land protection* is reduced because less value is placed on protected land.

Transport supply sector

- *Road capacity addition, transit capacity addition, road lane mile capacity, and transit route mile capacity* rates are all reduced due to very low investment in transport capacity.

4.5 Specifying a Custom Scenario

To specify a custom scenario, the user should start from one of the four pre-existing scenarios. In many cases, users would be expected to start from the momentum scenario, and then specify their scenario by making changes relative to the inputs for this scenario, but any of the four scenarios can be used as the starting point.

As an example, consider a scenario where the birth rate is projected to increase by 50 percent. This scenario can be specified by starting from the default input on the “Momentum Scenario” tab, as displayed in Figure 4-1. (Note that the input in the figure has already been changed for year 2005 to reflect some possible recession-related changes in income distribution and workforce participation.)

Scenario: Momentum												
	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	
1	Return to Main Menu											
2	Scenario multipliers on base rates											
3	SOCIO-DEMOGRAPHIC SECTOR											
4	Death Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
5	Birth Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
6	Marriage Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
7	Divorce Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
8	Empty Nest Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
9	Leave Workforce Rate	1.00	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
10	Enter Workforce Rate	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
11	Leave Lowest Income Group Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
12	Enter Lowest Income Group Rate	1.00	1.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
13	Leave Highest Income Group Rate	1.00	1.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
14	Enter Highest Income Group Rate	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
15	Foreign Immigration Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
16	Foreign Outmigration Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
17	Domestic Migration Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
18	Intra-Regional Migration Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

Figure 4-1: Example of changes in the Momentum Scenario (before)

To specify the scenario, it could be assumed that birth rates have increased by 25 percent in 2015 and by 50 percent in 2020 and thereafter. This would be specified as shown in Figure 4-2.

The screenshot shows a Microsoft Excel spreadsheet titled "NCHRP_Impacts_2050_V1_8.xlsxm - Microsoft Excel". The ribbon menu is visible at the top. The active sheet is labeled "Momentum Scenario". The table below is titled "Scenario: Momentum" and contains data for various socio-demographic sectors from 2000 to 2050. The table includes columns for "Death Rate", "Birth Rate", "Marriage Rate", "Divorce Rate", "Empty Nest Rate", "Leave Workforce Rate", "Enter Workforce Rate", "Leave Lowest Income Group Rate", "Enter Lowest Income Group Rate", "Leave Highest Income Group Rate", "Enter Highest Income Group Rate", "Foreign Immigration Rate", "Foreign Outmigration Rate", "Domestic Migration Rate", and "Intra-Regional Migration Rate". The values in the table are color-coded, with some cells highlighted in green, red, or yellow.

	A	B	C	D	E	F	G	H	I	J	K	L	
1	Return to Main Menu	Scenario: Momentum											
2	Scenario multipliers on base rates	2000	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	
SOCIO-DEMOGRAPHIC SECTOR													
4	Death Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
5	Birth Rate	1.00	1.00	1.00	1.25	1.50	1.50	1.50	1.50	1.50	1.50	1.50	
6	Marriage Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
7	Divorce Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
8	Empty Nest Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
9	Leave Workforce Rate	1.00	1.20	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
10	Enter Workforce Rate	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
11	Leave Lowest Income Group Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
12	Enter Lowest Income Group Rate	1.00	1.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
13	Leave Highest Income Group Rate	1.00	1.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
14	Enter Highest Income Group Rate	1.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
15	Foreign Immigration Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
16	Foreign Outmigration Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
17	Domestic Migration Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
18	Intra-Regional Migration Rate	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

Figure 4-2: Example of changes in the Momentum Scenario (after)

Taking the other “what if” questions set out in Section 1.2 in turn:

- Travel behavior question: What happens if the gas price doubles? This scenario can be specified by increasing the gasoline price scenario multipliers given in the “Travel Behavior Subsector” inputs section.
- Employment question: What if technological changes lead to increased job creation rates? This scenario can be specified by increasing the job creation rate scenario multipliers specified in the “Employment Sector” inputs section.
- Land-use question: What if households start to live more efficiently in smaller dwellings to use fewer resources or save money? This can be specified using the “residential space per household” multiplier in the “Land Use Sector” inputs section.
- Transport supply question: What would happen if no new roads were built in the next 30 years, but population growth continues? This scenario can be specified by setting the road capacity addition rate multipliers to zero in the “Transport Supply Sector” inputs section.
- Regional competition question: What if the other regions in the US develop very differently than this region? This can be specified by changing the external demand/supply ratios for the various indicators, in the “External Indices for Other Regions” inputs section.

CHAPTER 5

Running the Tool

Once base data for the region have been defined (if running for a custom region), and any modifications to the standard scenario inputs have been specified, *Impacts 2050* is ready to be run.

To run the scenario-analysis tool, the user simply needs to follow these steps from the “Main Menu” tab:

1. Under box ②, select the region from the first drop-down box, and the scenario from the second drop-down box..
2. Enter the scenario output file name in the input cell at the bottom of box ②.
Note that the scenario output file name cannot contain any spaces.
3. Click the “Run Model” button to run the simulation.

This process is illustrated in Figure 5-1.

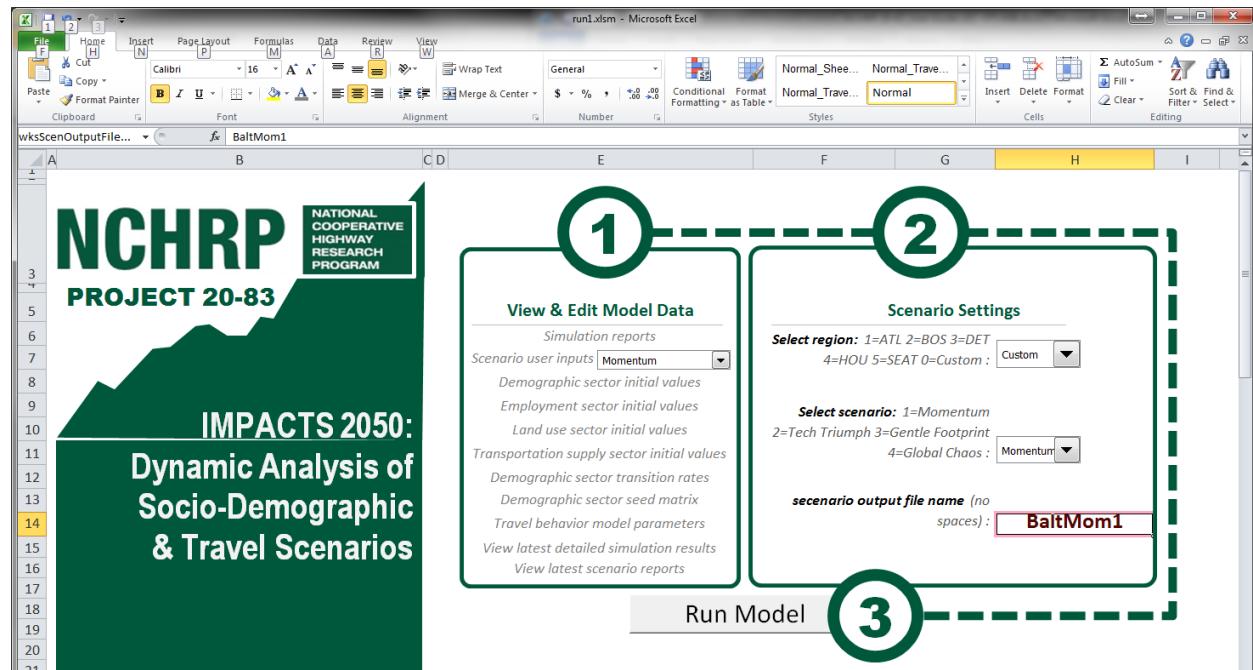


Figure 5-1: Running the Scenario Analysis Tool

In the example given in Figure 5-1, the user has specified base year data for its region (e.g. Baltimore) as per Chapter 3, and has selected “Custom” from the region drop-down menu. The scenario is “Momentum,” selected from the scenario drop-down menu. The scenario output file name is “BaltMom1.”

Then to run the simulation, the user simply clicks the “Run Model” button. To run the simulation, the spreadsheet outputs a series of .dat files that specify the base year stocks by sector, the scenario user inputs, the parameters in the travel demand model, the demographic seed matrix, the demographic transition rates, and the scenario user inputs. The spreadsheet then calls the accompanying **“NCHRP_Impacts_2050_V1.10.exe”** executable program, which reads in the information from the *.dat files and runs the simulation over half-year increments from 2000 through 2050. The program runs in a console window, which indicates the year being simulated and then closes when the simulation is finished. The program creates a .csv file as output, which uses the scenario output file name.

Once the simulation is complete, the spreadsheet automatically reads in the simulation results from the .csv file, copies it to the “Simulations Results” sheet, updates the summary results table and graphs on the “Simulation Reports” sheet, brings the “Simulation Reports” sheet to the user’s screen, and saves the output to the new spreadsheet named using the specified scenario output file name. So in the example given in Figure 5-1, a spreadsheet named “BaltMom1.xlsm” is created.

When the output spreadsheet is created, all of the sheets are copied across, not just the output sheets. This means that the resulting spreadsheet contains full documentation of the base data used to make the run, as well as the scenario inputs and any other changes that were specified. The macros are also copied across, so it is possible to use the output spreadsheet to specify the next scenario run following exactly the same procedure. This functionality is useful if the user wants to make a series of related scenario runs where the 2nd scenario is specified by making modifications to the 1st scenario, the 3rd scenario is specified making the modifications to the 2nd scenario, and so on. This functionality facilitates exploratory analysis to investigate the sensitivity of model results to particular scenario inputs.

CHAPTER 6

Other Parts of the Model

Three other sheets are defined in the model. The expectation is that the inputs in these sheets would not be modified under most scenarios. Nonetheless, they are described here briefly so the user can understand how they are used in the model, and for those users who wish to change these inputs.

6.1 Demographic Transition Rates

The “Demographic transition rates” sheet contain the transition rates that define how the people in the region will transition over time between the different categories of the socio-demographic variables. The transition rates define how the population will transition from one “state” to another, and are therefore fundamental to the simulation of the socio-demographic sector.

Two of the transition rates are structural, as they depend only on the passing of time. The first of these is aging, where the population transitions from one age cohort to the next. The model assumption is that working with 15-year cohorts, one-fifteenth of the people who survive transition into the next cohort. The second of these is acculturation transition. As people’s ethnicity and place of birth (foreign or native) do not change during their lifetime, the only transition that applies to acculturation is related to how long people have lived in the United States. The model assumption is that each year, one-twentieth of the foreign-born population transitions to the “greater than 20 years” category.

Transition rates other than aging and acculturation were determined from analysis of the Panel Survey on Income Dynamics (PSID), the only available panel data source with this type of demographic transition information. The PSID data allowed individual rates of change to be determined for the individual categories comprising each socio-demographic variable. Rates of change were determined from the three most recent pairs of waves: 2003 versus 2005, 2005 versus 2007, and 2007 versus 2009. Note that sample sizes among immigrants were very limited, so the same transition rates were often used to represent different race/ethnicity groups for the non-native segments.

The resulting transition matrix is given on the “Demographic transition rates” sheet, in cells D5:Q149. For each possible combination of age group, ethnic/acculturation group, and household type, the following base transition rates are defined:

- death rate/year
- birth rate/year
- marriage rate/year
- divorce rate/year
- leave nest—single rate/year
- leave nest—couple rate/year
- empty nest rate/year
- enter low-income group rate/year
- leave low-income group rate/year
- enter high-income group rate/year

- leave high-income group rate/year
- enter workforce rate/year
- leave workforce rate/year

Note that some combinations of segments and transitions are not possible, so these are given as structural 0's and shaded pink, while the rest of the cells are shaded as in orange and could be changed. However, to test the impact of changes to these base transition rates, the preferred method is to specify reductions or increases relative to the base rates using the scenario multipliers defined on the scenario sheets.

Immediately below the base transition rates matrix, the base demographic delays are given in cells B151:B156. The user can change the time period over which these processes take place by reducing or increasing the numbers of years over which these processes operate.

Next, cells C160:D165 provide rates that determine, for changes in household type, the fraction of the resulting households where children are present. These rates are derived from analysis of the PSID data. Users could change these national values if they have data that provide alternative values for their region.

Cells B168:B171 provide base migration rates, which are multiplied by the current population of the region. (The foreign migration rates are only multiplied by the current population living in the United States for less than 20 years, not the full population.) These rates are based on analysis of Census and ACS data from 2000 through 2010. Again, users could change the default national values if they have better data that are specific to their region.

The final set of values presented on this sheet are the migration attractiveness functions. In cells B177:D185, weights defining the relative attractiveness of three different measures that affect predicted migration levels are specified for different area and migration types:

- job supply/demand index
- residential space supply/demand index
- road mile supply/demand index

The shapes of the attractiveness functions for these three supply/demand measures are specified in cells B189:D209 and illustrated in the graph plotted immediately to the right of these cells.

The inputs for the migration attractiveness functions are highlighted in orange, indicating they should not be modified in most cases, unless the user wishes to change the basic assumptions of the model.

Appendix A and provides further information about how the rates are defined and used.

6.2 Demographic Seed Matrix

The “Demographic seed matrix” tab contains the seed matrix that was generated from the 2009 NHTS microdata. This seed matrix describes the base population that is broken down into the $3 \times 2 \times 3 \times 12 \times 4 \times 6 = 5,184$ possible combinations of the socio-demographic dimensions. The seed matrix is national, as there are not sufficient microdata to define this multidimensional matrix at the regional level.

When the simulation is run for a particular region, this national seed matrix is converted into a regional matrix by applying an iterative proportional fitting (IPF) procedure. The marginal totals for each population dimension used to apply the IPF procedure are taken from the “Demographic Initial Values” tab.

The values for the demographic seed matrix are highlighted in orange, indicating they should not be modified by users in most cases (unless users have a similar seed matrix from a very large sample representing their region, such as Public Use Microdata Sample/ACS microdata).

6.3 Travel Behavior Models

The “Travel behavior models” sheet specifies the model parameters used in the travel behavior models. In the scenario-analysis tool, the travel behavior model is a subsector of the socio-demographics sector, predicting demand for travel as a function of the characteristics of the regional population at each point in time.

The four travel behavior models were estimated from the full sample of the 2009 NHTS, including all add-on subsamples. The development of these models is described in more detail in Appendix A.

The four travel behavior models are applied in the following order:

1. The **Car Ownership Model** was estimated using a multinomial logit (MNL) discrete choice model, and predicts the probability that an individual falls into one of three groups:
 - 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 each driving-age adult 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 the at least two driving-age adults may need to share a vehicle.
 - c. “*No car*”—The person lives in a household with no vehicles.

The Car Ownership Model parameters are defined in cells B6:C31. “Own car” is the base alternative with zero utility, so the parameters for “share car” and “no car” are interpreted as the differences in utility (attractiveness) relative to the “own car” alternative.

2. The **Trip Rate Models** were estimated as log-linear regression models, with the dependent variable defined as the number of trips plus one to avoid taking the log of zero for zero-trip observations. The NHTS data include all days of the week throughout the year, including weekends and holidays; therefore, the models give trip rates for what is truly an “average day.” Two different models are applied:

- a. Work trips, which are trips to or from work, or work- or business-related activities.
- b. Non-work trips, which are all other trips.

The parameters for the trip rate models are defined in cells D6:E31.

3. The **Mode Choice Models** were estimated as MNL discrete choice models. Separate models were estimated for non-work trips, work trips, and children’s travel. Four modes are represented:
 - a. Car driver.
 - b. Car passenger.
 - c. Transit.
 - d. Walk/bike.

The parameters for the Mode Choice Models are defined in cells F6:M31. For the non-work and work models, the model parameters are defined relative to the car driver base mode. For children's travel, where car driver is not available, the model parameters are defined relative to the car passenger base mode.

4. The **Trip Distance Models** were estimated as log-linear regression models, with dependent variable the log of distance plus one to avoid taking the log of zero for zero-distance observations. Three separate distance models have been estimated for car driver, car passenger, and transit trips. There is no representation of transport supply for walk and bike modes in the simulation, so there are no Trip Distance Models for these modes. The parameters for the Trip Distance Models are defined in cells N6:P31.

CHAPTER 7

Analyzing the Model Output

Impacts 2050 automatically generates two sets of output to allow the user to analyze the simulation results: (1) a simulation report sheet presents pre-specified tabulations and plots, and enables users to specify their own plots; and (2) a simulation results sheet offers full flexibility for more detailed analyses.

7.1 Simulation Reports

Once the simulation has been run, the scenario analysis tool will automatically present the “Simulation Reports” sheet. At the top left of the sheet, a table is presented, which summarizes the simulated change in the socio-demographic characteristics of the region’s population over the forecast period, and predicted changes in travel behavior. Table 7-1 illustrates the summary results generated for the Atlanta region under the Momentum scenario.

Table 7-1: Summary of Table of Population and Travel Behavior

Year	2000	2010	2020	2030	2040	2050
Population	4,247,982	5,262,023	6,300,547	7,076,865	7,691,863	8,225,550
Percent under age 16	23%	22%	22%	23%	23%	23%
Percent over age 60	11%	14%	16%	18%	19%	19%
Percent in single household	13%	19%	21%	23%	24%	24%
Percent in HH w/ children	63%	64%	62%	61%	61%	61%
Percent Immigr. >20 yrs in U.S.	2%	5%	9%	10%	10%	9%
Percent Immigr. <20 yrs in U.S.	8%	10%	9%	7%	5%	4%
Percent White/other	61%	59%	57%	56%	55%	55%
Percent Hispanic	6%	8%	10%	11%	12%	12%
Percent Black	29%	26%	25%	25%	24%	24%
Percent Asian	3%	6%	8%	9%	9%	10%
Percent low income group	31%	32%	34%	34%	33%	33%
Percent in high income group	18%	19%	22%	25%	26%	27%
Percent in workforce	51%	47%	43%	41%	40%	39%
Percent non -car-owning	2.4%	2.5%	2.7%	2.8%	2.9%	3.0%
Percent car-sharing	22.6%	21.8%	21.9%	21.9%	21.9%	21.8%
Avg. car-occupancy-Work	1.13	1.13	1.13	1.13	1.13	1.13
Transit mode share - Work	1.7%	1.9%	2.1%	2.3%	2.4%	2.5%

Year	2000	2010	2020	2030	2040	2050
Walk/bike mode share - Work	5.2%	5.6%	5.9%	6.1%	6.2%	6.3%
Avg. car-occupancy-Non-work	1.82	1.76	1.75	1.75	1.76	1.76
Transit mode share - Non-work	1.5%	1.6%	1.7%	1.8%	1.9%	1.9%
Walk/bike mode share - Non-work	11.2%	11.5%	11.7%	11.8%	11.9%	12.0%
Work trips/capita per day	0.61	0.55	0.51	0.48	0.47	0.46
Other trips/capita per day	2.82	2.86	2.93	2.96	2.98	2.99
Auto VMT/capita per year	11,726	11,115	10,714	10,472	10,336	10,251

In addition to the summary presented in Table 7-1, the “Simulation Reports” spreadsheet creates 14 predefined plots that show how the simulation results evolve over time. Each plot is generated as both a line graph and a stacked area graph, where the dimensions sum to 100 percent. The plots generated are summarized in Table 7-2.

Table 7-2: Summary of Predefined Plots

Plot Title	Sector	Dimensions
Demographic Transitions	Socio-demographic	Empty nest First child Divorces Marriages Births Deaths
Population by Age Group	Socio-demographic	0–15 16–29 30–44 45–59 60–74 75+
Population by Household Type	Socio-demographic	Couple with kids Single with kids Couple without kids Single without kids
Population by Race/Ethnicity (summed across acculturation levels)	Socio-demographic	Hispanic Black Asian White/other
Population by Acculturation Level (summed across race/ethnicity)	Socio-demographic	Born in the U.S. Foreign born—In the U.S. >20 yrs. Foreign born—In the U.S. <20 yrs.
Population by Income Group	Socio-demographic	Upper Income Middle Income Lower Income
Population by Workforce Participation	Socio-demographic	Not in workforce In workforce
Population by Residence Area Type	Socio-demographic	Rural area Suburban area Urban area

Plot Title	Sector	Dimensions
Population by Car Ownership Level	Travel behavior	No car Share car Own car
Daily Trips by Purpose	Travel behavior	Work trips Non-work trips
Daily Work Trips by Mode	Travel behavior	Walk/bike trips Transit trips Car passenger trips Car driver trips
Daily Non-work Trips by Mode	Travel behavior	Walk/bike trips Transit trips Car passenger trips Car driver trips
Foreign and Domestic Migration	Socio-demographic	Domestic out-migration Domestic in-migration Foreign out-migration Foreign in-migration
Jobs by Area Type and Sector	Employment	Rural area, other jobs Rural area, service jobs Rural area, retail jobs Suburban area, other jobs Suburban area, service jobs Suburban area, retail jobs Urban area, other jobs Urban area, service jobs Urban area, retail jobs
Land by Area Type and Land Use	Land use	Rural area, protected land Rural area, developable land Rural area, residential land Rural area, nonresidential land Suburban area, protected land Suburban area, developable land Suburban area, residential land Suburban area, nonresidential land Urban area, protected land Urban area, developable land Urban area, residential land Urban area, nonresidential land
Road Lane Miles by Area Type and Road Type	Transport supply	Lane miles, rural area, local roads Lane miles, rural area, arterials Lane miles, rural area, freeways Lane miles, suburban area, local roads Lane miles, suburban area, arterials Lane miles, suburban area, freeways Lane miles, urban area, local roads Lane miles, urban area, arterials Lane miles, urban area, freeways

The “Simulation Reports” spreadsheet also allows the user to create custom plots that plot the evolution of any of the stock variables represented in the simulation. The variables to be included in the plot can be selected from the drop-down boxes available in cells A33:A49, and up to 17 different variables can be plotted. The variables to be included in the plot should be selected working top-down in cells A33:A49.

In the example shown in Figure 7-1, two custom plots have been created to examine the variation in the number of births by income group over the simulation period.

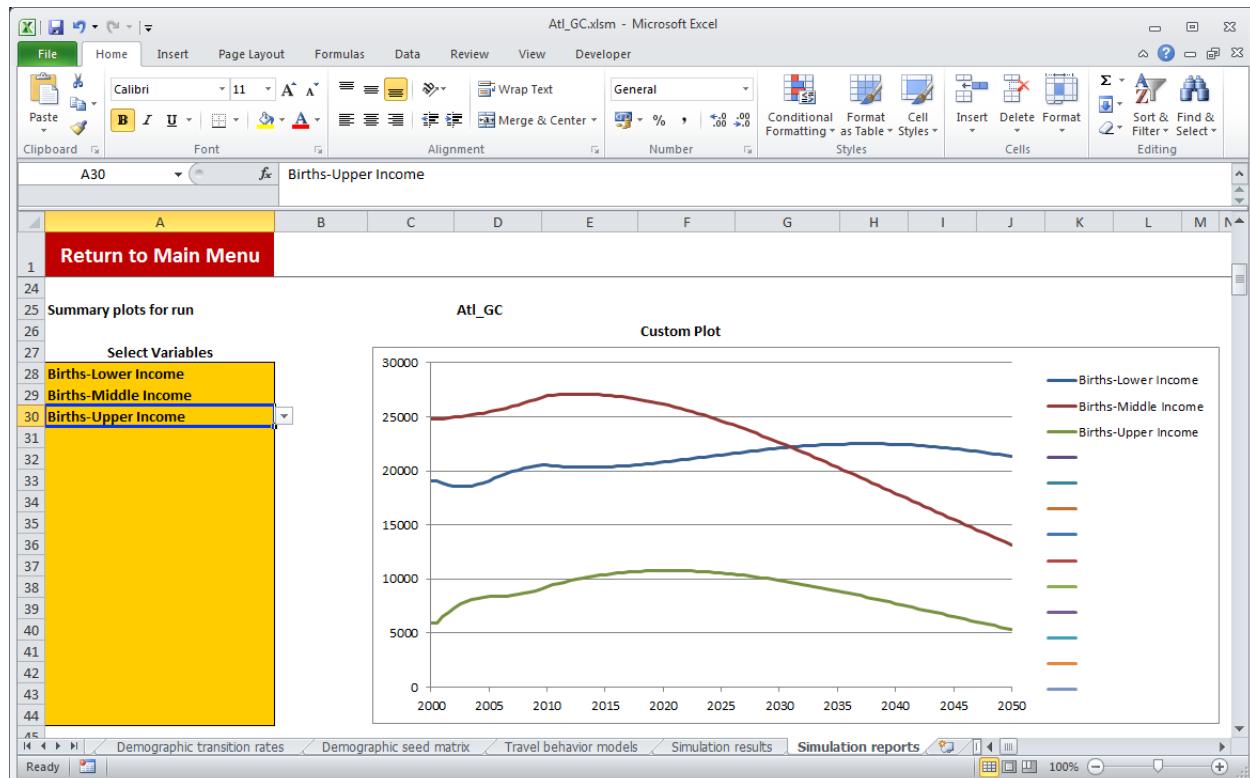


Figure 7-1: Custom Plot: Births by Income Group over Simulation Period

7.2 Simulation Results

The detailed simulation results are plotted on the “Simulation Results” tab, which appears immediately to the left of the “Simulation Reports” tab. Providing users with the detailed simulation results gives them full flexibility to analyze changes in any of the stock variables in the model over the simulation period.

The detailed simulation results provide 1,504 variables. The variables appear as rows, and the columns give the year, with results given for every half-year period from 2000 through 2050. The variables are named in Column A. The first variable given in row 2 is the total population.

APPENDIX A

Impacts 2050 Model Structure Documentation

A.1 Demographic Sector

The "stock variable" is the number of people in a regional population of interest, and it is segmented into the dimensions below. These dimensions were selected for their strong relationship with travel behavior, based on the knowledge of the research team and our Tasks 1 and 2 findings, documented in 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 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 lifecycle and behavior but long enough to avoid many different cohorts.
- **Household structure:** Four categories: Single without children, couple with children, single with children, couple with children. A “couple” is defined as either married or co-habiting partners (but not, for example, two non-related adults).
- **Acculturation group:** Three categories: Foreign-born with less than 20 years in the US, Foreign-born with 20 or more years in the US, Native-born. The threshold of 20 years in the US for foreign-born was selected to distinguish “acculturated” from “non-acculturated” residents.
- **Race / ethnicity:** Four categories: White/ other, Asian, Black, Hispanic.
- **Workforce status:** Two categories: Participating in the workforce, not participating in the workforce. This includes those who are employed or looking for employment.
- **Household income:** Three categories: lowest quartile (\$0-\$34,999), middle two quartiles (\$35,000-\$99,999), and highest quartiles (\$100,000 up). These are 2009 dollars. 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, 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 4000 jobs per square mile or 10,000 residents per square mile inside the tract. For suburban, it is at least 500 jobs per square mile or 1,000 residents. Rural is defined as having less than 500 jobs or 1,000 residents per square mile.

Note that 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.

Running the SD model for a specific region requires the initial distribution of the population along all of the variables above simultaneously. With the categories above, that requires values for $6 \times 4 \times 3 \times 4 \times 2 \times 3 = 5184$ different combinations, or “cells” in a multi-dimensional matrix. We have kept the number of socio-demographic stock variables and dimensions as concise as possible to constrain the number of cells 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 multi-dimensional matrix for a given region (i.e., age x household structure x acculturation group x race/ethnicity x workforce status x household income x residence area type). So we applied an iterative proportional fitting (IPF) technique to derive a multi-dimensional matrix for each region. IPF is a procedure for adjusting a table of data cells such that they add up to selected total for columns and rows in the table. The data cells are referred to as the “seed” cells and the selected total are referred to as the “marginal totals.”

First we developed a table that would serve as the “seed” cells. We used the National Household Travel Survey, 2009 (for which we did have access to the necessary micro data) to develop a national multi-dimensional 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 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 2000 census is shown here:

- Age 0-14 = 955,906 persons
- Age 15-29 = 941,083 persons
- Age 30-44 = 1,135,495 persons
- Age 45-59 = 758,505 persons
- Age 60-74 = 313,953 persons
- Age 75+ = 143,038 persons
- Total = 4,247,981 persons

A.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 one fifteenth of the people who 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:** A person'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 persons have lived in the US. Our model assumption is that each year 1/20th of the foreign-born persons transitions to the "greater than 20 years" category.

Rates of change other than ageing and acculturation have been derived from the Panel Survey of Income Dynamics (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. So 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 person 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 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 persons 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 US 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 and the "with children" Household structure, and "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 US-born/Non-white or Hispanic ethnicity.
- **Deaths:** Deaths can occur in all age groups, although the death rates are quite 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) quite small. There is, however, 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 those in the lowest income quartile tend to live shorter lifespans, 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”: fraction per year of single people getting married or starting cohabitation
 - “Divorce”: 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 divorced 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”: 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.

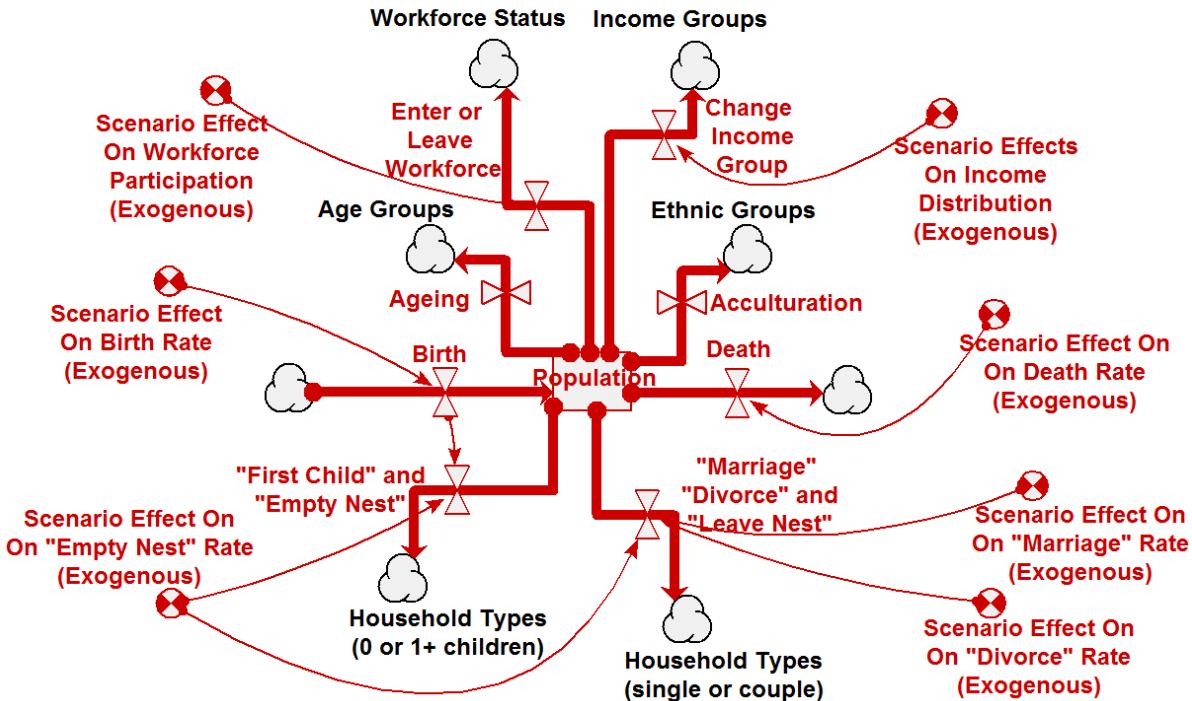
Note that the result of “marriage”, “divorce” or “leave nest” are not purely structural in terms of whether or not there will be any children in the resulting household. Singles who marry or young adults that “leave the nest” may join a partner that already has children. Similarly, a “divorce” in a household 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 persons in the workface that are employed versus unemployed is endogenous to the model, based on the size of the workforce relative to 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 in a later year.
- **Household income group:** Transitions in household income can be one of four types, each of which has a separate rate: (a) entering the low income group from the middle income group, (b) leaving the low income group to the middle income group, (c) entering the high income group from the middle income group, (d) leaving the high income group to the middle income group. These rates are defined in terms of the percent 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 A-1a shows some detail of the socio-demographic transitions related to the rates of change that have been discussed thus far in the form of a 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 FigureA-1a, birth and death, result in people entering or leaving the simulation completely. The other rates simply shift the socio-demographic categories of people.

SOCIO-DEMOGRAPHIC SECTOR TRANSITIONS (1)

(Base transition rates based on Panel Survey on Income Dynamics 2003-2009)



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, it 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 A-1a: Socio-demographic Sector Transitions (1)

We continue the discussion of the rates of change variables.

- **Residence location transitions:** This is an important aspect of the model because as population's change (i.e., people age) they might make different residence location decision 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 (e.g., foreign migration, domestic migration, 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 regions of the US.
- **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 American Community Survey and /or the Census. For migration within the US (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 below.

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

The equations for migration are in the following form: (a) a current population number, (b) a base migration rate that multiplies the current population, (c) a multiplier effect due to the attractiveness of the region/area type for residents (see below for more information on this), and (d) an exogenous modifier effect that the user can define for different scenarios (relating to the scenario variable pertaining to immigration policy).

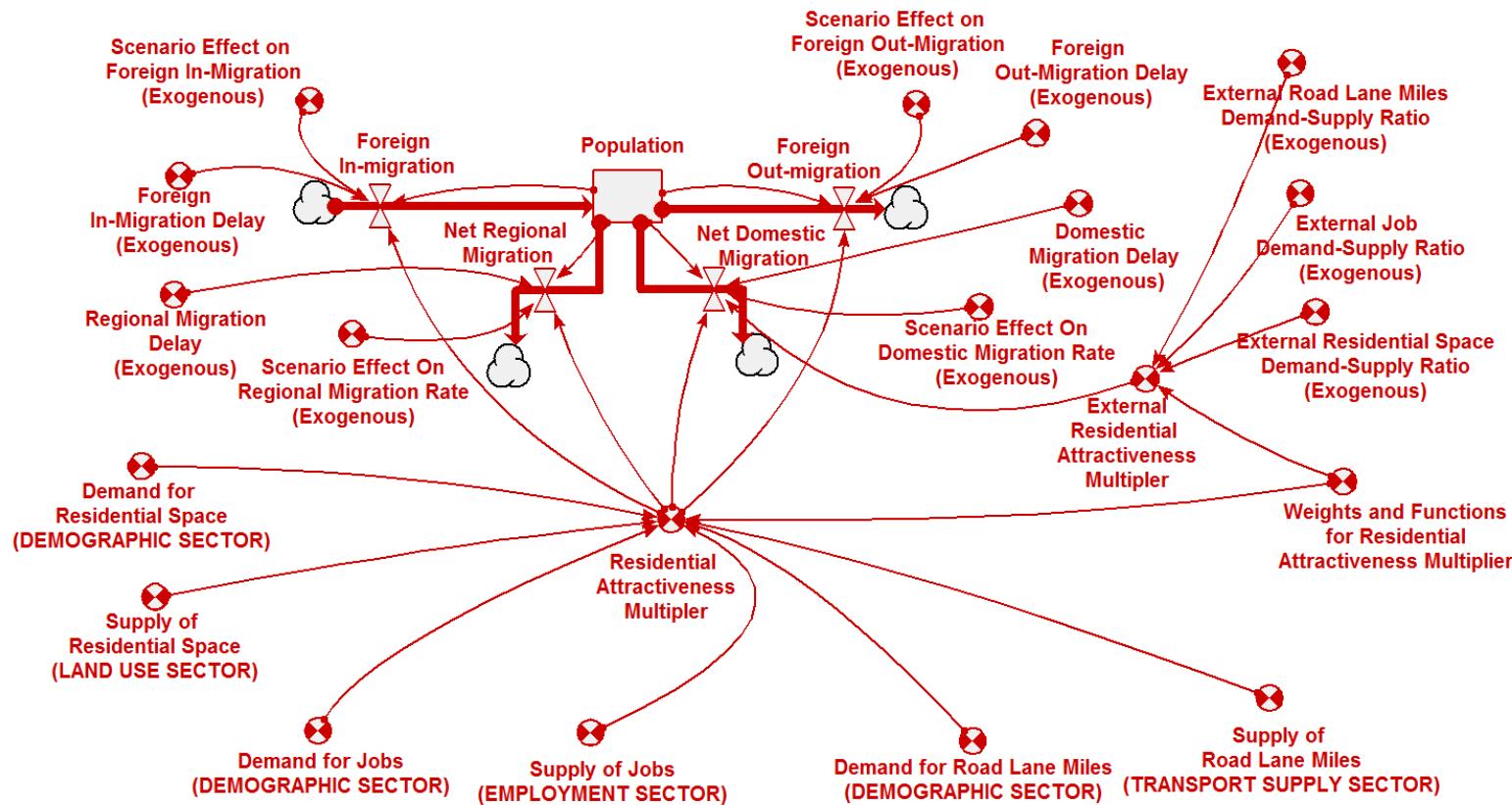
A.1.1 Attractiveness Function Effects on Base Residence Location Transition Rates

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 A-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 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 higher attractiveness. For Domestic migration, the attractiveness of competing regions of the US 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 comparing to another region or area type.

SOCIO-DEMOGRAPHIC SECTOR TRANSITIONS (2)



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, it 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 A-1b: Socio-demographic Sector Transitions (1)

The socio-demographic variables are summarized in Table A-1.

Table A-1: 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+	Ageing	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 Death rate “Marriage” rate “Divorce” rate “Empty nest” rate “Leave nest” rates	New births enter model in “with children” category Deaths can impact both presence of children and single/couple status. Marriage and divorce rates mainly affect single/couple status Empty nest rate effects presence of children Children “leave nest” to form various types of households
Acculturation Group	Foreign born, In US <20 years Foreign born, in US >20 years US 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 (a) other countries, (b) other regions of the US, (c) other area types in the same region

A.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 their “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 zero vehicles.
2. The **Trip Rate Models** indicate the number of trips per day made by the persons 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. Non-work 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 travelled 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 is the full sample of the 2009 National Household Travel Survey (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).

A.2.1 Car Ownership

1. “*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 their “own” vehicle.
2. “*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.
3. “*No car*”: The person lives in a household that has zero vehicles.

The dependent variable is percent 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 A-2. “Own Car” was selected as the base category and “share car” and “no car” are interpreted relative to the base category. 22% of persons were in “Share Car” households and 6% in “No Car” households, leaving 72% in “Own Car” households. The base categories apply to the independent variables as well. The base categories are the variables “not found”: (a) 30-44 age group, (b) single person households, (c) white, non-Hispanic ethnicity, (d) not employed, (e) \$35-100K income, (f) living in suburban area type, (g) living outside all of the 5 selected MSA region. As with the dependent variable, the other categories are interpreted relative to the base category.

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% 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. Those who live in households with couples (versus single adults), and those age 16-29 are more likely to share a car, but less likely to be in a zero-car household.

Those in non-white or Hispanic ethnic groups are more likely be in low-car households, and this effect is even stronger if the person was born outside the US, and stronger still if the person has been in the US 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 those 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.

Table A-2: 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	-.526	-27.7	-.838	-24.0
Age group 16-29	.543	37.2	-.076	-2.6
Age group 45-59	-.131	-8.4	-.121	-4.2
Age group 60-74	-.405	-21.2	-.324	-10.1
Age group 75 up	.189	8.2	.202	5.7
Couple in household	.834	56.5	-.1058	-38.9
1+ children in household	-.452	-32.5	-.433	-12.1
Single with children	.670	32.0	.190	4.8
Ethnicity non-white or Hispanic	.592	49.7	.999	48.6
Born outside of US	.292	13.8	-.309	-8.9

Variables	Alternative			
	Share Car	(22% share)	No Car	(6% share)
	Coefficient	T-statistic	Coefficient	T-statistic
Born outside US, < 20 years in US	.369	15.0	.435	10.4
Worker	-.597	-51.2	-1.133	-53.5
Low income group	1.111	101.3	1.661	82.0
High income group	-.701	-45.2	-.635	-14.5
Urban residence area type	.690	49.9	1.757	85.5
Rural residence area type	-.528	-46.1	-.599	-24.4
Atlanta MSA region	.106	2.9	-.232	-3.0
Boston MSA region	.135	3.8	-.042	-0.7
Detroit MSA region	.650	20.0	-.133	-1.8
Houston MSA region	.172	4.8	-.213	-2.8
Seattle MSA region	-.235	-5.1	.362	4.6

Note: Although the sample person expansion weights were used in estimation to account for non-representative 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 (in order to avoid inflated measures of statistical significance).

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.

A.2.2 Trip Rates

Log-linear regression models were estimated for the number of work trips and non-work 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 non-work 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 includes all days of the week throughout the year, 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 A-3. The independent variables are the same as in the previous model, except that two new variables are added, “no car” and “share car”, 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 to 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. Non-white and

Hispanic make slightly fewer work trips, but this is offset by a positive additive coefficient for those born outside the US. 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 Non-work Trip rate model shows stronger effects, with the strongest negative effect being for workers, who, presumably, make fewer non-work trips because they are busy working. There is also an age effect, with non-work trip rates increasing with age up until age 75. People in households with children also make substantially more non-work 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 US tend to make fewer non-work trips, all else equal. Non-work trip rates increase with income, and they decrease in rural areas, where distances are longer and people tend to group more activities into each tour. (One home-based tour that visits two different non-work destinations requires 3 trips, whereas visiting them on two separate home-based tours would require 4 trips.) People in low-car, and especially no-car households also make fewer non-work 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.

Table A-3: Daily Trip Rate Models

Variables	Alternative			
	Work Trips		Non-work trips	
	Coefficient	T-statistic	Coefficient	T-statistic
Constant	.825	155.1	1.597	310.4
Age group 0-15	n/a		-.209	-45.0
Age group 16-29	-.031	-6.7	-.069	-18.4
Age group 45-59	.000	.1	.018	5.1
Age group 60-74	-.076	-12.4	.058	12.5
Age group 75 up	-.153	-9.3	-.004	-.6
Couple in household	-.007	-1.5	-.028	-7.6
1+ children in household	-.040	-9.4	.115	33.3
Single with children	-.008	-1.0	.010	1.8
Ethnicity non-white or Hispanic	-.027	-6.1	-.009	-2.8
Born outside of US	.035	4.6	-.073	-12.7
Born outside US, < 20 years in US	.020	2.3	-.017	-2.4
Worker	n/a		-.473	-153.3
Low income group	-.016	-3.6	-.031	-10.1
High income group	-.008	-1.9	.065	20.7
Urban residence area type	-.013	-2.5	.008	2.2
Rural residence area type	-.001	-.2	-.052	-19.5
Atlanta MSA region	.014	1.1	-.027	-2.9
Boston MSA region	-.084	-7.5	.000	.0
Detroit MSA region	-.077	-6.5	.127	14.6
Houston MSA region	.005	.4	-.056	-5.8

Variables	Alternative			
	Work Trips		Non-work trips	
	Coefficient	T-statistic	Coefficient	T-statistic
Seattle MSA region	-.009	-.6	-.083	-8.0
No car household	-.078	-8.0	-.110	-18.6
"Share car" household	-.021	-4.6	-.016	-5.1

A.2.3 Mode Choice Models

Three separate mode choice models were estimated, one for work trips, one for non-work 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.

A.2.3.1 Work Trips

The Work Trip Mode Choice model, shown in Table 4, was estimated on a sample of about 244,000 work trips. As before, the data was 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% Car driver (the base alternative), 7.6% Car passenger, 3.3% Transit, and 6.6% Walk/Bike.

We again use 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.

Table A-4: 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	.638	31.1	.079	2.2	-.111	-4.5
Age group 45-59	-.136	-6.2	-.092	-2.8	-.206	-9.5
Age group 60-74	.003	.1	.154	3.1	-.264	-7.9
Age group 75 up	-.607	-5.4	.109	.7	-.364	-3.7
Couple in household	.275	11.5	-.633	-17.1	-.356	-15.0
1+ children in household	-.053	-2.6	.273	7.2	.004	.2
Single with children	.125	3.5	-.327	-6.0	-.756	-17.5
Ethnicity non-white or Hispanic	.107	5.0	.243	7.1	-.366	-14.7
Born outside of US	.176	5.0	.199	4.3	.035	.9

Variables	Alternative					
	Car Passenger		Transit		Walk/Bike	
	Coefficient	T-statistic	Coefficient	T-statistic	Coefficient	T-statistic
Born outside US, < 20 years in US	-.012	-.3	.256	5.3	.195	4.5
Worker	n/a		n/a		n/a	
Low income group	.318	16.0	-.199	-6.2	-.215	-8.8
High income group	-.039	-1.8	.406	11.8	.439	21.3
Urban residence area type	-.012	-.5	1.366	46.5	.982	44.4
Rural residence area type	.198	11.2	-1.252	-23.7	-.363	-16.4
Atlanta MSA region	.252	4.7	-.783	-4.9	-.027	-.4
Boston MSA region	-.176	-2.8	-.006	-.1	-.511	-7.3
Detroit MSA region	-.197	-3.2	-.957	-7.4	-.296	-4.2
Houston MSA region	-.095	-1.5	-.720	-6.1	-.334	-4.4
Seattle MSA region	-.011	-.1	1.026	10.9	-.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)	.005	.6	-.050	-3.6	.102	11.1

The results in Table A-4 show that age has strong effects on work trip mode choice, with workers under age 30 more likely to go as car passenger and the older age groups over 45 are less likely to bike or walk. The age effects for transit use are not strong. Those 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, and the same pattern is found for low-income workers (and the opposite pattern for high income workers). Non-white and Hispanic are more likely to rideshare and use transit for the work trip, but less likely to walk, and this effect is even stronger for those born outside the US. The effects by area type are also strong, as those 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 might expect, the most important variables are related to car ownership, with those 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, but counter-intuitively, the transit share seems to decrease somewhat.

A.2.3.2 Non-Work Trips

A mode choice model with the same multinomial logit (MNL) specification was estimated for non-work trips made by people age 16+ (old enough to be a car driver). The sample is roughly 750,000 weighted trips, with 65.5% by Car driver, 20.1% by Car passenger, 21.0% by Transit, and 12.3% by Walk/Bike. The model fit (McFadden Rho-squared) is 0.107, and the results are shown in Table A-5.

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. Non-white or Hispanic are more likely to rideshare or use transit, but less likely to walk/bike. Being born outside the US does not have a strong influence, except being more likely to walk or bike,

especially if less than 20 years in the US. 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 non-work stops that car drivers make as part of work tours.)

The area type once again shows significant effects, with those in core urban areas less likely to use car passenger and more likely to go by transit and walk/bike, and those in rural areas showing just 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.

Table A-5: Non-Work 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	.682	79.1	.628	24.8	.218	20.0
Age group 45-59	-.075	-8.1	-.020	-.7	-.039	-3.7
Age group 60-74	-.013	-1.2	-.342	-10.1	-.311	-22.8
Age group 75 up	.230	16.2	-.519	-11.9	-.625	-30.8
Couple in household	.533	57.2	-.347	-12.8	-.102	-9.3
1+ children in household	-.146	-17.6	.018	.6	-.109	-10.2
Single with children	.312	22.2	-.318	-8.2	-.021	-1.2
Ethnicity non-white or Hispanic	.053	6.6	.378	16.0	-.213	-20.6
Born outside of US	-.009	-.7	-.050	-1.5	.152	8.9
Born outside US, < 20 years in US	.087	5.0	.137	3.6	.215	11.0
Worker	-.523	-78.3	-.526	-25.9	-.248	-29.4
Low income group	.039	5.1	.008	.4	-.031	-3.2
High income group	.048	5.9	.176	5.5	.198	19.9
Urban residence area type	-.098	-9.5	1.501	69.9	.780	76.5
Rural residence area type	.075	11.0	-.884	-22.8	-.186	-19.9
Atlanta MSA region	-.026	-1.0	.402	5.2	-.057	-1.8
Boston MSA region	.171	7.7	.444	9.0	.264	10.7
Detroit MSA region	-.131	-6.2	-.809	-9.1	-.163	-5.9
Houston MSA region	.013	.5	-.363	-4.1	-.089	-2.8
Seattle MSA region	.063	2.1	.525	6.3	.460	14.5
No car household	2.653	109.7	5.261	154.4	3.641	156.0
"Share car" household	.645	85.4	1.524	56.6	.575	59.6
Fuel price (per dollar)	.041	12.6	.124	12.7	.124	30.8

A.2.3.3 Children's Travel

The final mode choice model, shown in Table A-6, was estimated only for children age less than 16. (Because children under 5 do not have travel diaries in NHTS, the age group for estimation is 5-15). This is about 135,000 weighted trips, with mode shares 79.6% for car passenger, 1.6% for transit, and 18.7% 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, either because they applied to all cases or to no cases. Those variables are indicated by n/a in the table. The model fit (McFadden Rho-squared) is 0.86.

As in the other mode choice models, the car ownership effects are the strongest. Non-white or Hispanic children are more likely to use transit or walk/bike, somewhat more so if born outside the US. 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).

Table A-6: Non-Work 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	-.235	-4.5	-.007	-.4
1+ children in household	n/a		n/a	
Single with children	n/a		n/a	
Ethnicity non-white or Hispanic	.896	14.6	.102	6.0
Born outside of US	n/a		n/a	
Born outside US, < 20 years in US	.271	3.3	.107	2.9
Worker	n/a		n/a	
Low income group	.166	2.8	.248	13.0
High income group	1.067	15.7	-.026	-1.4
Urban residence area type	1.631	31.5	.377	17.9
Rural residence area type	-1.592	-13.0	-.359	-20.7
Atlanta MSA region	.960	7.8	-.325	-5.3
Boston MSA region	-.991	-4.4	.325	6.4
Detroit MSA region	-20.000	n/a	-.661	-10.9

Variables	Alternative			
	Transit		Walk/Bike	
	Coefficient	T-statistic	Coefficient	T-statistic
Houston MSA region	-.911	-4.1	-.401	-6.5
Seattle MSA region	.191	.8	.710	14.2
No car household	3.258	47.0	1.828	49.8
"Share car" household	1.112	18.0	.387	19.5
Fuel price (per dollar)	.090	3.9	.089	11.7

A.2.4 Trip Distance Models

The final set of models, shown in Table A-7, are 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 vehicle-miles traveled (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 that is used to calculate VMT from the trip distance model is described next. The car ownership model splits the demographic categories further into sub-categories by car ownership type. Then, within that demographic/car ownership group:

$$VMT = (\text{work trips} * \text{work trip car driver mode share} * \text{work trip car driver trip distance}) + (\text{non-work trips} * \text{non-work trip car driver mode share} * \text{non-work trip car driver trip distance})$$

There are 6 different models to get the 6 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.

Table A-7: 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	.218	6.6	-.211	-36.2	-.401	-15.9
Age group 16-29	.044	13.4	-.070	-11.1	-.008	-.5
Age group 45-59	-.051	-17.5	-.027	-3.8	-.100	-5.8
Age group 60-74	-.083	-22.0	-.088	-10.7	-.154	-6.8
Age group 75 up	-.178	-30.6	-.204	-19.7	-.140	-4.4
Couple in household	.042	13.3	-.061	-8.3	.008	.4
1+ children in household	-.050	-16.8	-.059	-9.8	.035	1.8

Variables	Trip Type: Dependent = LN(Distance + 1)					
	Car Driver Trips		Car Passenger Trips		Transit Trips	
	Coefficient	T-statistic	Coefficient	T-statistic	Coefficient	T-statistic
Single with children	.039	7.9	-.058	-6.7	.047	1.9
Ethnicity non-white or Hispanic	.052	17.7	-.003	-.6	.001	.1
Born outside of US	.022	4.3	.097	9.1	.240	10.1
Born outside US, < 20 years in US	-.008	-1.3	-.044	-3.5	-.239	-9.2
Worker	.434	179.8	.190	25.9	.277	20.4
Low income group	-.074	-25.7	-.067	-13.9	-.119	-7.9
High income group	.043	15.5	.047	10.1	.073	3.9
Urban residence area type	-.105	-27.8	-.108	-17.2	-.229	-16.7
Rural residence area type	.229	95.4	.295	73.7	.270	10.0
Atlanta MSA region	.131	15.4	.087	6.1	.678	13.0
Boston MSA region	.116	14.5	-.121	-8.8	-.025	-.7
Detroit MSA region	.010	1.3	.021	1.7	.478	8.1
Houston MSA region	.097	10.8	.002	.2	.191	3.4
Seattle MSA region	.150	14.6	.108	6.6	.061	1.3
No car household	.101	6.1	-.274	-25.1	-.294	-16.3
"Share car" household	-.026	-8.1	-.055	-11.6	-.171	-9.9
Fuel price (per dollar)	.008	7.2	-.005	-2.8	.027	4.3

The strongest effect in the models is the “work trip purpose” variable, which indicates that trips made for work tend to be longer than non-work 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). Non-white and Hispanic tend to make longer car driver trips, while those born outside the US 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 taking into consideration other variables, particularly area type. Those in low-car and no-car households tend to make shorter trips by car—perhaps 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 is different than the finding in the mode choice models, and might 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). We will test the sensitivity of the SD model to fuel price changes, and adjust model parameters if necessary.

A.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, non-residential, developable and protected). This stock variable is segmented into:

1. Urban, suburban, rural residential space
2. Urban, suburban, rural non-residential space
3. Urban, suburban rural developable space
4. Urban, suburban, rural protected space

A.3.1 Land Use Rates of Change

The rates of change that are relevant to this sector are (see also Figure A-2):

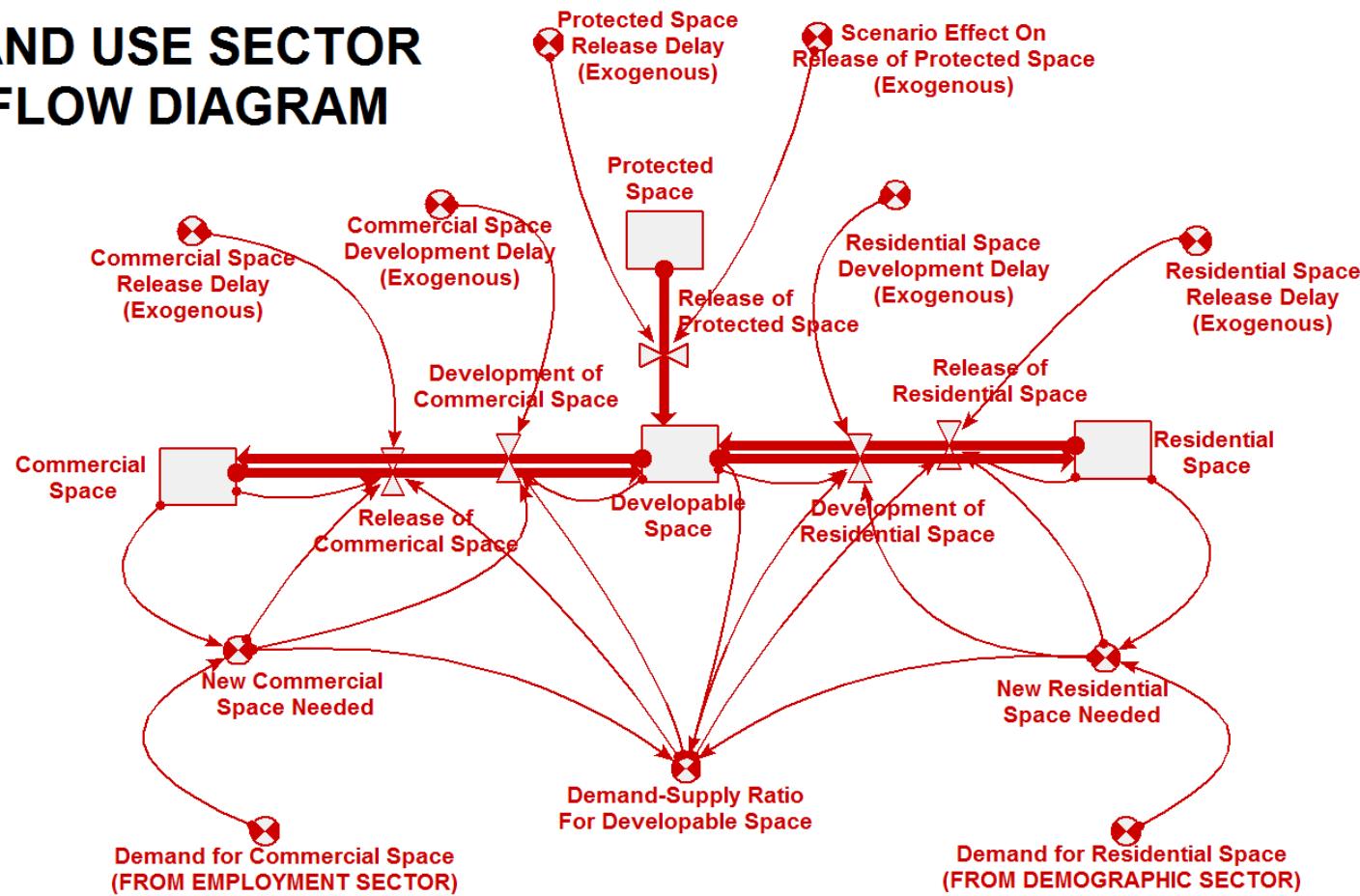
- **Development of Residential Space and Release of Residential Space:** Converting land from Developable Space to use for housing,
- **Development of Non-Residential Space:** Converting land from Developable Space to use for employment, industry and other commercial uses,
- **Release of Non-Residential Space:** Conversion of land back to Developable Space, e.g. through rezoning, redevelopment, demolition, etc.,
- **Release of Protected Space:** Redesignation of land from Protected to Developable. (Note that this can be negative, which would signify the case of more land put under protection.)

The equations that comprise the rates for the first three bullets above have four main components: (a) the existing stock of space in the use that would be converted out of, (b) the amount of new space needed for the relevant land use (that can be zero or negative), (c) 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 (d) 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 non-market 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 Non-Residential 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 might be in the more distant future. Although purely speculative development is fairly rare in reality (e.g. there is not much construction 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.

LAND USE SECTOR FLOW DIAGRAM



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, it is land area in various use categories.
- 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 arrows represent direct relationships that are (parts of) equations in the model.

Figure A-2: Land Use Sector Flow Diagram

A.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 was the Longitudinal Employer-Household Dynamics data from the U.S. Census Bureau, 2002 and 2010.

A.4.1 Employment Rates of Change

The rates of change that are relevant to the Employment sector are (see also Figure A-3):

- **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.

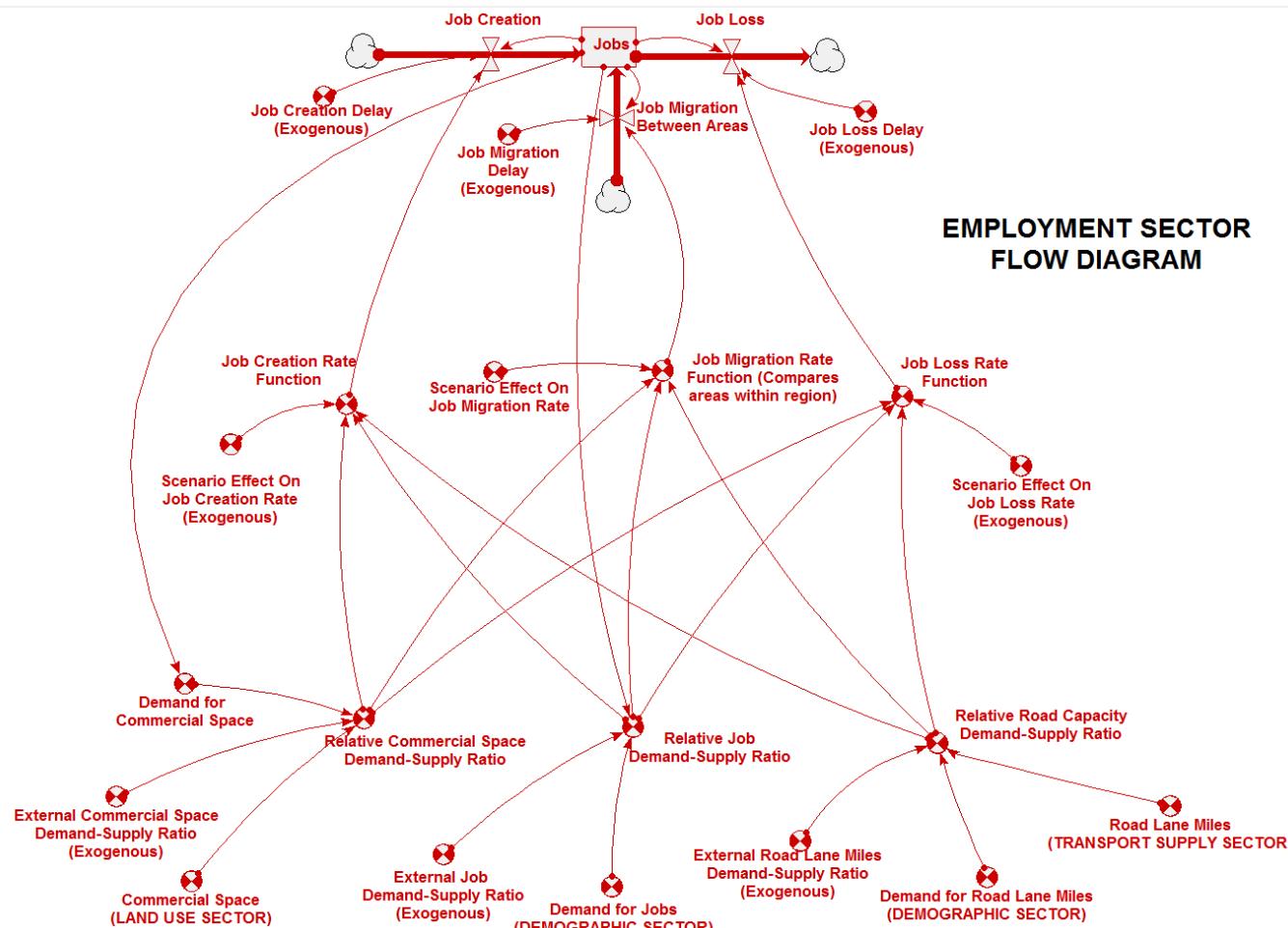
The equations that comprise this sector have three main components: (a) the existing stock of jobs, (b) the indicated change in the stock of jobs, and (c) the market delay time needed to reach the indicated level. The delay time is exogenous, and could reflect, for example, job creation programs or tax 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: (a) an exogenous scenario effect, reflecting, for example, the health of the economy for creating new jobs, (b) the balance of supply and demand for jobs, reflecting availability of labor, (c) the balance of supply and demand for commercial space, reflecting availability of land, and (d) 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/supply relationships that enter 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 CAPS at the bottom of Figure A-3.
- The same three demand-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, particular for jobs coming from or going to other regions (reflect 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. In this case, the weights vary by area type and employment type.

**KEY FOR FLOW DIAGRAM:**

- Rectangles are stock variables. In this diagram, it is 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 that are outside the scope of the model.
- The arrows represent direct relationships that are (parts of) equations in the model.

Figure A-3: Employment Sector Flow Diagram

A.5 Transport Supply Sector

The “stock” variable is the amount of road lane miles by area type (urban, suburban, local) and by road type (freeway, major arterial, other), and amount 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 non-rail transit route-miles

The source for these data was the National Transit Database of the Federal Transit Administration, 2002 and 2010.

A.5.1 Transport Sector Rates of Change

The rates of change that are relevant to this sector are (see Figure A-4):

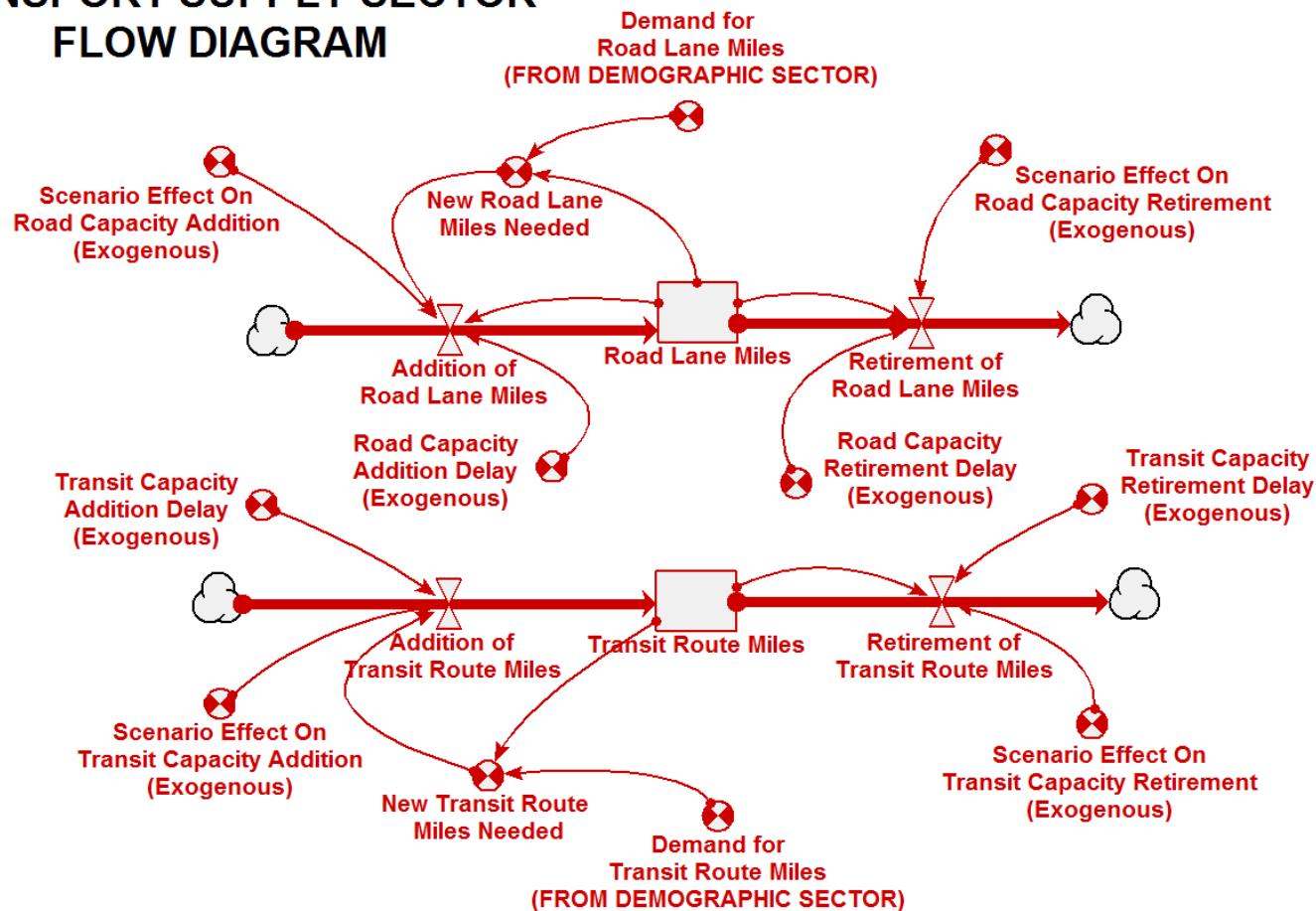
- **Addition to Road Lane Miles:** Construction of new road capacity (which could include widening of existing roads).
- **Retirement of Road Lane Miles:** Reflects road capacity being closed or becoming unusable due to lack of maintenance.
- **Addition to Transit Route Miles:** Opening of new transit 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.

The demand for peak hour road supply is a function of the number of work and non-work trips by car driver 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 non-work trips.

Multiplied together, these determine the peak hour demand for lane miles for each road type within each area type, which can be compared to the road supply. Because the model does not use explicit network assignment, this provides an approximation of traffic demand growth relative to supply over time.

The rate equations for this 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. The exogenous scenario inputs represent (a) 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 (b) 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: (a) the fraction of existing capacity to be retired (for example, the decision to discontinue certain transit services), and (b) the rate in time at which existing capacity is to be retired.

TRANSPORT SUPPLY SECTOR FLOW DIAGRAM



KEY FOR FLOW DIAGRAM:

- Rectangles are stock variables. In this diagram, it is road lane miles and transit route miles in service.
- 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 A-4: Transport Sector Flow Diagram