Simplified Integrated Transportation and Land Use Modeling to Support Metropolitan Planning Decisions: An Application and Assessment

by

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A Dissertation
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Public Policy

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Date: 4/26/2011	Spring Semester 2011 George Mason University Fairfax, VA

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ACKNOWLEDGEMENTS

I would like to acknowledge the following people who were instrumental in me completing this research: Kelly, Zachary, Gretchen, Mom, Dad, Kevin, my colleagues at Noblis (Jim, Karl, Don, and Carolina), and my colleagues at AASHTO. Thank you for your help and patience.

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ABSTRACT

SIMPLIFIED INTEGRATED TRANSPORTATION AND LAND USE MODELING TO SUPPORT METROPOLITAN PLANNING DECISIONS: AN APPLICATION AND ASSESSMENT

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This dissertation explores the role that a simpler transportation and land use modeling approach can play to support decision-making within metropolitan planning. Metropolitan planning is driven today, in part, by the need to develop and implement new policies such as smart growth, congestion pricing, and environmental regulation that affect transportation and land use. In addition, there are many different categories of metropolitan planning decision-making: policy development, visioning, strategic analysis, and tactical assessment, all of which need to be supported with data, analysis, and information. Thus, an important aspect of metropolitan planning is the ability to analyze policy scenarios in an integrated fashion using integrated transportation/land use modeling (ITLUM) tools. This dissertation reviews the literature, identifies a role for a simpler ITLUM tool, surveys practitioners and experts in the field of metropolitan

planning, and develops a simpler ITLUM tool using the Washington, DC region as a case study.

CHAPTER 1: INTRODUCTION

Transportation and land use planning, collectively referred to as the metropolitan planning process, has a rich history in the United States (U.S.) that has evolved over the past century because of the involvement of decision makers and stakeholders in developing transportation and land use policies; federal requirements and funding availability; and advances in computing technologies and modeling theories. Any discussion of the metropolitan planning process inevitably includes a discussion of the models, tools, and methodologies used by decision makers to support various decisions ranging from transportation infrastructure placement to zoning for land use. The use of modeling tools has grown since von Thünen first seriously considered the land use-transportation relationship in 1826 (Sinclair 1967).

Computer modeling tools have a rich evolutionary history and researchers have described the evolution in different ways. Miller, *et.al.*, and Wegener describe the evolution from simple to complex with the goal of developing tools that are, generally speaking, more complex in nature (E. Miller, Kriger, and Hunt 1998; Wegener 2004, 2) Mile, *et. al.*, however, describes it slightly differently where tool selection to support transportation planning is a trade-off between system complexity and spatial complexity (Mile and G. Emberger 2004). Most recently, Hardy, *et. al*., in discussing the application and use of transportation models for work zone design and evacuation modeling, describe the evolution in terms of a spectrum of modeling tools where selection is based upon five aspects: functionality, results, time, training, and cost (Hardy et al. 2007; Hardy, Wunderlich, and Bunch 2009). What is absent from these frameworks of model evolution and selection is an inherent decision-making functionality that a computer modeling tool supports. Today, decision makers rely on a spectrum of modeling tools to support the necessary decision-making[1] throughout the metropolitan planning process.

Historically, beginning in the 1930s, the metropolitan planning process grew out of a desire to plan transportation networks using traffic survey data. In the late 1960s and 1970s, environmental regulation drove metropolitan planning as concerns about community impacts, air quality and environmental preservation emerged. Today, metropolitan planning is being driven, in part, by the need to develop and implement new policies associated with transportation and land use such as smart growth, congestion pricing, and environmental regulation. Often, these three policy tools are examined in isolation as stand-alone instruments designed to combat a social ill. For example, congestion pricing is seen as a means to mitigate traffic congestion while smart growth policies are aimed at mitigating the negative effects of rapid suburbanization. Environmental regulations (such as CAFE standards) have traditionally been relegated to the federal government to implement with little concern about local fiscal impacts. From a policy perspective, what is interesting about these three policies is the interplay and interrelationships among them. Thus, an important aspect when assessing these policies as part of the metropolitan planning process is the ability to analyze the effects in an

[1] This research identifies four decision-making categories associated with the metropolitan planning process. These four categories include policy development, visioning, strategic planning, and tactical assessments which are described in more detail in Section 2.1.

integrated fashion. To this end, decision makers rely on the use of computer modeling tools to support decision-making within the metropolitan planning process.

The use of computer modeling tools has been an integral part of metropolitan planning, though very few tools exist to look at the transportation and land use system in an integrated manner (U.S. Government Accountability Office 2009). Within the transportation planning process an entire set of transportation forecasting modeling tools has been developed that date back to the 1950s and are primarily based upon the four-step planning process (Iacono, Levinson, and El-Geneidy 2008)[2]. Today, every federally designated metropolitan planning organization employs some type of transportation forecasting model. The land use planning process, however, is not as well-established in terms of tool development or application. Of the 35 largest metropolitan areas, only 12 were using commercially available land-use models (C. Porter, Melendy, and Deakin 1995).

Iacono, et. al, refer to the early development of computer modeling tools as being focused on the available expertise associated with developing a modeling approach and the availability of data to test the approach (Iacono, Levinson, and El-Geneidy 2008). Over time, expertise began to grow and the ability to reasonably collect data increased such that the focus of model development shifted to incorporating more functionality into the model and better representation of real-world systems. For example, the development

[2] The four-step planning process consists of trip generation, trip distribution, mode split, and route assignment.

of microsimulation modeling approaches occurred in parallel with increasing computing power and data storage.

While many resources have been devoted to the development of more complex computer modeling tools (e.g., UrbanSim and TRANSIMS) less attention has focused on simpler modeling approaches. Just as one cannot use only a hammer to construct a house, one modeling tool cannot support the entire metropolitan planning decision-making process. Recently, the use of system dynamics[3] as a simpler approach has been discussed as a means to support the metropolitan planning decision-making process. Abbas and Bell articulate twelve reasons why system dynamics might positively contribute to the metropolitan planning process (Abbas and Bell 1994). Many of these reasons have been supported by later research most notably that of Sussman, et. al, who articulate the need for system dynamics as part of a regional strategic planning process to better engage stakeholders (Sussman, Sgouridis, and Ward 2005; Mostashari and Sussman 2005).

To this day, researchers and policy makers continue to debate the role and purpose of computer modeling tools to support metropolitan planning. On one hand, researchers cite the need for complex, large-scale modeling tools that are able to include more functionality with a higher degree of accuracy in the results (Badoe and E. J. Miller 2000; Waddell, Gudmundur F. Ulfarsson, and Franklin 2007). These researchers suggest the need to further develop the complex and comprehensive tools that were created as a result of ISTEA and the 1990 Clean Air Act Amendments (CAAA) such as UrbanSim or

[3] System dynamics is a modeling approach designed to incorporating complex feedback relationships to better assess system analysis. A detailed discussion is presented in Section 3.3.

TRANSIMS (Waddell, Gudmundur F. Ulfarsson, and Franklin 2007). On the other hand, other researchers and decision makers indicate the high cost, difficulty of use, and large data requirements required to run large-scale models and identify the need for simpler models (Fehr & Peers 2007). This group suggests there is a need to incorporate the complexities of the dynamic urban process by way of simpler computer modeling tools that are more accessible to decision makers (Sussman, Sgouridis, and Ward 2005). This research builds upon this debate and provides evidence to suggest that the use of a simpler modeling approach can be a cost-effective approach to supporting certain aspects of the metropolitan planning decision-making process.

1.1 MOTIVATION

The increasing complexity of social, political and economic factors associated with metropolitan planning have driven researchers to develop a new regime of modeling tools called integrated transportation and land use models (ITLUM). These tools are being developed in part based upon the recognition that transportation and land use planning is a complex process; the need to analyze various inter-related policy initiatives to support decision-making; and the requirement to satisfyingly involve stakeholder groups in the metropolitan planning process. The ITLUM tools being created are often complex in nature requiring large amounts of detailed data, resources (time and money), functionality, and expertise. Unfortunately, many of the more complex tools are not easily accessible by many planning agencies in the U.S. And, researchers often criticize the use of simpler modeling tools given the complex nature of urban systems as being too simplistic (Abbas and Bell 1994).

However, there is some evidence to suggest that a complex modeling approach is not necessarily appropriate for all aspects of the decision-making process and that a simpler tool may be sufficient in order to capture the complexities associated with understanding the transportation and land use system dynamics (Mostashari and Sussman 2005). In fact, if a goal of the planning process is to better engage stakeholders, then creating ITLUM tools that are better accessible to stakeholders and decision makers alike may be a useful exercise (Mostashari and Sussman 2005). Thus, the motivation for this research is to further explore how a simplified modeling approach (one that requires less data, resources, functionality, and expertise to operate[4]) can support decision making within the context of the metropolitan planning process in the U.S.

A key aspect of this research is that computer modeling tools, by definition, are used to *support* the decision-making process. As discussed in the conclusions of this research, the development of computer modeling tools has followed a trajectory form simple to complex based upon the notion that as computers become faster and data becomes more readily available, we can build computer modeling tools that are more accurate and faster. However, what is often overlooked are the decisions these tools are supporting. This research proposes four decision-making categories associated with metropolitan planning that computer modeling tools should support: policy development,

[4] The distinction between simple and complex modeling approaches are based upon four requirement categories: data, resources (time and money), functionality, and expertise. Simple modeling approaches have lower requirements and complex modeling approaches have higher requirements. See Section 2.3.

visioning, strategic analysis, and tactical assessments. Selecting a specific modeling tool in supporting the decision-making process is a trade-off between certain factor requirements and model complexity.

1.2 Research Question and Hypotheses

The current literature is not clear as to what role computer modeling tools can have in the context of metropolitan planning in the U.S. Building upon this gap in the literature, this dissertation will explore what role a simpler modeling approach has in supporting the metropolitan planning decision-making process. The research question of concern for this dissertation is the following: What are the opportunities and limitations of using a simplified ITLUM approach as compared to the standard regional forecasting modeling approach in order to support the metropolitan planning decision-making process?

The following two hypotheses are established which will be validated in order to answer the research question:

- **Hypothesis 1**—Decision makers involved with the metropolitan planning process desire a simplified ITLUM tool that can be used to support the policy development and visioning categories of the decision-making process.
- **Hypothesis 2**—A system dynamics-based integrated transportation and land use modeling tool can be tractably used to serve as an improved modeling approach by decision makers involved with the metropolitan planning process to support

policy development and visioning as compared to traditionally-used regional planning modeling tools.

1.3 Contributions of this Research

The results of this research will be unique and contribute to the existing research in the following two ways:

- **Contribution #1**: *It will provide evidence about the utility that a simpler modeling approach can have in supporting metropolitan planning decision making*. This research assesses decision makers' opinions on the use and application of simplified integrated transportation and land use modeling tools.
- **Contribution #2**: *Build, Calibrate, and Test a Washington DC Metropolitan Activity Relocation Simulator (MARS) model (a system dynamics-based ITLUM tool)*. The result of this research will be an operational model that could be used by the Washington, DC region as well as a documented case study on how to create a MARS model for other regions in the U.S. In addition, it provides a detailed case study analysis using realistic data for a typical region in the U.S. to demonstrate that certain aspects of metropolitan planning can be supported using simpler ITLUM tools as part of an integrated analysis process. Future research will be able to assess the utility of this simpler approach. The results of constructing the Washington DC MARS model will further expand the range of modeling tools that decision makers can employ to support trade-off analysis among policy alternatives with complementary and conflicting goals.

1.4 DISSERTATION ORGANIZATION

This introductory chapter provides an overview of the research problem at hand, the research question and hypotheses, and the contributions of this research to the existing literature. Chapter 2 provides a more detailed literature review of the three main areas of concern with this research including metropolitan planning, policy tools driving the metropolitan planning process today, and integrated transportation and land use modeling tools.

Chapter 3 provides a summary of the mixed-method approach that is used to conduct this research. The mixed-method approach includes the use of survey and case study methodology to assess the effectiveness of the simplified modeling approach to transportation and land use planning. In addition, a system dynamics integrated transportation and land use model is constructed representing the simplified modeling approach.

Chapter 4 is a detailed summary of the practitioner survey disseminated to key stakeholders involved in the metropolitan planning process representing state DOTs, MPOs, consultants, and researchers and addresses Hypothesis 1.

Chapter 5 documents the case study methodology used to construct the system dynamics model for the Washington, DC region using the Metropolitan Activity Relocation Simulator (MARS) system dynamics model. The case study analysis includes detailed discussions of the network development, model calibration, and model testing and addresses Hypothesis 2.

Chapter 6 discusses the expert panel method which was used to assess the utility of using the simpler system dynamics modeling approach as it relates to policy development and visioning. The expert panel was used to gather feedback and opinion regarding the utility of the MARS model as it relates to both the regional forecasting modeling approach and the MARS model's effectiveness in supporting policy development and visioning. This chapter addresses Hypothesis 2.

Chapter 7 provides some concluding remarks regarding the overall findings of this research including hypothesis testing, public policy implications, and future research opportunities.

CHAPTER 2: LITERATURE REVIEW

This literature review synthesizes three broad areas associated with metropolitan planning including a historical assessment of metropolitan planning, discussion of prominent policies driving metropolitan planning today, and tools being used by policy makers to support decision-making associated with metropolitan planning.

2.1 METROPOLITAN PLANNING

Metropolitan planning is an amalgamation of two historically separate planning processes: transportation planning and land use planning as shown in Figure 1. Transportation planning is often associated with the four step planning process in order to develop travel demand forecasts for a region and is dominated by federal requirements intended to ensure regional coordination (RDC, Inc. 1995). Land use planning is somewhat different and includes the creation of a comprehensive plan predicting the type of development to occur and is implemented through a set of zoning and subdivision ordinances developed at the local (county and city) level (Kelly and Becker 1999, chap. 1). Taken together, these two separate planning components represent an interrelated process known as metropolitan planning that looks at transportation and land use holistically.

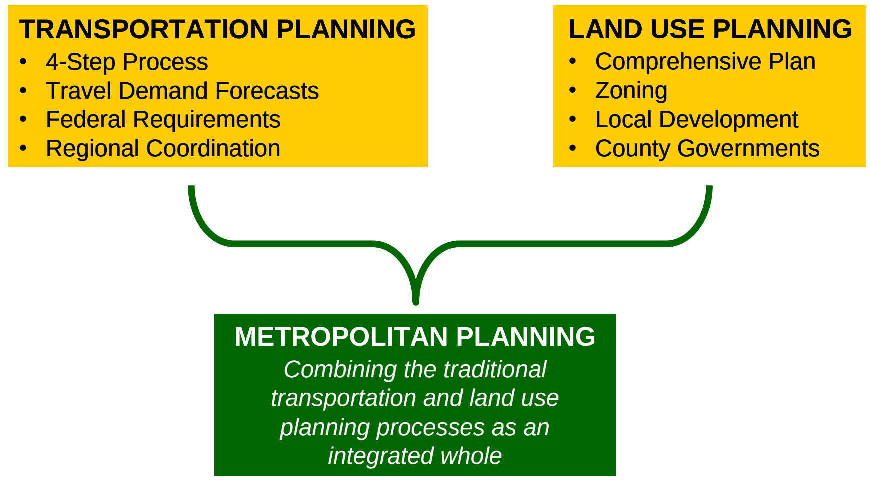

Figure 1 Metropolitan Planning Components

The transportation and land use planning processes were developed independently of each other through much of the twentieth century. Throughout the early twentieth century, the planning, design and construction of transportation systems was a function of state and local governments. However, in 1916, the U.S. Congress established the Federal Aid Highway Program which allocated funding for the construction of highways to state authorities. In 1956, Congress passed legislation establishing the Highway Trust Fund which launched the planning, design, and construction of the present-day Interstate highway system. The 1956 legislation established a motor fuel tax to fund 90 percent of the cost to construct designated sections of the interstate highway system (Gifford 2003, chap. 4). The golden age of highway construction endured through the 1960s. Beginning in the 1970s opposition to highway construction began to take hold in many cities throughout the U.S. with opponents demanding increased community involvement and serious consideration to non-highway modes (Gifford 2003, chap. 4). In 1969, the

National Environmental Policy Act (NEPA) required new levels of environmental planning associated with transportation projects receiving federal funds and was further strengthened by the 1970 Clean Air Act (CAA) and 1990 CAAA (Johnston 2004). Finally, the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) ushered in a new era of transportation planning establishing regional planning organizations as "…sources of objective, comprehensive analysis and planning." such that multi-modal transportation planning is conducted at a regional level in an objective manner (Gifford 2003, 119).

Transportation planning has evolved into a complex, institutionalized process embodied by many different products such as a transportation improvement program plan or a long-range transportation plan. They are developed based upon the involvement of various stakeholders from all levels of government and numerous stakeholder groups, though dominated by regulations and requirements established by the federal government.

The current transportation planning process has consistently been dominated by federal laws and regulations placed upon state and local transportation authorities in order that they receive federal funding with which transportation infrastructure could be built (Johnston 2004). These federal requirements required local and state governments to make improvements to the transportation planning process such that decisions on how to spend large amounts of federal funding could be justified financially, equitably and environmentally. A large proportion of these improvements have been in the form of developing improved transportation modeling tools that provide decision makers with a consistent framework to support local decisions on transportation infrastructure improvements (E. Miller 2003). Currently, all metropolitan areas have developed regional transportation planning models which are routinely used to support local decision-making on how federal funding should be spent on transportation infrastructure (U.S. Department of Transportation 2007).

Land use planning, in similar fashion to transportation planning, is also a complex process involving numerous actors and stakeholders. However, in contrast to transportation planning, land use planning occurs primarily at the local level (county or city) and is embodied by a local comprehensive plan and set of zoning ordinances (Kelly and Becker 1999, chap. 2). Developing the comprehensive plan is a local process whereby stakeholders from the community create a future vision of their neighborhoods in terms of housing mix, business locations, density, etc. Unlike the transportation planning process, the land use planning process does not place a heavy emphasis on the use of modeling tools to support the development of a comprehensive plan.

Historically, transportation has been taken as exogenous to the land use planning process but has now evolved to include a close coupling with land use planning (E. Miller, Kriger, and Hunt 1998). For example, development of a comprehensive plan now includes a transportation component. Also, many localities are tying major redevelopments to transportation infrastructure improvements. One of the first communities to accomplish this was Arlington County, Virginia and the planning for the redevelopment of the Rosslyn-Ballston Corridor that began in the 1960s. The county was proactive in having transportation planners to reexamine the role of MetroRail within the corridor as well as the impact that Interstate 66 would have on residents (Gifford 2003, 3; Schrag 2006). Today, the foresight of the local planners as well as intense community involvement that ensued has created one of the most widely cited examples of integrated transportation-land use planning (Schrag 2006).

The transportation and land use planning processes are depicted in Figure 2 and Figure 3 respectively. These figures show the three "Ps" of the planning process: participants, process and products. Representative participants include various federal, State, regional, and local stakeholders involved in the overall planning process. Participants are connected to the process with curved lines indicating where they are first engaged within the overall process. Underneath the process are the various stages of both transportation and land use planning. While both figures represent the process as iterative and sequential, the actual processes do not necessarily take on this form in reality. However, for the sake of clarity, the process is portrayed in this manner. The rectilinear lines connecting an individual process stage to a product indicate where the various outputs of the planning process are created.

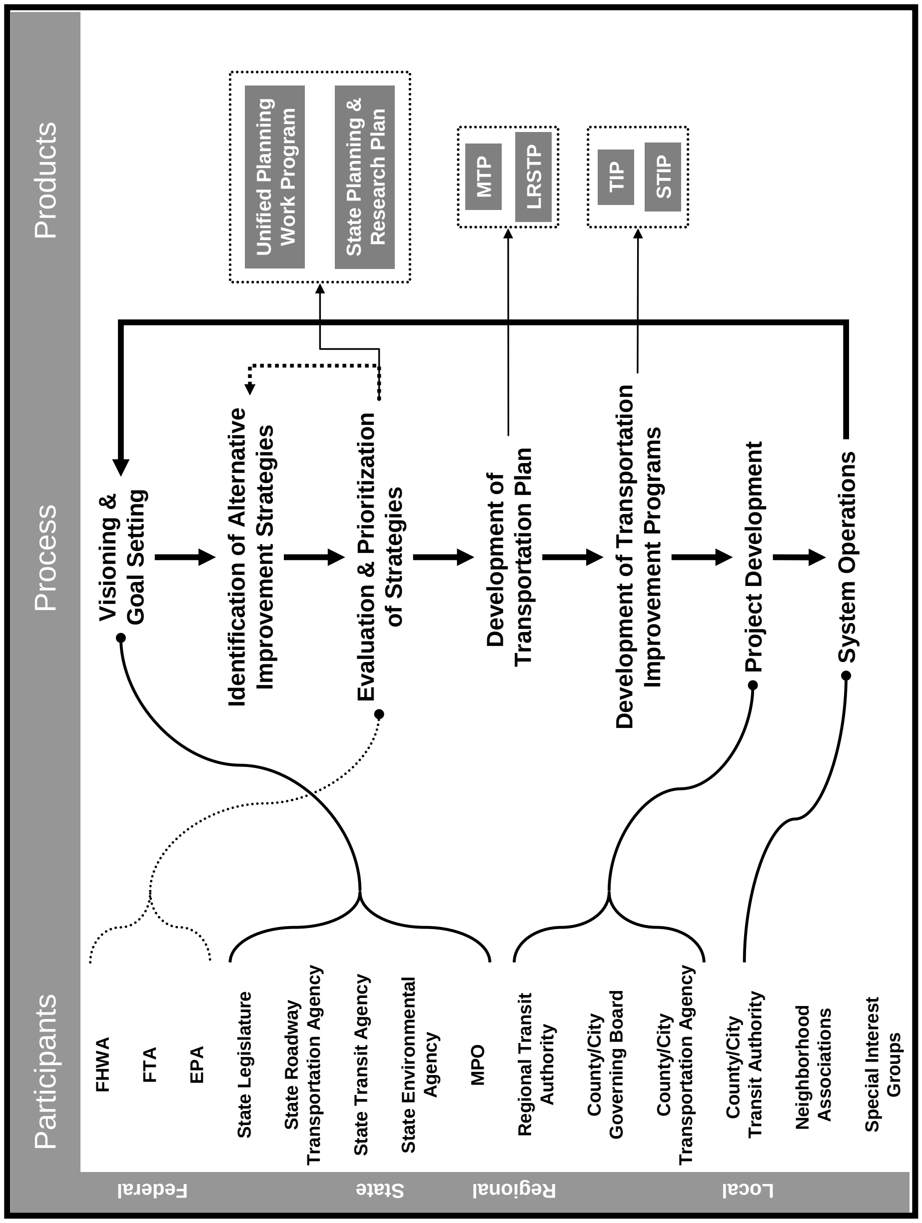

Figure 2 Transportation Planning Process
Source: (U.S. Department of Transportation 2007)

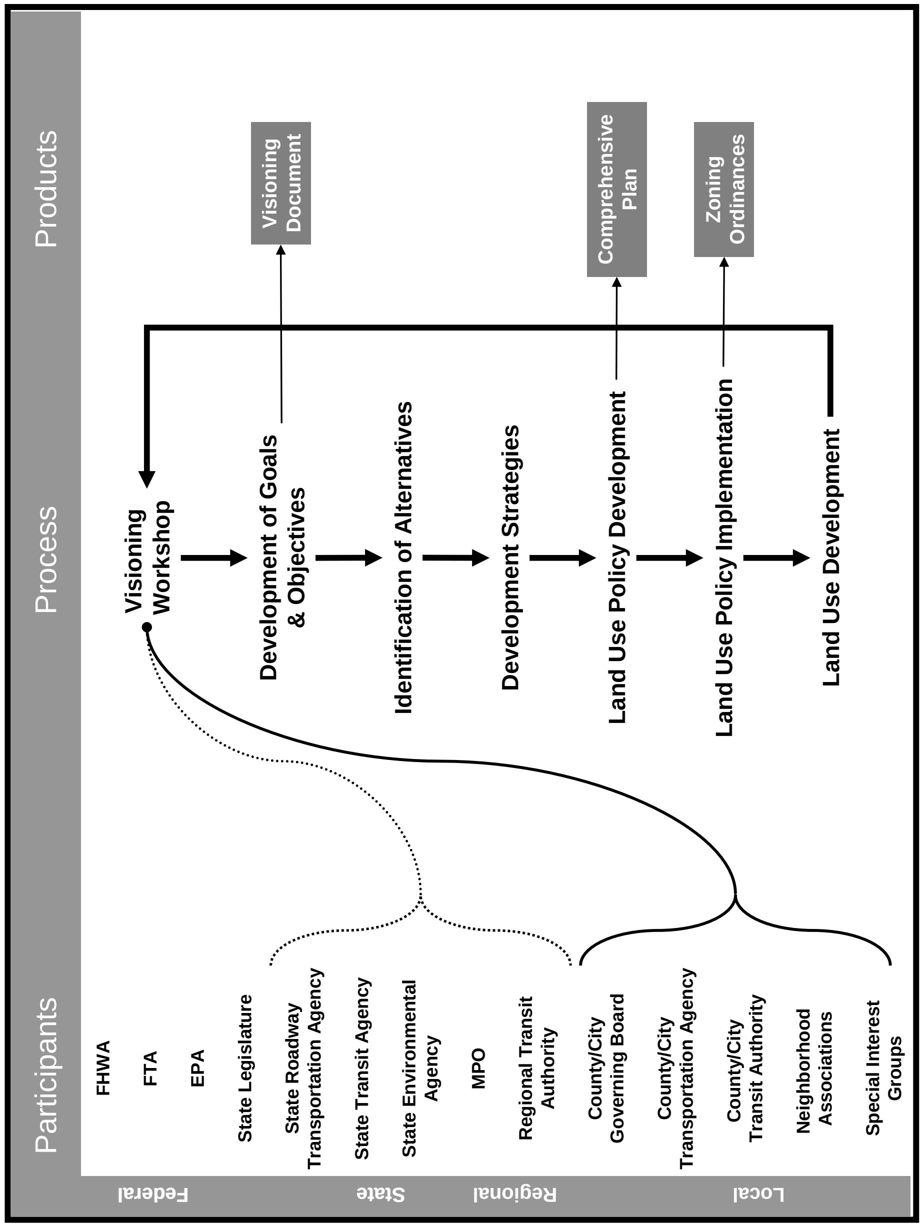

Figure 3 Land Use Planning Process
Source: (Kelly and Becker 1999)

As seen in Figure 2, the transportation planning process initially involves stakeholders at the federal, state and regional level. The role of state DOTs and local authorities is primarily the development of specific projects or operation of the system. The evolution of the transportation planning process has been occurring since the early part of the twentieth cnetury when federal funds were first made available to states for roadway construction (Gifford 2003). It was the availability of significant federal funds (upwards of 90 percent of total project cost) that had a tremendous impact on the evolution of the transportation planning process since the federal government instituted a number of requirements on state DOTs in order to receive funding under the 1956 Highway Act. As part of this act, Federal regulations required the development of a planning process that resulted in the creation of numerous computer modeling tools to assist planners and engineers forecast system demand and allocate the demand on the roadway network. Many of these tools implemented the traditional four-step planning process which treated land use as an exogenous variable associated with the trip distribution function. Absent from these modeling tools was a close coupling of transportation and land use impacts in part because land use was under the domain of county and city governments while transportation planning involved state and regional planning agencies. Thus, the transportation modeling tools placed a heavy emphasis on the transportation component and little, if any, on the land use component. In the early 1990s, however, the passage of the 1990 CAAA and ISTEA in 1991 created a federal mandate requiring transportation planners to account for land use changes in the traditional transportation planning process. As a result, new emphasis was placed upon the development of more sophisticated modeling tools such that decisions involving land use changes would be endogenous rather than exogenous to the transportation planning process (Meyer and E. Miller 2000, chap. 6).

In contrast to the heavy emphasis upon federal, state and regional participants within the transportation planning process the land use planning process is primarily composed of local participants as is shown in Figure 3. However, the influence of federal regulations is noticeable on land use planning in that these regulations forced regional and state authorities to account for land use as part of the transportation planning process in order to gain access to federal funding for transportation infrastructure (Kain 1990; Pickrell 1992). This influence is most notable with the availability of funding from the Federal Transit Administration (FTA) in the form of matching dollars for the construction of public transportation infrastructure associated with fixed-guideway projects (e.g. heavy rail, light rail and busways)[5] (Pickrell 1992). In order to compete for these funds, local planners were required to demonstrate positive effects to both the transportation system (in terms of increased ridership and reduced congestion) and the land use system (in the form of economic development for depressed neighborhoods). Thus, local planners began developing and using regional and sub-regional planning models that

[5] Schrag also demonstrates this in *The Great Society Subway* documenting the planning, design, and construction of the Washington Metro System. Interestingly, the results of the different approaches taken by Arlington and Fairfax counties are seen today in the intensity and type of development around various MetroRail stations in the respective counties (Schrag 2006).

could account for both transportation and land use impact in order to tap into these funds[6].

While the transportation and land use planning processes are different in terms of key participant involvement, the overall process is quite similar. Both transportation and land use planning include four decision-making categories as described below:

- ***Policy Development***—Policy development often involves exploring potential outcomes in a broad-based manner as a way of screening a large number of alternatives to identify strategies that are worthy of more investigation (DKS Associates and University of California, Irvine 2007). Policy development can occur as part of an organized process or on an ad-hoc basis. For example, an MPO may work with regional governments to analyze the effects of thirty different policy scenarios ranging from improved transit service to mileage-based user fees. The goal is not to understand the effect of any policy in great detail (depth) but rather assesses a great number against each other (breadth).
- ***Visioning***—Visioning (also referred to as scenario planning) is a concerted effort undertaken by the government to engage stakeholders in the planning process in order to elicit feedback regarding various transportation and land use scenarios (Howard/Stein-Hudson Associates, Inc. and Parsons Brinckerhoff Quade and Douglas 1996). Visioning has become a popular means to engage many different stakeholders and is associated with the

[6] As discussed later in this literature review, the overall believability of applying these models to account for land use effects has been heavily criticized. Pickrell (1992) documents the deliberate manipulations made by local planners and politicians in using these models.

qualitative aspects (imagination and creation) of a region's future rather than quantitative aspects (predicting or forecasting) future growth (B. Zhou, Kockelman, and Lemp 2009).

- ***Strategic Analysis***—Strategic analysis includes the identification, consideration, and analysis of alternative transportation systems (e.g., no-build versus light rail transit) or land use policies (e.g., high density versus low density growth). Within the context of transportation planning, strategic analysis is embodied by the FHWA/FTA Environmental Review Process report called an Environmental Impact Statement (EIS) as most recently outlined in SAFETEA-LU. A similar type of formal institutionalized process does not exist within the land use planning domain (U.S. Department of Transportation 2007).
- ***Tactical Assessments***—Tactical assessments are concerned with the design, construction, and operation of a specific project identified within the planning process. In the transportation planning process this is known as the Program Delivery Process where an identified project (e.g., a new replacement bridge) would enter into preliminary engineering, final design, construction, and operation. In land use planning this would be the formal process of a developer requesting the necessary construction permits to begin construction of a building or development.

This discussion of the evolution of the transportation and land use planning processes reveals four key observations. First, the development of the transportation planning process was driven primarily by federal requirements associated with access to significant federal funds. Because the federal government contributed a significant amount of funding to a transportation project, the federal government required a process to compete for the funds. Second, land use planning is the responsibility of municipal and county governments. However, land use planning has evolved in an attempt to integrate transportation planning within the land use planning process as both a formality (e.g. including a transportation section in the comprehensive plan) as well as a financial necessity (e.g. competing for federal transportation funds as part of an economic development revitalization effort associated with a fixed-guideway transit system). Third, the amount and role of participants has continued to increase resulting in decision makers having to account for stakeholder input in a more formalized fashion. Fourth, there are four key decision-making components decision makers must be concerned with: policy development, visioning, strategic analysis, and tactical assessments.

2.2 Policy Tools Driving Metropolitan Planning

Metropolitan planning is driven by the need to develop and implement new policies associated with transportation and land use. This section of the literature review examines three selected policy tools that are driving metropolitan planning today: smart growth, congestion pricing, and corporate average fuel economy (CAFE) standards. Clearly there are numerous other policy tools which are important to metropolitan planning today. However, these three were chosen because they:

1. represent a mix of primarily federal (CAFE standards), state (congestion pricing), and local (smart growth) policy tools, though there is no clear separation among the three policy tools and levels of government;
2. include policies that are traditionally seen as primarily land use (smart growth), transportation (congestion pricing), and neither (CAFE standards);
3. operate over separate temporal scales including time lags (e.g., smart growth policies affecting land use can take much longer to implement than transportation policies); and
4. have traditionally been examined by decision makers as isolated policy tools.

What these three policy tools have in common is that, in reality, they are complex, interrelated policies and affect both the transportation system and land use system, thus they are a driver of metropolitan planning. An overview of each policy is made followed by a discussion of why they are a driver of the metropolitan planning process.

2.2.1 Smart Growth

Smart growth is concerned with the management of land use changes in a community, typically focused upon the integration of the transportation system with the land use system. However, smart growth is a difficult concept to define and often takes on different meanings and perceptions. For example, the Chesapeake Bay Foundation defines smart growth as "…ensuring quality and choice for the growth of our neighborhoods and our economy, by maintaining and revitalizing existing communities, ensuring value from in-place public investment, and minimizing external costs such as congestion, pollution, and degradation of natural habitats" (Jantz, Goetz, and Shelley

2004). In contrast, Ewing et al. and Galster et al. define smart growth primarily as not being sprawl and articulate ten categories of comparison including density, growth pattern, scale, public services, transport, connectivity, street design, planning process, and public spaces (Ewing et al. 1996; Galster et al. 2001).

Defining the elements of smart growth is an example of what Schneider and Ingram call Degenerative Policy Design where policy making is characterized by two aspects: 1) how issues are framed and 2) patterns of interactions among policy makers (Schneider and Ingram 1997). Using smart growth initiatives as an example of Degenerative Policy Design, one could identify two significant groups who are framing the issues: critics of current land use policy (smart growth) and advocates of current land use policy (metropolitan structure)[7]. Figure 4 summarizes four key issues and places the smart growth and metropolitan structure advocates on separate ends of what is called the Land Use Framing Issues Spectrum.

[7] There is no consensus on how to label the opposing view of smart growth. Labeling it *dumb growth* would be pejorative. However, the notion that the opposite of smart growth is sprawl is not apparent. Thus, the non-pejorative term *metropolitan structure* is used here taken from Bogart (2006).(Bogart 2006)

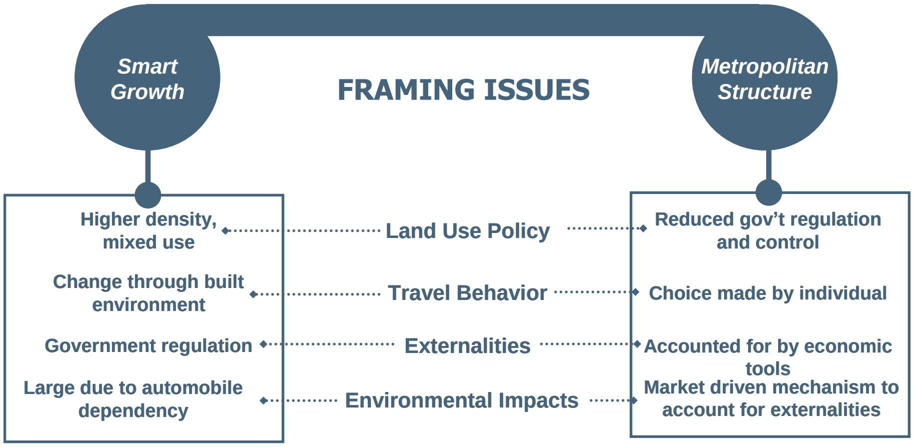

Figure 4 Land Use Framing Issues Spectrum
Source: Author's Assessment

On the left end of the spectrum are the smart growth advocates who generally call for wholesale change in land use policy that will improve transportation options for people (essentially changing travel behavior) by creating high density, mixed-use developments such as neo-traditional neighborhood developments, new urbanist communities and transit oriented developments (Litman 2000). The assumptions made by smart growth advocates are that by changing the built environment, one can influence the choices people make regarding travel behavior. Thus, changing land use directly impacts the transportation infrastructure in fundamental ways.

On the right side of the spectrum are metropolitan structure advocates who, in general, desire less government intervention and a stronger role for economic markets in dictating land use and development (Bogart 2006). Metropolitan structure advocates emphasize the choice that individual's have in where they live that is provided by the private market. Individual's can choose among many different options including high density development, low density suburban development, etc. And, the travel behavior they choose (car, bus, train, etc.) is a personal decision based upon economic conditions. According to this group, the presence of social ills (including traffic congestion, global warming and health issues) can be mitigated by taking into account the externalities of their decisions. For example, to alleviate traffic congestion, user fees can be instituted on highly congested roadways to provide incentives for drivers to change travel behaviors.

Smart growth is a current policy tool for metropolitan planning by its very nature since smart growth deals with both land use and transportation. There are three additional reasons why it is driving metropolitan planning today:

- ***Role of Transit*—**As discussed above defining smart growth is difficult. Thus, one of the issues associated with smart growth is how it is defined and what is included in that definition. For example, Cervero argues that smart growth should be centered on transit oriented development (TOD) where multi-modal options other than the personal automobile are available (Cervero 1998). Often, TOD is associated with rail-based transit since the research implies these systems can handle higher density development. For example, Jantz et al. in their analysis of land use change in the Metropolitan Washington DC region, examined the impact of smart growth policies and only included new and existing rail stations as a marker for smart growth rather than including all transit modes. This relegated the vast majority of the region to not being able to support smart growth principles since a relatively low percentage of the area is accessible by way of rail transit stations (Jantz, Goetz, and Shelley 2004).

- ***Suburbanization*****—**A question that has been raised is whether smart growth can occur in newly developed areas (greenfields) or only occur as part of a redevelopment effort (brownfields) (Filion and McSpurren 2007). This is an interesting question as to whether or not one effect of smart growth principles is further supporting suburbanization rather than reducing it for locations outside of a traditional urban core. For example, Loudoun County is currently planning for a high density, mixed use development at the last station of the extension of MetroRail to Dulles Airport in the county. While the development immediately surrounding the station will most likely incorporate smart growth principles established by Ewing, the overall impact may be additional suburbanization further out from the station as leap-frog development may occur. However, increased densification in existing neighborhoods already accessible by transit is less likely to contribute to development in greenfields.
- ***Social Equity*****—**An increasing concern associated with smart growth principles is that of social equity. Litman identifies equity impacts as one reason to implement smart growth policies since, in general, they increase accessibility to all rather than only those who own automobiles (Litman 2000)[8]. However, negative effects on social equity are also a concern of smart growth policies since they can ultimately drive up housing prices as part of urban redevelopment and gentrification. Thus, smart growth policies intended to spur new development in an economically depressed area may ultimately drive lower-income and older

[8] Self published research.

residents out of that neighborhood. This unintended consequence of smart growth has led housing advocates to suggest that higher density or redevelopment of an area is not necessarily good and policies should be in place to mitigate these unintended consequences (Wilson 2005).

2.2.2 Congestion Pricing

Congestion pricing is designed to reduce traffic congestion (what Pigou called externalities) by charging users a higher fee when roads are busier and a lower fee when they are not thus allocating finite resources (roadway capacity in the short term) in an efficient manner (Viegas 2001). In other words, congestion pricing mitigates the effects of too much demand on the roadway infrastructure and ensures efficient system utilization. Congestion pricing can also serve two other purposes: identifying areas needing increased capacity and acting as a funding mechanism (Viegas 2001).

Congestion pricing is not a new economic concept or theory, having first been introduced into the economics literature by Pigou in 1920 and Knight in 1924 (Viegas 2001). Since that time, most transportation economists agree that congestion pricing is an efficient method to allocate limited roadway capacity (Rouwendal and Verhoef 2006). Given the amount of research exploring the theory, an important question becomes why has the concept not taken hold in the U.S.? Two primary reasons can be articulated: technical feasibility and political acceptability (Giuliano 1994). When congestion pricing was first proposed by Pigou in 1920, one of the largest barriers to implementation was technical feasibility, but with the rapid deployment of open-road tolling technologies and the emergence of the U.S DOT connected vehicles program (formally called

IntelliDrive), the technical limitations have mostly been addressed. Concerning the political acceptability, congestion pricing requires elected officials and leaders to reexamine the method in which transportation infrastructure is funded and what is considered fair regarding use of the infrastructure (Giuliano 1994). It is this latter concern, fairness or equity, which has been the Achilles Heel of many congestion pricing projects recently planned in the U.S.

The prominence of congestion pricing programs has increased in the U.S. in recent years for two reasons. First, the amount of traffic on U.S. highways has steadily increased since data were first collected. Second, local and state governments, disappointed with available funding of transportation infrastructure, see congestion pricing as a means to collect revenue with which to maintain existing and construct new infrastructure. Thus, congestion pricing has become an important driver of metropolitan planning as leaders at the local and regional level develop new transportation policies to add roadway capacity and mitigate the effects of too much demand. There are three additional reasons why congestion pricing is driving metropolitan planning:

- ***System Rehabilitation and Renewal***—The appeal of implementing congestion pricing is that the policy can raise enough revenue to cover the cost of constructing new infrastructure and adding system capacity. Or, it can be priced higher to capture the costs of the negative externalities associated with driving such that a new revenue stream is made available to the local government and can complement, or be used in lieu of, existing taxes (Viegas 2001). More specifically user fees can be built into a congestion pricing scheme as a minimum cost that all drivers must pay to account for the costs of pollution and other negative externalities of driving.

- ***Suburbanization***—Wunderlich et al. discuss the possibility of constructing a network of congestion-priced roadway facilities such that a travel time guarantee can be made for any user of the system (Wunderlich, Roberts, and McGurrin 2007). The effect of this guarantee could be a reinforcement of suburbanization as people live further away from their work yet purchase a reliable travel time through the congestion pricing system. Or, this could suggest that time savings are undervalued by the pricing mechanism. While there is currently limited evidence to support this argument, this effect was demonstrated in the Northern Virginia region where users of the I-95/I-395 HOV lanes were able to purchase a hybrid vehicle and use it on the HOV lanes as a single occupant driver. They essentially "purchased" a reliable travel time via a hybrid vehicle, though it was not guaranteed (Shewmake and Jarvis 2009).
- ***Social Equity***—A growing concern of congestion pricing systems is that of social equity. Concerns center on the effect that congestion pricing may have on lower-income groups (Viegas 2001). The economics literature suggests that these concerns can be mitigated somewhat because all income groups could conceivably benefit from congestion pricing depending on how the revenues generated are used[9]. As a means to make congestion pricing politically

[9] For a more detailed discussion see Littman (2006), Small (2002), Weinstein and Sciara (2006), and Viegas (2001)

acceptable, equity is often addressed by ensuring that alternative modes such as transit are made available to users. However, this author concludes that, for congestion pricing projects in the U.S., while transit agencies *have* been included as important players in the projects they *have not* benefited in any direct way in terms of new infrastructure, service, or funding (Hardy 2009).

2.2.3 CAFE Standards

CAFE standards dictate the average fuel economy of an auto manufacturer's vehicle flee and are one major aspect of current U.S. energy policy is reducing the consumption of and reliance on gasoline. Energy policy was first brought to the forefront of U.S. policy debate during the oil embargos of the 1970's which focused public attention on the issue of vehicle fuel efficiency. During the OPEC oil embargo, the price of gasoline fluctuated between 72 cents a gallon in 1973 and $2.04 in 1981 and back to $1.20 in 1985 (2005 dollars) (Howitt and Altshuler 1999). CAFE standards were first enacted by Congress as part of the Energy Policy and Conservation Act of 1975 and were meant to address America's dependence on foreign oil. The CAFE standards dictated that the average fuel economy for a corporation's fleet of passenger cars (number of vehicles sold in one year as a function of weighted sales) increase from an average of 14 miles per gallon (mpg) in 1974 to 27.5 mpg in 1985 (CBO 2003). A separate CAFE standard for light trucks (and SUVs) was set at 20.7 mpg. More recently, the impact of hurricanes Katrina and Rita in 2005, the spike in gasoline prices during Summer 2008, and the political unrest in the Middle East in 2011 has refocused attention on U.S. dependence on foreign oil.

Congress had considered revising CAFE standards for some time. In his 2007 State of the Union Address, President George W. Bush proposed decreasing U.S. dependence on foreign oil by setting a goal of reducing U.S. gasoline usage by 20 percent in the next ten years through a combination of renewable and alternative fuels as well as reforming and modernizing the CAFE standards (Bush 2007). In addition, Congress had proposed legislation that would increase the standard by roughly 50 percent (Yacobucci and Bamberger 2007). In 2007, Congress passed, and the president signed, the Energy Independence and Security Act of 2007, which increased the CAFE standard by roughly 40 percent to 35 mpg for all passenger cars by 2020.

There is some debate as to the effectiveness of CAFE standards, with most of the debate centered on policy objectives outside the narrow issue of fuel economy. Opponents of the original CAFE standards legislation argued that the target of 27.5 mpg was an artificial mark and that if left unregulated, the market could have developed even more fuel efficient vehicles or alternative fuel vehicles (Coon 2001). Thus, these policy experts argue that the CAFE standards policy had a negative impact on the fuel economy of automobiles and was a poor policy tool because it did not take economic or market forces into account.

While local governments do not directly control CAFE standards, the effect of these policies are felt at the local level and have become an important driver in metropolitan planning. For example, certainly raising CAFE standards can increase the fuel efficiency of vehicles; however, it is not certain how consumers will respond in the marketplace at the local level. According to Gillinghand, there is a ‘rebound effect’ associated with CAFE standards where increased fuel efficiency without a commensurate rise in the cost of gasoline has enabled consumers to drive more at the same relative cost (Gillinghanm 2009). Thus, two key issues can be identified as to why CAFE standards are a current driver of metropolitan planning:

- ***Suburbanization***—A combination of weak CAFE standards and the relatively cheap cost of gas partially contributed to the rise of suburbanization in major cities throughout the U.S. (Portney et al. 2003). For example, the increased fuel efficiency of vehicles enabled drivers to consume the same amount of gas but have longer commutes to work (Gillinghanm 2009). Since CAFE standards did not account for the environmental and economic externalities associated with driving (environmental damage and congestion) consumers were able to spend the same cost on driving while owning a home further out.
- ***System Rehabilitation and Renewal***—Currently, transportation infrastructure is primarily funded through the motor fuel tax levied by the federal, state, and local government. Historically, vehicle miles driven have outpaced the increase in fuel efficiency, thus motor fuel revenues have not decreased, but rather increased ((Downs 2004). However, a significant increase in CAFE standards may have a negative impact on gas tax revenues at both the Federal and State level. A Congressional Budget Office (CBO) study indicated that the least expensive method to reduce gasoline consumption by 10 percent would be through a gas tax increase and not higher CAFE standards (CBO 2003). To some extent, the policy

goal of raising fuel efficiency is in conflict with the goal of sustaining transportation funding.

2.3 INTEGRATED TRANSPORTATION AND LAND USE MODELING TOOLS

An important element in the metropolitan planning process is the ability to analyze the effect of various policy tools in an integrated fashion. Thus, the purpose of this component of the literature review is to focus attention on the practical application of computer modeling tools to support decision-making within the metropolitan planning process by specifically examining the development, evolution, and application of integrated transportation/land use modeling (ITLUM) tools.

2.3.1 Development and Evolution of ITLUM Tools

Each of the four decision-making categories identified in the previous section on Metropolitan Planning (policy development, visioning, strategic analysis, tactical assessments) typically involve some type of analysis or assessment to provide a decision maker at the federal, state, or local level with information in order to make a decision regarding the implementation of a policy tool. In order to assist the decision maker some type of modeling tool is often used. Within the transportation planning process this is normally conducted as part of the Strategic Analysis where a number of different alternatives are identified and evaluated. As a result, an entire set of transportation forecasting modeling tools has been developed which date back to the 1950s and are primarily based upon the four-step planning process (Iacono, Levinson, and El-Geneidy 2008). Subsequently, an entire industry has grown up around the care and use of these models. Today, every federally designated metropolitan planning organization employs some type of transportation forecasting model. The land use planning process, however, is not as well-established in terms of tool development or application. As of 1995 (the most recently available data), only 12 of the 35 largest metropolitan areas were using commercially available land-use models (C. Porter, Melendy, and Deakin 1995).

Wachs describes modeling tools as having two roles within metropolitan planning: practical and intellectual: *practical* in the sense that computer modeling tools provide decision makers with quantitative assessments of policy effects that can be used to support decision-making; and *intellectual* in the sense that the modeling tool enables a scientist and analyst to better understand and explain complex systems (Wachs 1998). The development and evolution of ITLUM tools to support metropolitan planning has been ongoing since Von Thünen first proposed a model of the transportation-land use connection. At that time, the tool he created was a simple mathematical representation between rents, land use and transportation costs relative to a city center (Sinclair 1967). Today, there are many modeling tools available to assess the transportation-land use connection. The most recent academic review of ITLUM tools includes 18 operational models available to researchers, analysts, and practitioners that combine elements of transportation and land into a single integrated tool (Iacono, Levinson, and El-Geneidy 2008).

It is important to understand what is meant by an "integrated" tool since most transportation models include a land use variable and most land use models include a transportation variable. Martinez provides a framework of the transportation-land use connection consisting of a growth model, land use model (including location, land use and rents), and a transportation model (consisting of the four-step planning process) (Martinez 2007). Each of these modeling groups has well-established theoretical underpinnings developed in isolation from the other two modeling groups. For example, transportation models arguably are the most developed of the three model groups whereby numerous tools are available to support the transportation planning process[10]. Transportation models used for demand forecasting are rooted in the four-step planning process whereby trip generation (step one) is based upon exogenous land use variables.

Non-integrated models do not utilize an inherent feedback loop between the various sub-models (Martinez 2007). This approach is represented in Figure 5 where outputs from the growth model are used as inputs for the land use model and outputs from the land use model are used as inputs to the transportation model and can be represented as sequential or iterative. Miller suggests that an integrated transportation-land use model is one in which transportation is a derived variable within the land use model (referred to as the urban activity system) as well as the transportation system influencing overall land development and location choice (E. Miller 2003). In other words, an integrated transportation-land use model is one where transportation and land use effects are derived endogenously within the model. This approach is represented in Figure 6.

[10] For a review of transportation modeling tools see (Martinez 2007).

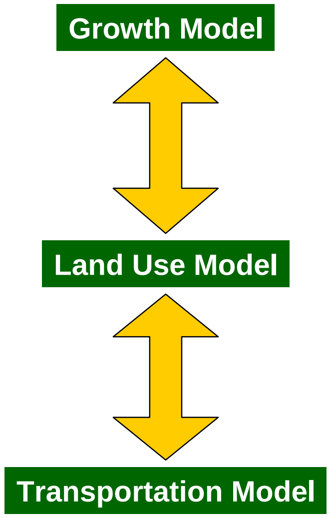

Figure 5 Iterative Metropolitan Planning

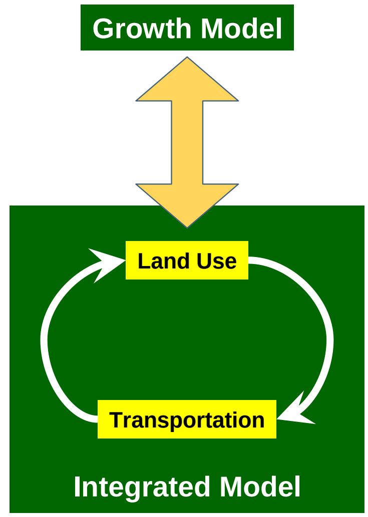

Figure 6 Integrated Metropolitan Planning

Compared with transportation modeling tools, ITLUM tools to support decision making in the metropolitan planning process are not readily available. The development of ITLUM tools began in the 1970s by Putnam and then accelerated with the passage of the 1990 CAAA and ISTEA in 1991 requiring regional and state transportation planning organizations to take into account land use effects within the existing transportation planning process[11] (Kain 1990; Putnam 1983). Regional planning bodies initially linked existing land use models into an already well-established and complex transportation planning process. The linking of models, as depicted in Figure 5, resulted in an iterative planning process whereby the three models were run separately with outputs from a particular model acting as exogenous inputs for other models.

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[11] It is important to note that the burden was placed upon transportation planners to improve existing regional travel demand models rather than create new ITLUM tools. As will be discussed later, this created implications later on in the development of competing ITLUM tools which support different components of the metropolitan planning process.

This approach, however, was not sufficient as explained by Garrett and Wachs who document the complex legal maze that the Metropolitan Transportation Commission (MTC)[12] found itself in when trying to comply with the 1990 CAAA and 1991 ISTEA legislation (Garrett and Wachs 1996). Garrett and Wachs demonstrate how the historical transportation planning process became a much more complex decision-making process involving the integration of transportation *and* land use decisions that had to be supported using outdated tools and methodologies involving a new set of stakeholder groups. In the end, the court upheld a lawsuit against the MTC that required the agency to develop better models and modeling techniques in order to account for regional impacts (including land use changes) due to transportation improvements (Garrett and Wachs 1996). Essentially, the courts encouraged regional and state transportation planning agencies to develop integrated tools as shown in Figure 6.

The ruling against the MTC had a major impact on the transportation planning community and highlighted the need to develop ITLUM tools to better support the decision-making process (Garrett and Wachs 1996). The result has been an evolution of ITLUM tools that now include a multimodal activity-based transport model integrated with an activity-based land use model (Wegener 2004). Examples of these tools include TRANSIMS and UrbanSim which have been funded in large part by the U.S. Department of Transportation[13]. These large-scale ITLUM tools represent a concerted effort to develop models able to represent transportation and land use activity on the smallest scale

[12] The MTC is the federally designated transportation planning body for the San Francisco Bay region charged with conducting regional transportation planning.
[13] TRANSIMS and UrbanSim are microscopic simulation models that are described in more detail later in this section.

possible—either as an individual person (TRANSIMS) or an individual parcel of land (UrbanSim).

The application of large-scale modeling tools such as TRANSIMS and UrbanSim brings up a historical debate on their use as part of the decision-making process. In 1973, Lee professed the eventual disappearance of large-scale urban models because of "seven deadly sins" including hypercomprehensiveness, grossness, data hungriness, wrongheadedness, complicatedness, mechanicalness, and expensiveness (Lee, Jr. 1973). Today, much of the debate surrounding the use of large-scale regional models (including ITLUM tools) centers on criticizing the overall usefulness of such tools that are so complex in nature that they are expensive to run (expensiveness), difficult to use (complicatedness), and unable to represent reality (wrongheadedness) (Rabino 2007).

Critics of large-scale regional models point to the historic mis-use of these tools during the 1970s and 1980s as part of the planning for rail systems in U.S. cities and the manipulation of the models in such a way as to provide erroneous results that only catered to political needs (Kain 1990). Pickrell provides a succinct analysis of this phenomenon in showing how regional planning models significantly overestimated ridership forecasts and underestimated capital costs (Pickrell 1992). The results of these large-scale urban models were used to justify spending billions of dollars on heavy- and light-rail transit systems in the U.S. for the purpose of economic development. Subsequent analysis however, does indicate a slight improvement in ridership forecasting but a continued tendency to overestimate benefits (ridership) and underestimate costs (capital and operating/maintenance) (Hardy et al. 2008). In developing discrete choice models, McFadden demonstrated the inaccuracies of the regional demand models used for the planning of the Bay Area Rapid Transit (BART) system in the San Francisco Bay Area. The regional demand model forecasted 15 percent demand in the transit system while McFadden predicted 6.3 percent. In an analysis of actual demand, the real number was 6.2 percent (McFadden 1974).

Nearly twenty years after the passage of ISTEA and the ruling against the MTC, there appears to be a revival in the development and adoption of using large-scale urban models as changes in society, technological advances, and improvements in data collection have all but forgiven Lees' seven deadly sins (Rabino 2007). Proponents of using large-scale regional models point to how these models have improved over time in forecasting ridership since Pickrell published his work (Hardy, Doh, Yuan, X. Zhou, and Button 2008). In addition, as seen in Table 1, there is evidence to suggest that the development and adoption of ITLUM tools is strong and that a substantial amount of effort is being poured into the research and development of ITLUM tools.

Table 1 Summary of ITLUM Tool Research Studies

Year	Authors	Title	Tools Reviewed in the Article
2008	Iacono, Levinson, and El-Geneidy	*Models of Transportation and Land Use Change: A Guide to the Territory*	18
2007	Allen, Strathern, and Baldwin	*Complexity: the Integrating Framework for Models of Urban and Regional Systems*	11
2007	Fehr & Peers	*An Assessment of Integrated Land Use/Transportation Models*	12
2007	FHWA	*Metropolitan Travel Forecasting: Current Practice and Future Direction*	6
2006	Chang	*Models of the Relationship between Transport and Land-use: A Review*	9
2005	Hunt, Kriger, and Miller	*Current operational urban land-use-transport modeling frameworks: A review*	15
2005	Klosterman and Pettit	*An Update on Planning Support Systems*	5
2004	Waddell and Ulfarsson	*Introduction to Urban Simulation: Design and Development of Operational Models*	4
2004	Wegener	*Overview of Land Use Transport Models*	20
2000	Meyer and Miller	*Urban Transportation Planning*	5
1998	Miller, Kriger, and Hunt	*Integrated Urban Models for Simulation of Transit and Land Use Policies: Guidelines for Implementation and Use*	6
1995	Southworth	*A Technical Review of Urban Land Use--Transportation Models as Tools for Evaluating Vehicle Travel Reduction Strategies*	13
1994	Wegener	*Operational urban models*	20

2.3.2 Operational ITLUM Tools

The most recent review of ITLUM tools includes a discussion of 18 operational tools and suggests that no tool is sufficient for supporting all of the necessary decisions associated with the metropolitan planning process because of the complex nature of the decision-making process (Iacono, Levinson, and El-Geneidy 2008). Parker et al. and Sussman et al. support this argument and note that the complexity of the systems being modeled coupled with the decisions that need to be made warrant the development and use of a wide range of models rather than a specific few (Parker et al. 2003; Sussman, Sgouridis, and Ward 2005). For purposes of this discussion a detailed review of all available ITLUM tools is not prudent; however, identifying a range of available ITLUM tools that support the metropolitan planning process is important. Thus, a discussion of a representative sample of *operational* ITLUM tools is provided. Operational is defined as the following (E. Miller, Kriger, and Hunt 1998):

1. Commercially Available—Widely accessible tools available for a license fee, freely available via open source arrangements, and academic-based research models.
2. Established History and Use—The tool has been used by planners over time and has been documented.
3. Applied in a *practical* setting—The tool has been used by planning or transportation agencies to support the metropolitan planning process (preferably U.S agencies).

Based upon the review of the thirteen ITLUM tool research studies presented in Table 1, four ITLUM tools were identified to be further reviewed as part of this research. In addition, a review of current literature pointed to the addition of a fifth tool not included in previous research studies. The five tools include the Metropolitan Activity Relocation System (MARS), TRANUS, Transportation Economic and Land Use Model (TELUM), UrbanSim, and TRANSIMS.

- ***Metropolitan Activity Relocation System (MARS)***—MARS is a system dynamics-based ITLUM tool and includes a land use and transportation sub-model that operate simultaneously to determine key measures such as user benefits, operator costs, investment costs, etc. based upon various scenarios and policy instruments to be analyzed (Pfaffenbichler 2008). MARS is designed to analyze strategic-level policy decisions on an aggregate basis. However, it does include the functionality to assess spatial impacts for a given policy instrument at smaller spatial areas such as corridors or sub-regions within a larger regional MARS model. MARS operates over a thirty-year time horizon using one year time increments.
- ***Transportation, Economic and Land Use Model (TELUM)***—TELUM is a derivative of the Integrated Transportation and Land Use Package (ITLUP) first developed by Stephen Putnam for the Federal Highway Administration in 1971 (Fehr & Peers 2007). TELUM is an example of a Lowry gravity model (spatial interaction) and includes three separate models to make predictions including the Disaggregate Residential Allocation Model (DRAM), an Employment Allocation

Model (EMPAL), and a standard travel demand model. These three models are used to project the location of new residential and nonresidential development for various user-defined analysis zones based upon an analysis of prior as well as existing residential and nonresidential development, the location of transportation infrastructure and improvements, and overall congestion within the roadway system.

- ***TRANUS***—TRANUS is a commercially available ITLUM model that incorporates four components of the urban system: land use, human activity, real estate market and transportation systems into an integrated model such that policy analyses can be conducted ranging from urban development plans to travel demand management. The basis on which TRANUS is built includes econometrics (e.g., McFadden), spatial interaction models (gravity and entropy land use models), regional economic development (input-output theory), and various transport model theories including the four step planning process and activity-based modeling.
- ***UrbanSim***—UrbanSim is described as an urban simulation system that includes a suite of models used to determine the effects of various land use policy scenarios on the urban system at large (Waddell 2002). UrbanSim was created to specifically address decision makers having to support complex decisions associated with land use-transportation interactions. Seven individual models create the core of UrbanSim including accessibility; economic and demographic transition, mobility, location choice, real estate development, land price and

export. These seven models are run sequentially for each simulation year. UrbanSim incorporates econometrics (discrete choice theory originally developed for transportation mode choice selection) to determine broad categories of land use changes, population distribution, household/business types, densities, and land prices. UrbanSim is primarily a cellular automata microsimulation model operating on 150 meter grid cells with a time-step of one year[14]. Currently, UrbanSim is an open source program available to anyone who wishes to download and apply it to a metropolitan region. The program was originally developed under sponsorship of the Oregon Department of Transportation to support regional metropolitan land use planning with the intent that it could be easily integrated with existing transportation planning models.

- ***Transportation Analysis and Simulation System (TRANSIMS)***—TRANSIMS incorporates a suite of five integral modules designed to provide transportation planners with detailed information on traffic impacts, congestion levels, and pollution from vehicles (Waddell and G. Ulfarsson 2004; Meyer and E. Miller 2000). These five modules represent the traditional four-step transportation planning process and include a population synthesizer (trip generation), activity generator (trip distribution), route planner (mode choice) and traffic microsimulator (route assignment). The fifth module, emissions estimator, is not original to the four-step process but has been incorporated into the transportation

[14] Cellular automata models simulate systems which are discrete in space and time. For example, UrbanSim uses a 150 square meter cell and a one-year time steps.

planning process since the 1980s. What makes TRANSIMS unique from the four-step process is the way it operates using a 7.5 m^2 grid cell on which individual vehicles and people operate. Also, TRANSIMS includes an integrated land use model representation to account for land use changes. Finally, TRANSIMS operates over a consistent temporal scale of one second increments. Thus, TRANSIMS represents the first agent-based cellular automata model developed for transportation planning. In other words, TRANSIM models the transportation system at the highest level of granularity: an individual (or the agent) using the land use system (cellular automata model). Similarly to UrbanSim, TRANSIMS is an open source program and is freely available to anyone who wishes to download and run the program. TRANSIMS was born out of the ISTEA legislation and is supported through the TMIP program at FHWA.

Table 2 provides a summary of the five ITLUM tools and includes documented locations where the tool has been applied (Applications), which approaches it incorporates (Approach), the purpose of the tool in terms of the four decision-making categories (Purpose), the spatial scale on which the tools operates (Spatial Scale), and the temporal scale of the tool (Temporal Scale). The last four columns in Table 2 provide an assessment made by the author as to the requirements of each tool in terms of data, resource availability, functionality, and expertise required. The table was developed from a literature review of the models and assessed by the author of this research.

Table 2 Summary of Operational ITLUM Tools

Tool	Applications	Approach	Purpose	Spatial Scale	Temporal Scale	Data[a]	Resource Availability[b]	Function-ality[c]	Expertise[d]
MARS	▪ Leeds, England ▪ Madrid, Spain ▪ Vietnam	Hybrid System Dynamics	▪ Policy Development ▪ Visioning	Aggregate	1 year time step	Low	Low	Medium	Medium
TELUM	▪ 50+ planning organizations in the U.S.	Spatial Interaction	▪ Policy Development ▪ Strategic Analysis	Disaggregate	5 year time step	Medium	Medium	Low	Medium
TRANUS	▪ Sacramento, CA ▪ Baltimore, MD ▪ State of Oregon	Hybrid Microsimulation	▪ Strategic Analysis	Disaggregate	1 year time step	Medium	Medium	Medium	High
UrbanSim	▪ Eugene-Springfield, OR ▪ Portland, OR ▪ State of Utah ▪ Oahu, HI	Hybrid Microsimulation *Cellular Automata*	▪ Policy Development ▪ Strategic Analysis	Disaggregate 150 m^2 grid	1 year time step	High	High	High	High
TRANSIMS	▪ Portland, OR ▪ Dallas, TX	Hybrid Microsimulation *Cellular Automata* *Agent-based*	▪ Strategic Analysis	Disaggregate 7.5 m^2 grid	1 second time step	High	High	High	High

Source: Author's evaluation.
[a] *Data describes the amount of inputs needed to populate the model in order for it to run.*
[b] *Resource Availability describes the amount of money and time required to build and run the model.*
[c] *Functionality describes the number of measures the modeling tool is able to calculate.*
[d] *Expertise describes the necessary understanding by an analyst to build and run the model.*

As seen in Table 2, the ITLUM tools have been used in a number of application settings to support a variety of decision-making categories. TELUM is the most widely used while TRANSIMS has been successfully applied in only two locations[15]. Four of the tools (excluding TELUM) use a hybrid approach incorporating elements of both spatial interaction and econometric approaches. MARS is based upon a system dynamics approach which has not been seriously addressed in recent research studies on ITLUM tools (Mostashari and Sussman 2005). Also, four of the tools (excluding MARS) are used to support strategic analysis as part of the metropolitan planning decision-making process. This fact is interesting because these four models also operate on a disaggregate spatial scale whereas MARS does not. Three of the tools are used for policy development and only one (MARS) is used for visioning. Four of the tools (excluding TRANSIMS) operate on some type of yearly temporal scale. TRANSIMS, however, operates on a one second time step which is indicative of its history rooted in transportation modeling which attempts to model vehicular movement to the smallest time-step possible. In contrast, UrbanSim was developed primarily to model land use changes which occur more slowly over time (once a year).

As discussed by Miller et al. the requirements associated with an ITLUM tool (data, resource availability, functionality, and expertise) will play a significant role in how it is used as part of the metropolitan planning process (E. Miller, Kriger, and Hunt 1998). While Miller et al. do not indicate specific requirement categories in their discussion of operational ITLUM tools, the four categories identified for purposes of this

[15] TRANSIMS is being heavily supported by the U.S. DOT in the form of research grants to many different University Transportation Research Centers in order to develop TRANSIMS model applications.

research are useful in locating the five tools on a spectrum from simple to complex. Thus, the last four columns indicate the degree of requirements for each category based upon a qualitative ranking of low, medium or high. The five tools are representative of a modeling spectrum representing simple tools on the left and complex tools on the right. Simpler tools require less data, resources, and expertise to run but also have less functionality whereas complex tools are data-hungry, require more resources and expertise to run but also include a larger amount of functionality. In other words, a simpler tool may require less in terms of data, resources, and expertise but also has less functionality in terms of the measures it is able to calculate, the accuracy of the results, or the ability to represent the real-world systems. The five ITLUM tools included in this analysis span this entire spectrum beginning with the MARS model on the simple end and the UrbanSim and TRANSIMS models on the complex end.

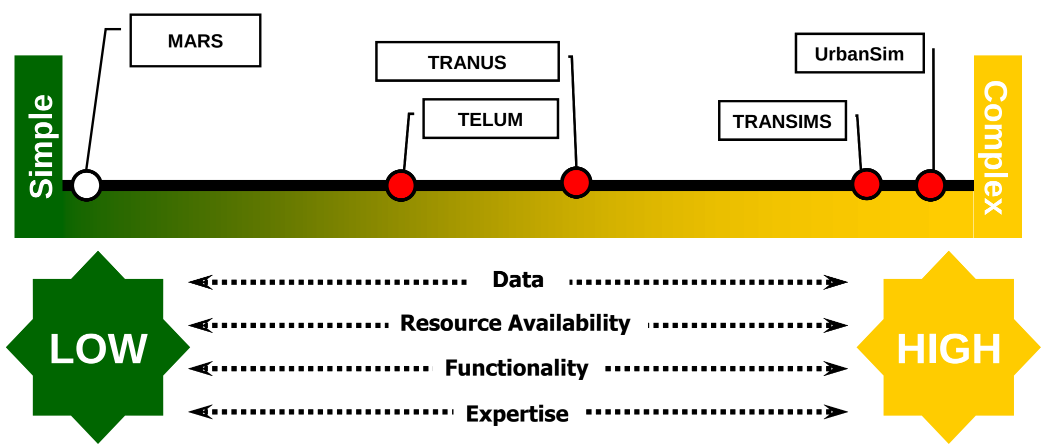

Figure 7 ITLUM Tool Spectrum and Requirements
Source: (Hardy, Larkin, Wunderlich, and Nedzesky 2007)

Figure 7 show that the use of an ITLUM tool must strike a balance among four modeling requirements: data, functionality, expertise, and resources. Not all decisions associated with the metropolitan planning process require the most powerful and technologically advanced ITLUM tool. Nor can the simplest of tools address all of the complex decisions that have to be made. Thus, a spectrum of tools is appropriate in order to support a range of decisions that have to be made as part of the metropolitan planning process. While many resources have been devoted to the development of more complex ITLUM tools (e.g., UrbanSim and TRANSIMS) less attention has focused on simpler modeling approaches.

Meyer and Miller as well as Wegener portray the evolution of ITLUM tools to model more complicated transportation behaviors (multimodal/activity-based) coupled with a complex activity-based land use model using microsimulation (Meyer and E. Miller 2000; Wegener 1994). Clearly a tool that can model the real world as accurately as possible is an improvement. However, the assumption that the increasing computing power will enable this to occur does not account for the still present technical barriers (calibrating, validating, and verifying a model) as well as the institutional barriers (availability of data, resources, and expertise) (Rabino 2007; Lee, Jr. 1973). In contrast to the assertions of Meyer and Miller and Wegener is the work of Sussman et al. who articulate a need for a range of models to be used to support the metropolitan planning process. Sussman et al. describe the availability of modeling tools akin to a Christmas tree where the tree itself represents the metropolitan planning process with the individual ornaments hanging on the tree representing the available modeling approaches used to support decision-making (Sussman, Sgouridis, and Ward 2005). Thus, efforts should not be concentrated on developing ITLUM tools that are broad enough to cover all aspects of the planning process ("one-size-fits-all mentality"), but rather developed based upon specific identifiable needs and applications.

2.3.3 Application of ITLUM Tools

No previous surveys regarding the application and use of ITLUM tools by state DOTs or MPOs have been conducted. However, two recently conducted surveys by the Transportation Research Board and the U.S. Government Accountability Office (GAO) have been conducted relating to the application of travel demand models, an important component of ITLUM tools: *Determination of the State of the Practice in Metropolitan Area Travel Forecasting* and *Metropolitan Planning Organization: Options Exist to Enhance Transportation Planning Capacity and Federal Oversight*, respectively. The first was conducted on behalf of the Transportation Research Board, the Committee for the Determination of the State of Practice in Metropolitan Area Travel Forecasting (B0090) (Vanasse Hangen Brustlin, Inc. 2007). The study was requested by the United States Department of Transportation Office of the Secretary, Federal Highway Administration, and Federal Transit Administration. The purpose of the project was to gather information and determine the state of the practice for metropolitan area travel demand modeling by metropolitan planning organizations (MPOs) and state departments of transportation (DOTs).

One critical component of this research was a national survey of MPO modeling practices concerning best practice, state-of-the art, and exceptional practices in travel demand modeling. The survey included more than 90 questions and had responses from 60 percent of the 381 MPOs in the U.S.. The survey categorized MPOs by three different sizes: small (population less than 200,000), medium (population between 200,000 and 1 million) and large (population greater than 1 million). While the focus of the survey was on travel demand modeling (e.g., the traditional four-step process), there were questions concerning integrating the travel demand model with a land use model. Many MPO's responded that *accurate land use data* was one of the best features of their model; however, the *land use forecasting* of their model was the worst feature. In other words, the MPOs had good data but poor analytical capabilities with which to analyze the data.

The second survey was conducted by the GAO at the request of U.S. Senate Committee on Environment and Public Works. The survey was disseminated to all 381 MPOs in the Unites States with an 86 percent response rate. Responses were categorized in the same three categories as the TRB survey (U.S. Government Accountability Office 2009). In similar fashion to the TRB survey, the GAO survey documented a current "state-of-practice" of MPOs related to transportation modeling. In addition, the survey asked respondents to rate their perception and opinion of the use and application of not only travel demand models, but land use models as well. The GAO survey came to the conclusion that MPOs are faced with three primary challenges related to transportation planning: a) funding and staffing, b) authority, and c) technical capacity (U.S. Government Accountability Office 2009).

Both surveys are useful as a means to inform this research. The TRB *State of the Practice in Metropolitan Area Travel Forecasting* report provides a good catalog of current practices in travel demand modeling. However, the survey did not address questions regarding the use or application of the travel demand model within the larger context of metropolitan planning decision-making. As discussed previously, there are strict requirements placed upon state DOTs and MPOs in the use and application of travel demand models as they relate to obtaining federal funding, air quality analysis, etc. While many of the survey respondents were using travel demand models because of federal and/or state requirements, the survey did not address how the models are being used for any other decision-making purpose. In addition, the survey did not include state DOTs as one of the respondents.

Regarding the GAO survey, of importance to this research are Questions 20, 21, and 22 that focused on, respectively, the use of land-use scenario planning models, plans by the MPO to use or enhance a land-use scenario planning model in conjunction with their travel demand model, and the challenges associated with nine separate factors associated with meeting the travel demand modeling needs of their region. Currently, only 26 percent of all MPOs use a land-use scenario planning model in conjunction with their travel demand model. However, 86 percent plan to use or enhance a land-use scenario planning model in the future. Given that most planners understand the symbiotic relationship between the transportation and land use systems, these responses suggest an unmet demand integrated transportation and land use models that can be used to support metropolitan planning decision making.

Question 22 in the GAO report is perhaps the most critical in informing this research. The question asked respondents to give their opinions regarding the challenges in meeting the travel demand modeling needs associated with nine separate factors. This research is concerned with four requirement categories when someone chooses to use a particular modeling tool. Seven of the nine GAO factors correspond directly with the four requirements articulated in this research as indicated below (U.S. Government Accountability Office 2009):

1. Data: Availability of Data (Q. 22e).
2. Resources: Turnaround time for modeling runs (Q. 22a), Access to models (Q. 22b), Cost of data gathering (Q. 22f), and Costs of models and modeling runs (Q 22.g).
3. Functionality: Flexibility of models (Q. 22c) and Capacity of models (Q. 22d).
4. Expertise: did not address.

2.4 Discussion

Metropolitan planning is a complex process requiring the assessment of complicated polices. The review of policy tools presented three examples of transportation and land use policies driving metropolitan planning which include smart growth, congestion pricing and CAFE standards. Often, these three policy tools are examined in isolation as stand-alone instruments designed to combat a social ill. What is missed is that each of these policy tools is connected with each other either in a complementary or conflicting manner (Hardy, Higginbotham, and Proper 2007). For example, congestion pricing may serve to complement both smart growth policies and CAFE standards by serving as a revenue source to fund new transit service thereby encouraging smart growth. Also, congestion pricing could address the issue of system rehabilitation and renewal associated with CAFE standards by funding new system capacity and maintaining existing systems.

This review of ITLUM tools supports the ongoing debate regarding the role of ITLUM tools in metropolitan planning. One group of researchers suggests a need to further develop the complex and comprehensive tools that were created as a result of ISTEA and the 1990 CAAA such as UrbanSim or TRANSIMS (Waddell, Gudmundur F. Ulfarsson, and Franklin 2007). Another group argues the need to incorporate the complexities of the dynamic urban process by way of simpler ITLUM tools such as TELUM or MARS (Sussman, Sgouridis, and Ward 2005). Both Meyer and Miller as well as Wegener portray the evolution of ITLUM tools to model more complicated transportation behaviors (multimodal/activity-based) coupled with a complex activity-based land use model using microsimulation (Meyer and E. Miller 2000; Wegener 1994). Clearly a tool that can model the real world as accurately as possible is an improvement. However, the assumption that increasing computing power will enable this to occur does not account for the still present technical barriers (calibrating, validating, and verifying a model) as well as the institutional barriers (availability of data, resources, and expertise) (Rabino 2007; Lee, Jr. 1973).

In the end, the use of an ITLUM tool must strike a balance among four modeling requirements: data, functionality, expertise, and resources. Not all decisions associated with the metropolitan planning process require the most powerful and technologically advanced ITLUM tool. Nor can the simplest of tools address all of the complex decisions that have to be made. Thus, a spectrum of tools is appropriate in order to support a range of decisions that have to be made as part of the metropolitan planning process. While many resources have been devoted to the development of more complex ITLUM tools (e.g., UrbanSim and TRANSIMS) less attention has focused on simpler modeling approaches.

The GAO survey is useful in informing this aspect of the research. In all of the questions concerning the challenges of using existing tools to meet current need, more than half of the respondents indicated a moderate challenge or more for each of the factors. For example, 70 percent of the respondents indicated quality data was a very great challenge, great challenge or moderate challenge in using the travel demand models. The results of the GAO survey suggest that if a tool were available that required less data, less resources, and improved functionality, it could fill an unmet need in the transportation planning community. What the two surveys did not address is how modeling tools, be they traditional travel demand models or ITLUM tools, can be used in the broader context of the metropolitan planning process which has become much larger than solely addressing federal requirements for funding.

CHAPTER 3: METHODOLOGY

This dissertation employs a mixed-method approach to answer the research question and validate the hypotheses presented in Section 1.2 including surveys, case study, and system dynamics. A mixed-method approach is characterized by elements of both qualitative and quantitative approaches. The value of the approach lies within the concept that Denzin calls “triangulation” where a researcher combines multiple observers, theories, methods, or data sources in order to overcome the intrinsic bias developed by single-methods, single-observer, and single-theory studies (Denzin 1988). In other words, a mixed-method approach can produce more robust results and opportunities for developing further insight into relationships between the methods chosen and the phenomenon studied, thus allowing researchers and the readers of their reports to improve their understanding of that phenomenon (Bliss et al. 2003).

First, two survey methodologies are used to gather feedback and opinion. The first survey methodology is a cross-sectional survey used to collect opinion from a broad base of industry practitioners regarding the use and application of simplified ITLUM modeling tools in order to investigate Hypothesis 1, that a simplified ITLUM tool can be used to support the metropolitan planning decision-making process. The second survey methodology is an expert panel used to gather detailed thoughts and opinions on a specific simplified ITLUM tool in order to investigate Hypothesis 2, that a system dynamics-based ITLUM tool can be tractable used and serve as an improved modeling approach to support decision making. Second, a case study approach, using the Washington DC region as the case study location, is used in order to partially support Hypothesis 2. Finally, a system dynamics-based model of the Washington DC region using the MARS model was developed representing a simplified modeling approach used in conjunction with the expert panel.

The process of applying the three methodologies in conducting the research is shown in Figure 8. In Part I, the cross-sectional survey (called the practitioner survey) is developed, deployed and analyzed and is documented in detail in Chapter 4. In Part II, the Washington DC MARS Model is built, calibrated, and validated, which is discussed in Chapter 5. Part III involves using the expert panel to assess the usefulness and applicability of the MARS model for metropolitan planning and is discussed in Chapter 6. Finally, Part IV provides some conclusions in Chapter 7.

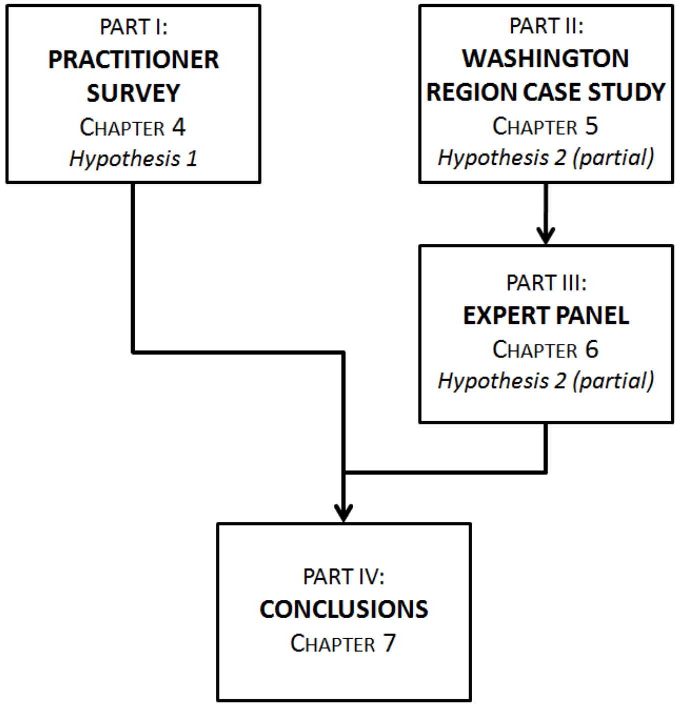

Figure 8 Research Methodology

3.1 SURVEY METHOD

Social scientists routinely use surveys, of which there are several types. Surveys can be useful when a researcher wants to collect data on phenomena that cannot be directly observed. As defined by Lavrakas, survey research is a systematic process using various methods to collect information that can be analyzed and used to generate insights (Lavrakas 2008).

Survey methods have two defining characteristics. First, a sample is taken from the population. In other words, unlike the U.S. decennial census, a survey does not attempt to observe an entire population but rather to collect a representative sample from which inferences can be made in a statistical manner. Second, survey methods employ the use of a standardized survey instrument to collect the data (Lavrakas 2008). Two different survey methods are used in this research: a cross-sectional survey and an expert panel.

3.1.1 Cross-Sectional Survey

A cross-sectional survey is employed to gather user opinions on how simplified ITLUM tools can be tractably used to support the policy development and visioning categories of metropolitan planning. Cross-sectional surveys collect data to make inferences about a population of interest at one point in time and have been described as snapshots of the populations about which they gather data (Lavrakas 2008). Typically, cross-sectional surveys are useful when wanting to collect data on relevant variables from a variety of people or subjects that will provide an analyst with a snapshot of those variables at one particular point in time. The resulting data can be cross-tabulated to generate insight regarding a particular question at hand with statistical rigorousness (Lavrakas 2008).

Cross-sectional surveys, like all survey methodologies, have both advantages and disadvantages. Numerous advantages and disadvantages of using cross-sectional surveys have been documented in the literature as show in Table 3 (Fowler 2001):

Table 3 Cross-Sectional Survey Characteristics

Advantages	Disadvantages
• Data on many different variables • Data from a large number of subjects • Data from dispersed subjects • Data on attitudes and behaviors • Good for exploratory research • Ease of data collection	• Increased chance of error • Cannot measure change • Cannot establish cause and effect • Static, time bound • Selection bias

For purposes of this research, a cross-sectional survey design is a useful means to collect the desired data. The survey is designed to collect data on many different variables and from a larger number of subjects from dispersed locations and agencies (State DOT, MPO, academia, researchers, consultants). Most importantly, the cross-sectional survey used for this research is designed to collect self-reported data on opinions, attitudes, values, and beliefs concerning the use of transportation and land use models as part of the metropolitan planning decision making process (Lavrakas 2008).

One of the principal disadvantages of concern for purposes of this research is selection bias. In order to address this concern, the survey was distributed via the web using Vovici (www.vovici.com). The survey was disseminated through a number of different organizations (AASHTO Standing Committee on Planning members and Association of Metropolitan Planning Organization members) to ensure an acceptable response rate from the identified population.

An integral part of conducting cross-sectional surveys is the instrument design. Much of the criticism of conducting cross-sectional surveys can be traced back to the design of the survey instrument (Fowler 2001). Babbie provides a series of guidelines in designing cross-sectional survey questions (Babbie 1990):

- Make items clear
- Avoid double-barreled questions where one question addresses two separate issues
- Respondent must be competent to answer
- Questions should be relevant
- Short items are best
- Avoid negative items
- Avoid biased items and terms

The data generated from cross-sectional surveys is useful for a number of purposes. First, cross-sectional data is useful in making comparisons between subgroups. For example, in this research, comparisons are made between different sized MPOs as well as state DOTs and MPOs. Second, statistical tests can be performed on the data to test for independence (chi-squared) and strength of independence (Cramer's V). Finally, cross-sectional data can better inform an analyst about a particular question that cannot be directly observed.

3.1.2 Expert Panel

In order to gather feedback on the use and application of a simplified modeling approach to land use and transportation policies, an expert panel was established. Many types of group processes could potentially be considered "expert panels." Advisory committees, review committees, stakeholder review boards, and facilitated group processes, for instance, all have similarities to expert panels. An expert panel can be used as a primary analysis method or in conjunction with other tools, and is a cost-effective technique that can be applied in a variety of settings to produce reliable results. Expert panels are not a replacement for quantitative data, but rather integrate data with the perceptions, intuition, and judgment of people familiar with the question at hand.

Expert panels have a long history of successful applications. Perhaps the most widely known expert panel survey method is the Delphi Method developed by the RAND Corporation in the 1950s for use in defense applications and has been used in a wide variety of settings since the 1960s, including recreation and tourism development, energy development, land use planning, marketing, education, and economic, social and community development (Gibson and M. M. Miller 1990). Delphis are also frequently used in aviation demand forecasting to supplement the results of mathematical models (Horonjeff and McKelvey 1993).

The traditional Delphi method is characterized by informed panelists providing information and thoughts regarding a complex problem (Linstone 1975). Typical Delphi panels consist of between 8 to 12 members, though the literature indicates a group as small as 4 or upwards of 100 could be used (Cavalli-Sforza and Ortolano 1984). The Delphi method assumes that panel members bring with them an expertise not found in the layperson. Thus, the expert draws upon two critical sources of data: past experience and in-depth knowledge (Cavalli-Sforza and Ortolano 1984).

Through the Delphi method, information is collected independently from panel members concerning future events and policy issues. Opinions and information are gathered without the participants having contact with each other. Moreover, feedback of information from participants is provided to each Delphi panel member in a multi-round, iterative process (Linstone 1975).

The purpose of the expert panel used in this research is not to generate any type of "ideal" or agreed-to future scenario of transportation and land use systems (as would be the case for a traditional Delphi panel). To this end, the traditional Delphi method is not employed in this research but rather a traditional panel consisting of experts[16] using a single questionnaire response form to gather thoughts and opinions based upon a webinar format.

Since being first used by the RAND Corporation in the 1950s, the Delphi method, as well as the use of expert panels in general, has been both criticized and praised by researchers. Sackman criticizes the method as being too unscientific and Martino lists six major concerns in using the method for scientific inquiry including discounting the future, simplification urge, illusory expertise, sloppy execution, format bias, and manipulation of Delphi (Sackamn 1974; Martino 1970). Much of the discussion criticizing the use of expert panels is focused on its implementation rather than the technique itself. In reality, the use of expert panels as a research method is useful in gathering opinion and feedback in a systematic method (Turoff 1970). In order for an expert panel process to be successful, Seskin, et. al. identify six systematic steps to be

[16] There may be a perception that an expert panel is primarily filled with stakeholders, which is problematic. While Linstone cautions that complete objectivity is impossible, it should be noted that all forms of analysis are inevitably subject to bias—even computer-run models are ultimately based on assumptions supplied by analysts (Linstone 1975). While an expert's bias may not be apparent, a stakeholder's is, and including individuals who are obviously stakeholders will harm the credibility of the expert panel.

followed to help ensure the success of using an expert panel (Seskin, Gray Still, and Boroski 2002):

1. **Know the Big Picture**—Inform the panelists of the objectives, identify the end use of the panel's analysis, and define roles and responsibilities.
2. **Design the Process**—Identify parameters, describe the panel's charge, describe the format, and plan the schedule.
3. **Create the Panel**—Identify and invite experts to serve on the panel.
4. **Final Preparations**—Develop and prepare final materials as well as test run the process.
5. **Manage the Process**—Work with the expert panel members in executing the plan.
6. **Document the Results**

In this case, expert panels combine an understanding of the theory of urban development, empirical knowledge of transportation/land use relationships, and detailed understanding of local conditions. Linstone remarked that conducting expert panels is more art than science (Linstone 1975). There is no single right way to carry out a successful expert panel process, and this is perhaps a key part of its strength. It is adaptable to many needs and resources. The key to success lies in careful attention to the numerous details that comprise each of the six steps described in this report.

3.2 CASE STUDY METHOD

This research uses a descriptive case study to illustrate the role that a simpler ITLUM can play in the metropolitan planning process. More specifically, the case study in this research will show why a simpler modeling approach can be used as an additional strategy for certain metropolitan planning decision-making categories. While no two regions are exactly the same, the results of this case study (examining the Washington, DC region) could be used to generalize how to deploy a simpler ITLUM tool since detailed data will be collected regarding model requirements, calibration, and testing. The data available for the Washington, DC region is similar to other regions in the U.S. and many regions are facing similar challenges regarding transportation and land use policies.

The case study method has been described by some researchers as a weak research method within the realm of social science. Critics point to the insufficient precision of the results, lack of objectivity by the researcher, lack of generalizability, and the limited academic rigor. Nonetheless, proponents point to recent evidence suggesting that it is a commonly used method that, if conducted properly, can mitigate concerns raised by critics. There are three key criteria that can be used to judge the quality of descriptive case studies (Yin 2008). First is "construct validity" or the establishment of the correct operational measures for the concepts being studied. In this case study, the operational measures focus on how the Washington Region model is constructed and then how it could be used. Second is "external validity" or the ability to make generalizations from the case study's findings. While every region in the U.S. is unique in some way, including the Washington, DC region, this region is typical of many regions in the U.S. in terms of data availability and transportation/land use policies being debated. Thus, the findings are applicable to other regions in the U.S. (though not necessarily other countries). Third is "reliability" or the ability to repeat the operations of the study with the same results. An important component of developing this case study is documenting exactly where the data comes from and how the simpler modeling approach is created.

By addressing the issues raised by critics, the case study method can be used as an effective investigative tool. The case study approach is useful when addressing research questions associated with "how" something can be used; where the researcher has little control over events; and the focus is on contemporary phenomena within a real-world context (Yin 2008). In other words, the case study approach is valuable when the context of the problem being explored is an important component of the analysis and comparative data is not available due to the contemporary nature of the problem at hand.

3.3 SYSTEM DYNAMICS

This research uses a system dynamics model as an example of a simpler modeling approach that could be used to support metropolitan planning decision making. The goal of this research is not to develop a new system dynamics ITLUM tool, but rather use an existing tool and apply it to the Washington, DC region in order to determine its usefulness in the metropolitan planning process. To that end, the Metropolitan Activity Relocation Simulator (MARS) system dynamics ITLUM tool was identified and acquired to be used as part of this research[17]. The MARS ITLUM tool is a scenario-based modeling program designed to examine high-level interactions between forces driving the

[17] A detailed description of the MARS model is provided in Section 5.1, MARS Model Description.

transportation systems and those driving the land use system in response to various policies. The MARS ITLUM tool was developed by researchers in Austria as an alternative to the data intensive disaggregate ITLUM tools. MARS was developed as a means to study the effect of policy scenarios on a transportation and land use system that is highly integrated and highly dynamic (Pfaffenbichler 2008). Thus, the model was built based upon the principles of system dynamics, which incorporate various stocks, flows, connectors, and converters creating numerous feedback loops.

The system dynamics approach was formally developed by Forrester as a means to model industrial and business processes and was later applied to better understanding the dynamics of urban development during the 1960s (Forrester 1961). System dynamics is designed to analyze the complexities of a “system of systems” and then run experiments on the model to see what effects various policies or changes will have on the system (Abbas and Bell 1994). At its core, system dynamics is an analysis methodology designed to model systems incorporating complex feedback relationships (Coyle 1996, chap. 6). System dynamics models include four elements: stocks, flows, connectors, and converters (Coyle 1996, chap. 3). Stocks represent the current state, magnitude, or condition of a state variable whose condition changes over time. Flows represent the actions or activities that fill or drain stocks and effectively change the amount or value of the stocks over time. Because system dynamics models include a temporal component, when the simulation stops a stock persists while flows disappear. Connectors are used to control the flows within a model and transmit actions or information required to generate the flows. Finally, converters are used as a means to tell how productive (quickly or slowly) action is unfolded by the driver of a flow.

Combining various stocks, flows, connectors, and converters creates a feedback loop. There are two types of feedback loops: negative (sometime referred to as goal seeking) and positive. A negative feedback loop is present when there is a difference between a desired and actual state of a system and actions are taken based upon policies designed to eliminate the difference. For example, there may be only 90 homes available in the Rosslyn-Ballston corridor for 100 home buyers. Arlington County may implement a policy to increase home density such that 100 homes are made available. Thus, a negative feedback loop attempts to create a balance in a system. Positive feedback loops are quite different in that they are growth generating mechanisms. Positive feedback loops are sometimes referred to as disequilibrating, destabilizing, or self-reinforcing (Lee 1995). For example, Arlington County may see an increase in population due to exogenous factors (growth in regional population, increase employment, etc.). Population increases would spur an increase in jobs and job growth would encourage more migration to the county increasing the population. A representative system dynamics model of Arlington County (or any metropolitan area) is shown in Figure 9 below.

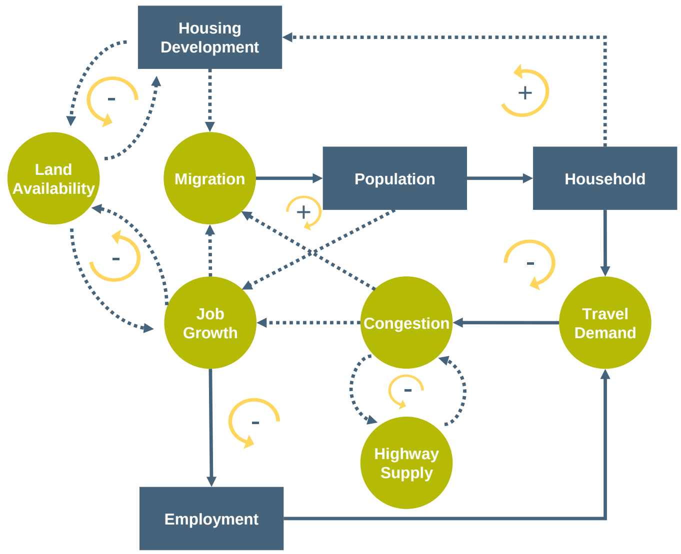

Figure 9 System Dynamics Model of Arlington County
Source: (Lee 1995, fig. 4.1.1)

Within Figure 9, three of the four basic system dynamics elements are represented. Stocks are the blue squares and include housing development, employment, population, and households. Flows are the green circles and include land availability, migration, job growth, congestion, highway supply, and travel demand. Finally, connectors are the solid and dashed blue lines connecting the various stocks and flows with each other. Two types of connectors are represented: information flows are dashed and material flows are solid. Together, these various stocks, flows, and connectors include seven different feedback loops represented by the orange circular arrows: two positive feedback loops and five negative feedback loops.

System dynamics has been applied to a number of different areas including business applications, economic dynamics, education, energy, health, military applications, operations management/supply chains, public policy, security, and transportation (Coyle 1996). While some areas have a richer history than others in the application of system dynamics (e.g., business application versus transportation), it is the area of public policy that has received significant attention as of late. In his requiem on large scale models, Lee specifically pointed to system dynamics as serving two purposes related to transportation and land use planning: 1) trace out consequences of different assumptions; and 2) employ the model in an operational gaming context (Lee, Jr. 1973).

System dynamics is not without its critics. In the 1960s, Forrester published *Urban Dynamics*, a non-industrial application of system dynamics, and came to the conclusion that many well-known urban policies (e.g., constructing low income housing) were counterintuitive in nature (Forrester 1969). In the 1970s, based upon conversations at the Club of Rome, Forrester developed *World Dynamics*, the first comprehensive model of the world based on system dynamics (Forrester 1973). Follow-on research expanding Forrester's *World Dynamics* model was conducted and in 1972, Meadows published *The Limits to Growth* (Meadows 1972). Forrester, in *World Dynamics*, includes just five basic variables to represent global ecological trends: population growth, capital investment, agricultural production, nonrenewable resources, and environmental pollution. The results of his study, and follow-on work by Meadows, projected the collapse of world socioeconomic systems fifty years from then (1970). Forrester argued that these models could be used as the basis for policymaking.

Both Forrester and Meadows received severe criticism regarding their models from around the world. Critics of both works cite the inappropriateness of the method and unacceptability of the results as being too extreme (Allen 1975). The criticism of both works was consistent and wide-ranging in saying the modeling exercise was meaningless to the process of decision making. Forrester and Meadows work is related, in part, to the application of system dynamics to the social sciences from its original purpose: industrial systems. The social science is an inherently more complex system than that of a manufacturing process and the advocacy by Forrester of precise quantifiable variables as the only basis for useful model building was not widely supported (Allen 1975). According to Towill, it is likely the over-zealous expansion of system dynamics outside of the original industrial dynamics framework and into the social science applications, which attracted the most criticism, appears to have unjustifiably broadened by implication to include all applications of system dynamics (Towill 1993).

Clearly, the work of Forrester and Meadows pushed the limits and understanding of system dynamics to large-scale social science systems from small-scale industrial applications. Today, much of the use of system dynamics is to understand smaller-scale systems. Proponents view the use of a system dynamics model as part of a process to better create policies associated with the complex socio-technical system in which they operate (Mostashari and Sussman 2005). They point out that current policy development is so complex in nature that analysts believe a complex technical and scientific analysis process is required, creating significant barriers to the involvement of stakeholders associated with addressing the problem (Mostashari and Sussman 2005). However, this belief is not necessarily correct and the use of system dynamics as a means to engage stakeholders and make the policy development process more transparent looks promising.

CHAPTER 4: PRACTITIONER SURVEY

Chapter 4 documents and summarizes the practitioner survey. The practitioner survey is important for a number of reasons. First, the literature review of this research suggests an unmet need for a simplified modeling tool that could be used to support transportation and land use policy assessment. Second, a review of the current literature also suggests that the definition of metropolitan planning is comprised of a number of different decision-making categories from the assessment of broad policy implications for an entire region (e.g., increasing the local gas tax) to very detailed assessments of new transportation infrastructure (e.g., MetroRail through Tysons Corner, Virgina). Finally, the literature also indicated broad application of traditional travel demand forecasting tools. However, what is missing is any type of indication concerning the application and use of ITLUM tools to assess the broad range of decision-making categories. Thus, the purpose of the practitioner survey is to better assess what role ITLUM tools can play in the metropolitan planning decision-making process.

As seen in Figure 10, Chapter 4 includes three separate sections and addresses Hypothesis 1. First, the instrument design and implementation is discussed including the George Mason University Human Subject Review Board (HSRB) requirements. Second, the analysis of the survey results is presented. Finally, some concluding remarks are made.

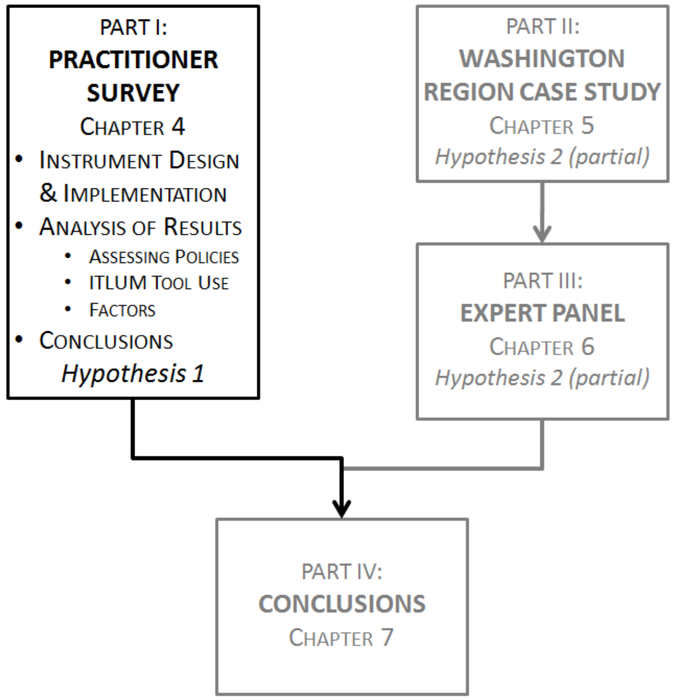

Figure 10 Chapter 4 Research Process

4.1 Instrument Design and Implementation

The practitioner survey was designed to address Hypothesis 1, that decision makers involved with the metropolitan planning process desire a simplified ITLUM tool that can be used to support the policy development and visioning categories of the decision-making process. The survey instrument is included in Appendix 1 of this report. The survey included thirteen separate questions all of which were closed ended, thus allowing only specific responses. However, each question did include a comments section in case respondents wanted to elaborate on a specific question or provide additional detail. The survey was developed as a web-based instrument using the Vovici software application service (www.vovici.com). Responses were stored on Vovici's computer servers and downloaded for analysis in both Excel (Microsoft Corporation) and Stata (Stata Corporation) statistical analysis software program.

Before distributing the survey to be completed, a draft version was circulated for comments from committee members, two state DOT personnel and one MPO staff member. Based upon comments received, the sequence and wording of some questions was modified. Once the questions were finalized it was submitted to the George Mason University HSRB for approval. Approval was received per protocol number 7196 on November 4, 2010. After HSRB approval, the final survey was then constructed in the Vovici software application and thoroughly tested before an invitation with the link was disseminated via e-mail.

The practitioner survey was disseminated to three groups of people. First, the survey was disseminated to members of the American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on Planning. Members of the AASHTO Standing Committee on Planning represent all 50 states plus the District of Columbia and Puerto Rico (52 states) and typically oversee all state DOT planning activities. Second, the survey was disseminated to the members of the Association of Metropolitan Planning Organizations (AMPO). AMPO membership include 200 of the roughly 381 MPOs in the U.S. AMPO members primarily represent large and medium-sized MPOs with some smaller MPOs as well. Small MPOs are primarily represented by the National Association of Development Organizations (NADO). While this researcher was unable to have NADO disseminate the survey to its members, AMPO membership does include small MPOs and a sufficient number of responses from small MPOs was received. The third group of people are those included on AASHTO Standing Committee on Planning and AMPO membership lists who represent other entities (e.g., the U.S. Department of Transportation, academic institutions, researchers, and consultants).

The survey was originally distributed to the AASHTO Standing Committee on Planning and AMPO members on November 23, 2010 with a response date of January 11, 2011. A total of 135 responses were received. One respondent sent an e-mail to this researcher concerning the wording of one question. No other e-mails were received. This may indicate some respondents misinterpreted the question. In addition, some respondents may have incorrectly entered a response. While these errors may remain, the data were reviewed for obvious errors none were found. The lack of obvious errors is due in part to the Vovici software application which is designed specifically for web-based surveys.

The practitioner survey was sent to a total of 252 state DOT and MPO employees plus others on the distribution list. Table 4 summarizes the responses received as they self-identified themselves for the type of organization for which they worked. A total of 131 useable responses were received. The majority came from MPOs followed by State DOTs. Local, Federal and Transit respondents indicated such in the *Other* field of Question 1. The specific populations of interest for this research are the State DOTs and MPOs. Table 5 summarizes the response rate for this target population. As seen in the table, 71 percent of the state DOTs and 30 percent of the MPOs responded to the survey. Of the MPOs, there was a higher response rate from small and large MPOs (59 percent and 50 percent respectively) than medium MPOs (13 percent). Overall, the survey had a response rate of 38 percent.

Table 4 Survey Responses

Organization	Responses
State DOT	37
All MPO	59
Small (population < 200k)	*23*
Medium (population between 200k and 1 million)	*16*
Large (population > 1 million)	*20*
Consultant	15
Academia/Researcher	12
Local	3
Federal	1
Transit	4
Total	**131**

Table 5 Survey Response Analysis

Organization	Population	Responses	Response Rate
State DOT	52	37	71%
All MPO	200	59	30%
Small (population < 200k)	*39*	*23*	*59%*
Medium (population between 200k and 1 million)	*121*	*16*	*13%*
Large (population > 1 million)	*40*	*20*	*50%*
Overall	252	96	38%

4.2 Analysis of Results

Analysis of the survey results was conducted using two different techniques. First, cross tabulations were constructed to identify frequency responses to each question by organization type. These cross tabulations provide the most insight to the data and can be organized into three general topic areas: 1) assessing transportation and land use policies;

2) use and application of ITLUM tools in the decision-making process; and 3) factors to consider in selecting an ITLUM tool. Questions 2, 3 and 4 address the transportation and land use policy assessments. Questions 5, 6, 7, 8 and 9 address the use and application of ITLUM tools. Questions 10, 11, 12 and 13 address the factors to consider in selecting an ITLUM tool. The following three sections address each general topic in more detail

The second technique used was statistical testing performed on the cross tabulations (contingency tables) to assess the overall statistical significance of the data within each cross tabulation in order to determine correlations between organization type and their response. The statistical test used for this analysis was Fisher's exact test. Fisher's exact test is a variant of Pearson's Chi-Square test. In order to use the Chi-Square test a number of conditions must be met, two of which are that the expected value of each cell must be greater than five and no cell should have an expected value less than one (Watkins, Scheaffer, and Cobb 2004). An analysis of the cross tabulations of this data revealed that Chi-Square cannot be used since many of the cell's expected values did not meet this threshold. The alternative test is Fisher's exact test which yields a similar result and one that some argue is a stronger test than Chi-Square. However, Fisher's exact test does require more extensive calculations.

Fisher's exact test is conducted to evaluate whether responses differ significantly from expected frequencies in contingency tables and provide a foundation for statistical inference of the data (Watkins, Scheaffer, and Cobb 2004). The analysis tests the null hypothesis (H_o) that there is no significant association between the two categorical variables. If the null hypothesis can be rejected, then one can accept the alternative hypothesis (H_a) and be confident that the two variables are associated. Thus, one can make inferences between the categorical variables. Significance is determined by the p-value that is calculated for Fisher's exact test. For purposes of this research, a p-value of less than 0.05 is sufficient to reject H_o and accept H_a.

A total of 46 contingency tables were constructed for this research. Each contingency table included Organization Type (e.g., State DOT, MPO, etc.) as the dependent variable and their response to the question as the independent variable. A summary of the contingency tables that were run and the expected p-values is shown in Table 6. The Stata model run outputs are included in Appendix 2 As seen in the table, many of the contingency tables that were created did not have strong enough p-values to reject the null hypothesis warranting the data to be used to make inferences between the categorical variables. More discussion on the contingency tables with statistically significant p-values is provided in the following three sections.

Table 6 Significance of Organization Type by Question

Question (table # in Appendix B)		Sample Size	Fisher's Exact
2.	**Importance of using computer modeling tools**	96	0.034**
3.	**Importance of considering effects of transportation and land use in an integrated fashion**	96	0.227
4.	**Importance of considering transportation and land use policies at the following spatial scales:**		
4a.	*Neighborhood*	95	0.000***
4b.	*Corridor*	96	0.044**
4c.	*County*	95	0.106
4d.	*Multi-County*	96	0.002***
4e.	*Region*	95	0.000***
4f.	*Statewide*	95	0.253
5.	**Importance of an ITLUM tool being dynamic**	94	0.270
6.	**Importance of an ITLUM tool being transparent**	96	0.541
7.	**Importance of ITLUM tools supporting the following decision-making categories**		
7a.	*Policy Development*	95	0.041
7b.	*Visioning*	96	0.800
7c.	*Strategic Analysis*	95	0.121
7d.	*Tactical Assessments*	96	0.602
8.	**Required level of detail of the outputs for the following decision-making categories**		
8a.	*Policy Development*	92	0.137
8b.	*Visioning*	92	0.431
8c	*Strategic Analysis*	92	0.717
8d.	*Tactical Assessments*	91	0.216
9.	**Required number of policy scenarios to assess with the following decision-making categories**		
9a.	*Policy Development*	95	0.230
9b.	*Visioning*	95	0.445
9c.	*Strategic Analysis*	96	0.201
9d.	*Tactical Assessments*	93	0.565
10.	**Data requirements for an ITLUM tool for the following decision-making categories**		
10a.	*Policy Development*	92	0.004***
10b.	*Visioning*	93	0.069
10c.	*Strategic Analysis*	93	0.023**
10d.	*Tactical Assessments*	94	0.013**

Question (table # in Appendix B)		Sample Size	Fisher's Exact
11.	**Resource requirements for an ITLUM tool for the following decision-making categories**		
11a.	*Policy Development*	93	0.005***
11b.	*Visioning*	94	0.039**
11c.	*Strategic Analysis*	93	0.127
11d.	*Tactical Assessments*	93	0.161
12.	**Functionality requirements for an ITLUM tool for the following decision-making categories**		
12a.	*Policy Development*	89	0.000***
12b.	*Visioning*	90	0.005***
12c.	*Strategic Analysis*	88	0.001***
12d.	*Tactical Assessments*	90	0.021**
13.	**Expertise required for an ITLUM tool for the following decision-making categories**		
13a.	*Policy Development*	91	0.572
13b.	*Visioning*	93	0.725
13c.	*Strategic Analysis*	93	0.755
13d.	*Tactical Assessments*	90	0.533

**Significant at the 0.10 level*
*** Significant at the 0.05 level*
**** Significant at the 0.01 level*

4.2.1 Assessing Transportation and Land Use Policies

Questions 2 through 5 asked respondents about the importance of using computer modeling tools to assess transportation and land use policy effects, the importance of considering transportation and land use policies in an integrated fashion, the importance of considering transportation and land use polices at various spatial scales, and the importance of assessing transportation and land use policies dynamically over time. As seen in Figure 11, 62 percent of all respondents felt it was either very important or critically important that computer modeling tools be used to support the metropolitan planning decision-making process. A more detailed analysis of this data examining responses by Organization Type can also be conducted since Fisher's exact p-value for this cross tabulation was statistically significant (see Table 6 above and Appendix 2 for the table). Large and medium-sized MPOs indicated higher importance placed upon modeling tools than did state DOTs and small MPOs. Small MPOs placed the least amount of importance on the use of computer modeling tools to support decision-making. The lack of importance that smaller MPOs place on the use of modeling tools could be indicative of smaller MPOs having fewer resources (time, money, expertise) with which to use computer modeling tools as opposed to the medium and large size MPOs.

Figure 11 also shows the importance of considering transportation and land use policy effects in an integrated fashion. Eighty percent of respondents felt it either *very important* or *critically important* to consider the effects and transportation and land use polices in an integrated fashion. The importance placed upon considering transportation and land use effects in an integrated fashion is likely reflective of the realization that policy makers cannot look at transportation and land use policies separately, but together.

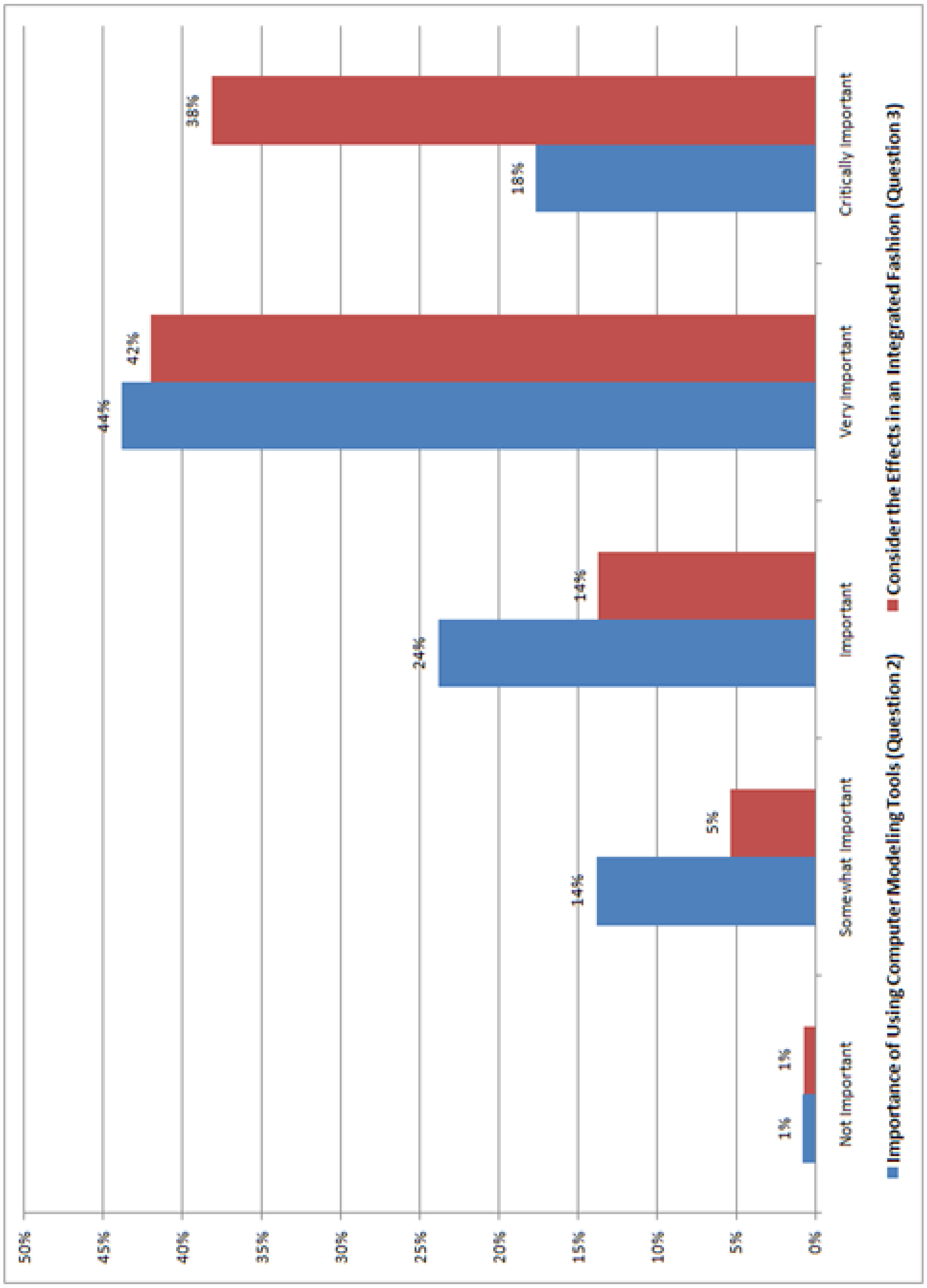

Figure 11 Importance: Effects in an Integrated Fashion

While Question 3 asked about the importance of considering transportation and land use policies in an integrated fashion, Question 4 asked respondents about the importance of considering transportation and land use policies at different spatial scales: neighborhood, corridor, county, multi-county, region and statewide. As seen in Figure 12, a vast majority of the respondents indicated that it was either very important or critically important that transportation and land use policies be considered at all six spatial scales. The County spatial scale had the highest number of respondents (95%) indicating it was at least important to consider transportation and land use policies. The Statewide spatial scale had the highest number (13%) indicating it was not important to consider transportation and land use policies at this scale.

Four of the six cross tabulations created by *Organization Type* were statistically significant based upon Fisher's exact p-value: neighborhood, corridor, multi-county, and region (see Table 6 above and Appendix 2 for the table). State DOTs placed the most importance on examining transportation and land use policies at the neighborhood scale with larger MPOs placing the least importance at the neighborhood scale. At the corridor, multi-county and regional spatial scales, large and medium MPOs indicated more importance of considering transportation and land use policies. The importance that large and medium MPOs placed on examining policies at the corridor, multi-county and regional spatial scales makes sense and is likely indicative of the nature of the work that large and medium MPOs are charged with, which is to serve, in part, as a clearinghouse for regional transportation planning. Land use planning is the jurisdiction of the local agencies where there is a tighter relationship between the DOTs and local jurisdictions.

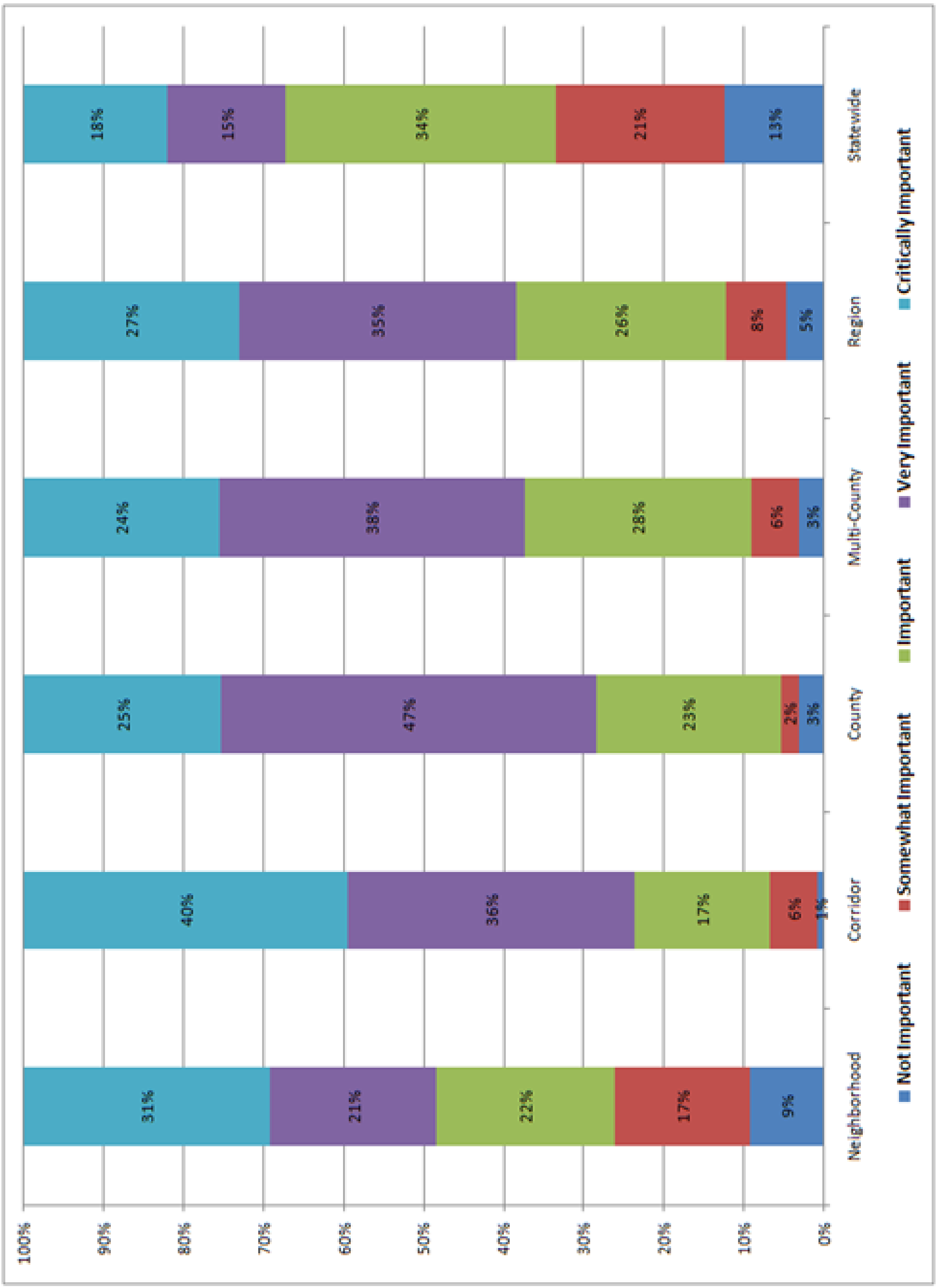

Figure 12 Importance: T-LU Policies at Diffeent Spatial Scales

Question 5 asked respondents the importance of considering transportation and land use policies dynamically over time. In other words, how important is it to examine policy effects not as static snapshots in the future (e.g., 30 years out) but to see how changes occur over a certain time period (e.g., every year for the next 20 years). Eighty-four percent of respondents indicated that it is *important*, *very important*, or *critically important* that transportation and land use policies be assessed dynamically over time. Only three percent of the respondents indicated it was not important that these policies be assessed in a dynamic fashion.

The analysis of Questions 2 through 5 yielded two important insights. First, the high level of importance given to the use of computer modeling tools is likely indicative of the pervasiveness of both transportation and land use models currently being used in the metropolitan planning process. In fact, the TRB and GAO surveys both support this conclusion (Vanasse Hangen Brustlin, Inc. 2007; U.S. Government Accountability Office 2009). Second, most state DOTs and MPOs consider computer modeling tools to be critical to supporting the decision-making process and a large majority also consider it critical to assess transportation and land use polices in an integrated manner, presumably using computer modeling tools. However, the results of the GAO survey of MPOs indicates that less than one quarter of the MPOs are currently using their existing travel demand models to assess land use policies (U.S. Government Accountability Office 2009). Thus, there appears to be an unmet need for ITLUM tools to support the broader metropolitan planning process.

4.2.2 Use and Application of ITLUM Tools in the Decision-Making Process

Questions 6 through 9 addressed the use and application of ITLUM tools in the metropolitan planning decision-making process. In regards to Question 6, 86 percent of respondents indicated that it was *important*, *very important* or *critically important* that an ITLUM tool operate in a transparent manner. Even more so, one-third of the respondents indicated that it was *critically important* that an ITLUM tool be transparent.

Questions 7 through 9 asked respondents their opinion about the use of ITLUM tools in supporting the four metropolitan planning decision-making categories: policy development, visioning, strategic analysis, and tactical assessments. Question 7 focused on the importance of using an ITLUM tool while Question 8 and 9 centered on the required level of detail of the results and the number of scenarios that would likely be assessed. Responses are summarized in Figure 13 through Figure 15.

Figure 13 Importance: Using ITLUM Tools

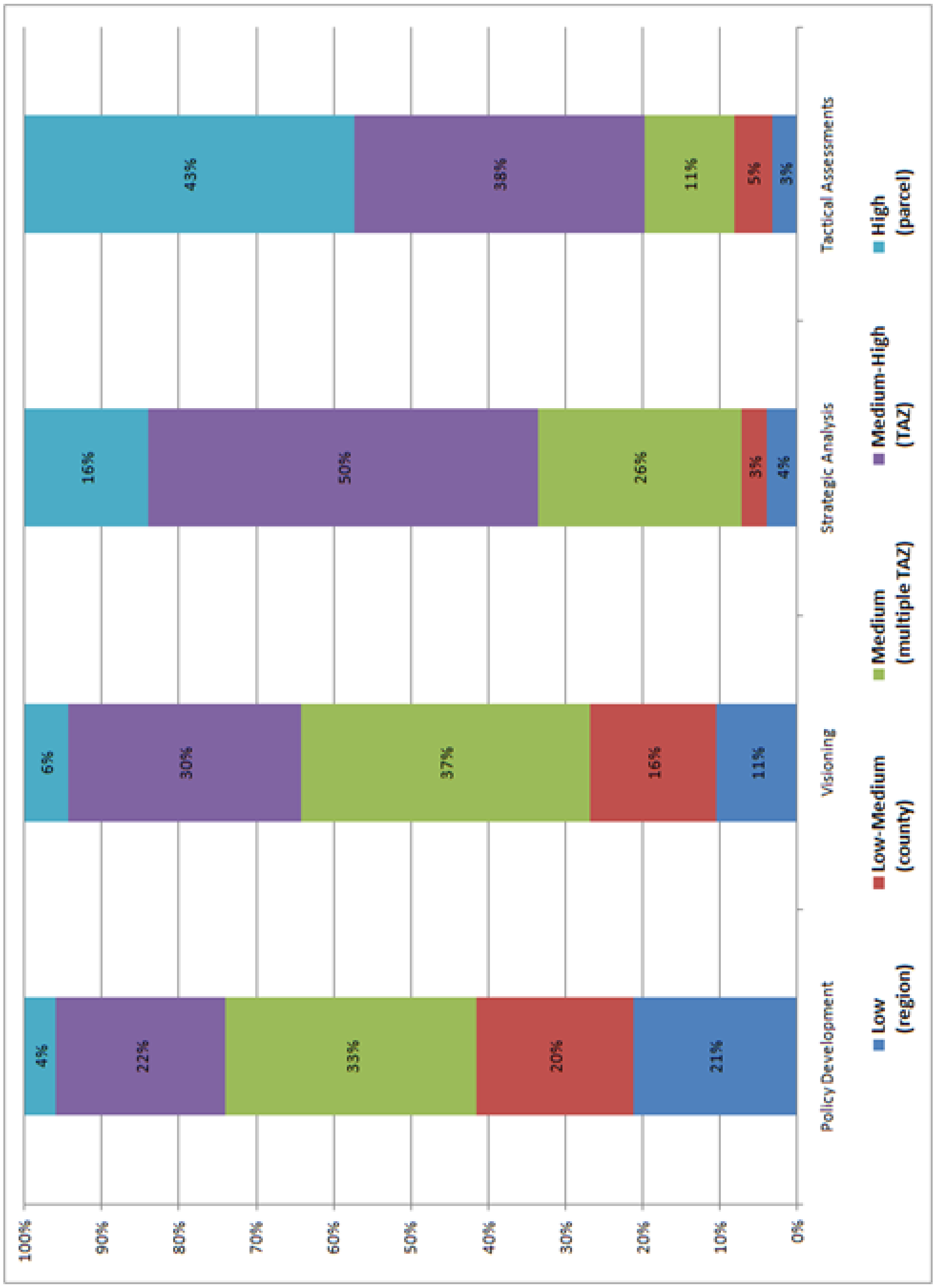

Figure 14 Level of Detail of Outputs

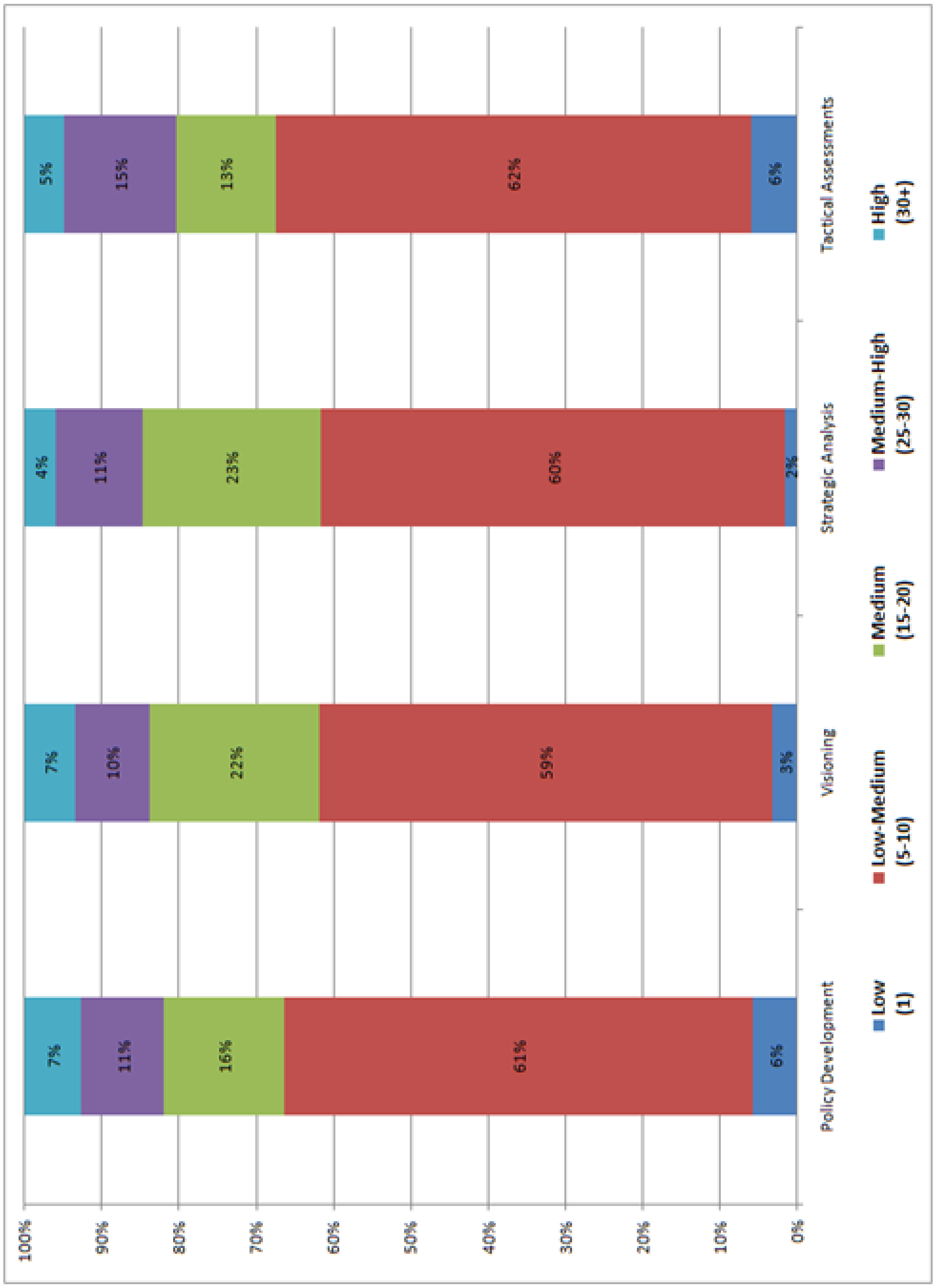

Figure 15 Number of Scenarios

First, as seen in Figure 13, most of the respondents thought it was at minimum *important* to use ITLUM tools to support all four categories of the metropolitan planning decision-making process. The strategic analysis and visioning categories received the highest and second highest number of *very important* or *critically important* responses, respectively. Policy development received the highest number of *somewhat important* and *not important* responses. Second, Figure 14 shows a clear indication that the importance associated with the level of detail of the model results increases from policy development to tactical assessments. In other words, decision-makers need more precision in the results in order to support a decision. Third, as seen in Figure 15, the number of scenarios one would expect to analyze for each of the four decision-making categories remains fairly constant.

Questions 6 through 9 centered on the use and application of ITLUM tools as they relate to the metropolitan planning process. The analysis reveals that respondents believe it is important that:

1. ITLUM tools be used to support all aspects of the metropolitan planning decision-making process;
2. the level of detailed required of an ITLUM tool will vary based upon which metropolitan planning decision-making category the tool is being used to support; and
3. ITLUM tools need to be transparent in how they operate.

The responses do send some mixed signals. The responses to the level of detail of the outputs (Question 8) makes sense because one would expect policy development and visioning to address numerous different policy ideas and scenarios that would need to be assessed thus requiring less detail in order to sort through the analysis. The decisions being made at the strategic and tactical levels are likely more detailed, requiring higher levels of detailed data. However, respondents indicated a consistent number of scenarios to be addressed for each decision-making category. This is not what this researcher expected which was more scenarios would be developed for policy development and visioning and less for strategic development and tactical assessments.

4.2.3 Factors to Consider in Selecting an ITLUM Modeling Tool

Questions 10 through 13 addressed what factors decision makers would consider when selecting an ITLUM tool to support the decision-making process. The respondents were asked to rate four factors that are paramount when selecting a modeling tool or approach: data requirements, resources, functionality, and expertise. For each of the four decision-making categories, respondents were asked whether more or less was required of each factor. The responses are summarized in Figure 16.

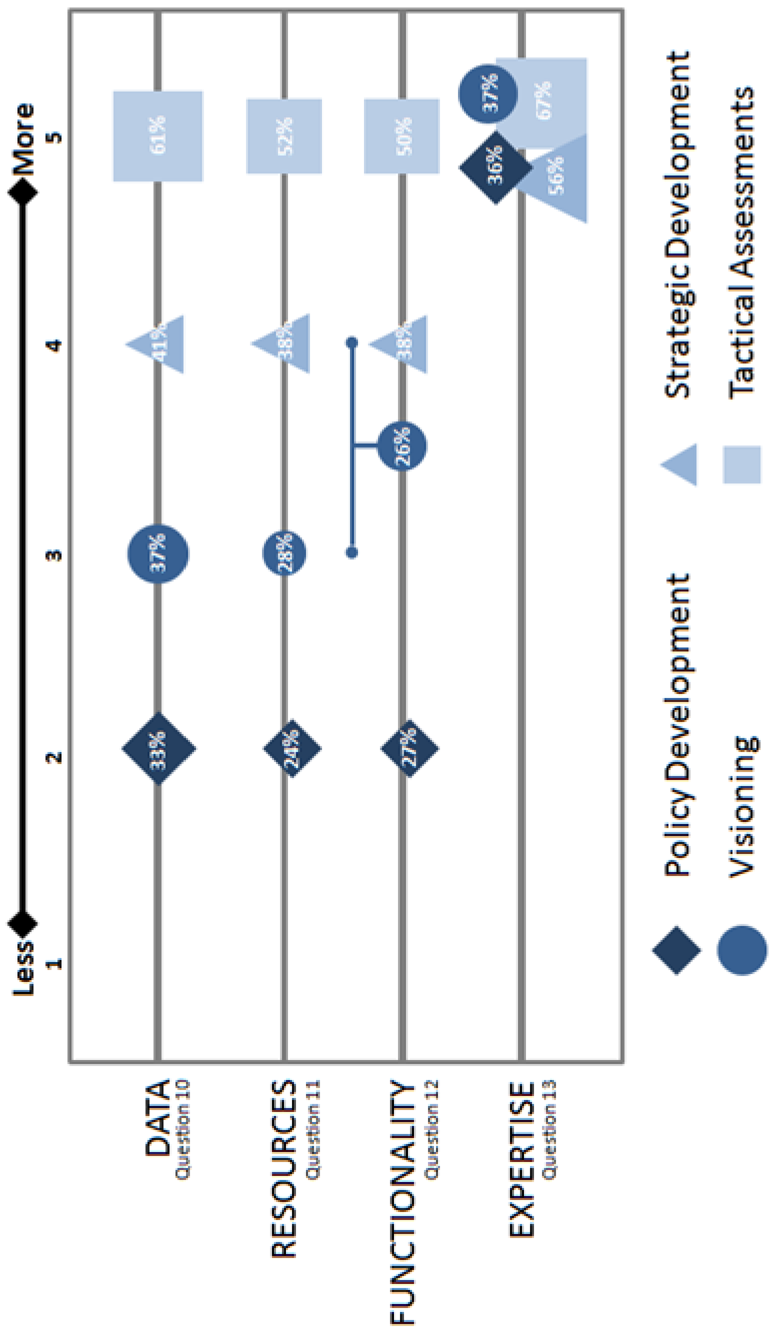

Figure 16 Factors to Consider in Selecting an ITLUM Modeling Tool

Figure 16 shows the highest frequency responses for each factor of each decision-making category. For example, 33 percent of the respondents indicated that less data were needed for policy development and 66 percent of respondents indicated that more data were needed to support tactical assessments. Responses were equal in their assessment concerning the functionality required of an ITLUM tool with 26 percent of respondents both indicating a rating of 3 and 4 on a scale on 1 to 5 (one being less functionality and 5 being more functionality).

The data and associated analysis of these four questions indicate that respondents were consistent in feeling that lower data requirements, resources and functionality are required of an ITLUM tool to support policy development and visioning. Respondents were also consistent in feeling that higher data requirements, resources, and functionality were necessary in order to use an ITLUM tool to support strategic analysis and tactical assessments. In other words, as one moves from policy development (high level assessment of policy effects) to tactical assessments (detailed analysis of system operations) the requirements of using an ITLUM tool (in terms of data, resources, and functionality) increases.

The questions concerning data requirements, resources, and functionality also had results that were statistically significant based upon Fisher's exact p-value from which additional inferences can be made (See Table 6 above and Appendix B for the table). Regarding data requirements for policy development, large MPOs indicated that higher data requirements were needed than did medium MPOs, small MPOs and state DOTs. Larger MPOs also indicated higher data requirements are associated with strategic analysis and tactical assessments. In other words, large MPOs believed that higher data requirements are needed for an ITLUM tool regardless of the decision-making category with medium MPOs, small MPOs, and state DOTs indicating a gradual increase in the data requirements as one moves from policy development to tactical assessments. A similar conclusion can be made for the other contingency tables associated with resources (policy development and visioning) and functionality (policy development, visioning, strategic analysis, and tactical assessments). While this survey cannot conclusively answer why larger MPOs believe higher data requirements are needed, one could speculate that larger MPOs typically develop and use more complex models, thus they have the more complex models readily available to support the decision-making process.

Respondents were also consistent in feeling that a higher level of expertise is required to run an ITLUM tool regardless of which decision-making category the tool is being used to support. This result may suggest that while a simpler ITLUM tool requires less data, resources, and functionality to support policy development and visioning, it still requires a higher degree of expertise to run and interpret the outputs. In other words, a simple tool is not necessarily an easy tool to use.

4.3 PRACTITIONER SURVEY FINDINGS

Hypothesis 1 stated that decision makers involved with the metropolitan planning process desire a simplified ITLUM tool that can be used to support the policy development and visioning categories of the decision-making process. In order to test this hypothesis a practitioner survey was designed and implemented. The survey was completed by 131 respondents, 96 of whom were associated with a state DOT or MPO.

The survey was designed to address three key areas: 1) assessing transportation and land use policies; 2) use and application of ITLUM tools in the decision-making process; and 3) factors to consider in selecting an ITLUM tool.

The practitioner survey provides strong evidence to support Hypothesis 1. First, respondents indicated it was important that ITLUM tools be used to support all four of the metropolitan planning decision-making categories: policy development, visioning, strategic analysis, and tactical assessments. Second, respondents indicated that a scalable ITLUM tool, one that could be used to analyze transportation and land use policies at different spatial scales as well as producing various levels of output details, is needed to support the four decision-making categories Finally, respondents indicated that a simplified ITLUM tool, one requiring less data, resources and functionality, are important features of an ITLUM tool that would be used to support the policy development and visioning. In other words, less requirements for policy development and more requirements for tactical assessments.

CHAPTER 5: WASHINGTON, DC REGION CASE STUDY

Chapter 5 provides a detailed summary of developing and applying the MARS ITLUM tool to the Washington, DC region. As seen in Figure 17, Chapter 5 includes five separate sections and addresses, in part, Hypothesis 2 that a system dynamics-based integrated transportation and land use modeling tool can be tractably used to support the metropolitan planning decision making process. First, a qualitative description of the MARS model is provided to familiarize the reader with its operation. Second, documentation is provided on how the necessary data were collected required to run the MARS model. Third, the process and results of calibrating the MARS model are documented. Fourth, reasonableness checking of using the MARS model for three different scenarios in the Washington, DC region is detailed. Finally, findings of the case study are presented.

The results of Chapter 4, Practitioner Survey, supported the development of the type of ITLUM tool that would be used in developing the Washington, DC region case study. The practitioner survey indicated that a scalable ITLUM tool requiring less data, resources and functionality to run is desirable. Thus, the MARS ITLUM model was an appropriate tool to apply in this case study of the Washington, DC region.

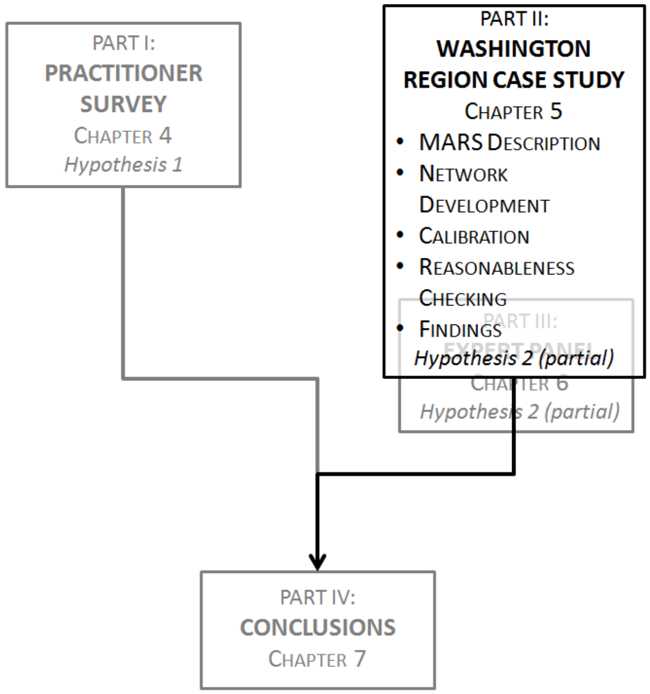

Figure 17 Chapter 5 Research Process

5.1 MARS Model Description[18]

The MARS model is a system dynamics model originally developed in Vienna, Austria by Pfaffenbichler (Pfaffenbichler 2008). Subsequently, it has been applied in sixteen European and Asian cities and one South American city (Porto Alegre, Brazil)[19]. This research is the first application of the MARS model in the U.S. and is based upon the application of the MARS model to the city of Leeds, England. The MARS model is an ITLUM tool consisting of two basic sub-models: the transportation model and the land use model. These two sub-models represent both the demand (land use) and supply (transportation) of a metropolitan region. Changes in the transport system cause time-

[18] A complete description of the MARS model is available in Pfaffenbichler (2008). What is included in this section is a qualitative description of the MARS model structure and functionality.
[19] For a detailed description of where the MARS model has been applied, see Pfaffenbichler (2008).

lagged changes in the land use system and changes in the land use system cause immediate reactions in the transport system. The land use sub-model can be further subdivided into a residential and a workplace location sub-model. The links between the sub-models are shown in Figure 18.

The MARS model is deterministic in nature, meaning there are no stochastic elements built into the model. While a stochastic model would yield different results each time it is run, the MARS model will yield the same results each time it is run unless an exogenous variable is changed prior to the start of the model run. The deterministic nature of MARS is one characteristic of it being a simpler tool.

An important element in understanding the MARS model is how the various sub-models are connected with each other. The connection between the sub-models is made through accessibility measures between the transportation and land use systems and the spatial distribution of residents and work places that change over time. For example, accessibility in the year *n* is used as an input into the location models in the year *n*+1. Workplace and residential location is an output of the land use model. The number of workplaces and residents in each zone in year *n* is used as a new production and attraction element in the transport model in the year *n*+1. There are also links between the land use sub-models as they are competing for land and availability of land influences its price. MARS iterates in a time lagged manner between the transport and the land use sub-model every year over a maximum period of 30 years.

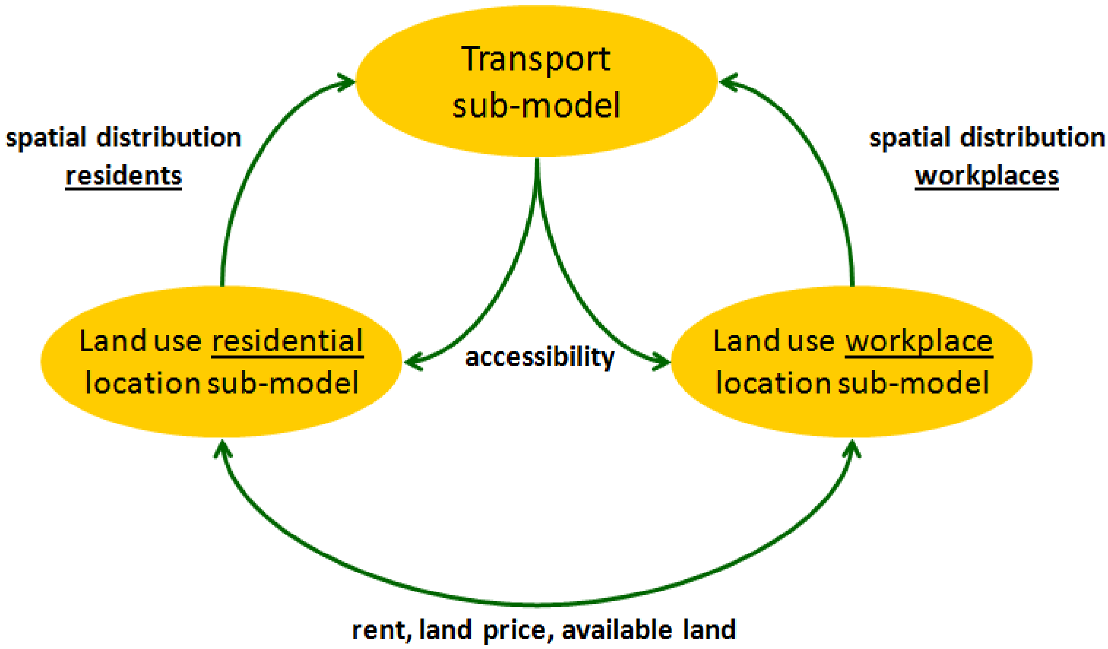

Figure 18 MARS Sub-model Relationships

One important task in model development is to clearly understand and articulate the limits of a model (Sterman 2000). A model boundary table is a useful tool for this task and is shown in Table 7 below. The model boundary table shows which variables are endogenous to model (calculated within the model or as an output of the model), exogenous to the model (input variables), and excluded from the model. A summary description of the manner in which the endogenous variables are calculated is provided in Sections 5.1.1 through 5.1.3. A detailed description of the exogenous variables is provided in Section 5.2. It is important to note those aspects that are specifically excluded from the model including freight transport, route choice, gross domestic product, and the ageing population. These aspects were excluded in order focus the model on key policy variables (freight transport, GDP, and ageing) and to make the model run quickly (route choice)

Table 7 MARS Model Boundary Table

Endogenous	Exogenous	Excluded
Number of Trips Private Vehicle Transit Bike/Pedestrian	Growth Rate Service Sector Production Sector Residents	Freight Transport Route Choice GDP Ageing
Distribution of Trips	Car Ownership Growth Rates	
Mode Share	Household Income	
Private Vehicle Speeds	Household Size	
Accessibility	Households Moving	
Fuel Consumption	Technological Improvements	
New Housing Units	Policy Instruments	
Available open Space	Transportation Network Data	
Rent		
Land Price		
Distribution of Households Moving Out of a Zone In to a Zone		
Distribution of Workplaces Service Sector Production Sector		

5.1.1 Transportation Sub-model

The MARS transportation sub-model implements three of the four components of the traditional four-step planning process: trip generation, trip distribution, and mode choice (Figure 19). MARS does not conduct the trip assignment step in order to simplify the functioning of the model. The MARS transportation sub-model uses the highest representation of the transportation network by aggregating to one link each origin-destination (OD) pair. There are two critical consequences of this design. First, there is no route assignment step in MARS. Second, the MARS model runs extremely fast compared to traditional forecasting models that include a route assignment step.

- **Trip Generation**—MARS employs a tour-based concept where a tour is defined as a sequence of a simple trip generations starting at the home and ending at either work or other (e.g., school, stores, etc.). Thus, two different types of tours are considered in MARS:
    - Commuting Trips: Home—Work—Home (HWH) and
    - Other Trips: Home—Other—Home (HOH)

  Trip generation follows the overall principle of constant travel time budgets. Zahavi first wrote extensively about the concept of constant travel times in 1974 (Zahavi 1974). In his research, he examined empirical data related to travel time for three different spatial scales: nationwide averages, urban areas and a single metropolitan region (Washington, DC). Two key results from his research are applicable to how the MARS model functions. First, average travel time budgets are stable across urban areas. Second, automobile drivers trade travel time savings with more trips. Using these two principles, the MARS model allocates trips where trip rates per capita and day are assumed being constant for the HWH (commuting trips). HOH (other trips) are based upon the remaining available travel time after HWH trips have been satisfied. Thus, the travel time associated with sum of the tours HWH and HOH throughout the day is constant.
- **Trip Distribution—**The transportation sub-model distributes trips simultaneously to destinations and modes. The trip distribution and mode choice sub-model is further divided into a HWH and HOH-sub-model. Two

person groups, those with access and those without access to a car, are considered in each of the sub-models.

- HWH Tour (Commuting Trips)—The number of commuting trips per origin zone *i* is defined exogenously by the trip generation sub-system. The trip distribution and mode choice sub-model calculates the probability that a destination and mode combination is chosen for a commuting trip from a given origin. The attraction of a zone *j* to be a destination for a commuting trip is the number of workplaces within the zone. Workplace location is given by the land use sub-model. Those with access to a car can choose between personal car, fixed-route transit, bus transit, and non-motorized. Those without access to a car can only choose between non-motorized and public transportation. Travel times and costs per mode and OD pair are the link to policy instruments where policy instruments affect either directly or indirectly the supply side (e.g., travel times, and/or the travel costs such as fuel costs and parking).
- HOH Tour (Other Trips)—The travel time available for the purpose of non-commuting trips per origin zone *i* is defined exogenously by the trip generation sub-system. This time is then distributed to modes and destinations. The attraction of a zone *j* as a destination is given by the land use sub-model. Travel times and travel costs per mode and OD

pair give the friction factor per mode and OD pair. The number of trips is calculated by dividing the total travel time per mode and OD pair by the specific travel time per mode and OD pair.

- **Mode Choice**—MARS represents up to four distinct modes: personal car, fixed-route transit (e.g., LRT, HRT, and BRT), bus transit, and non-motorized.

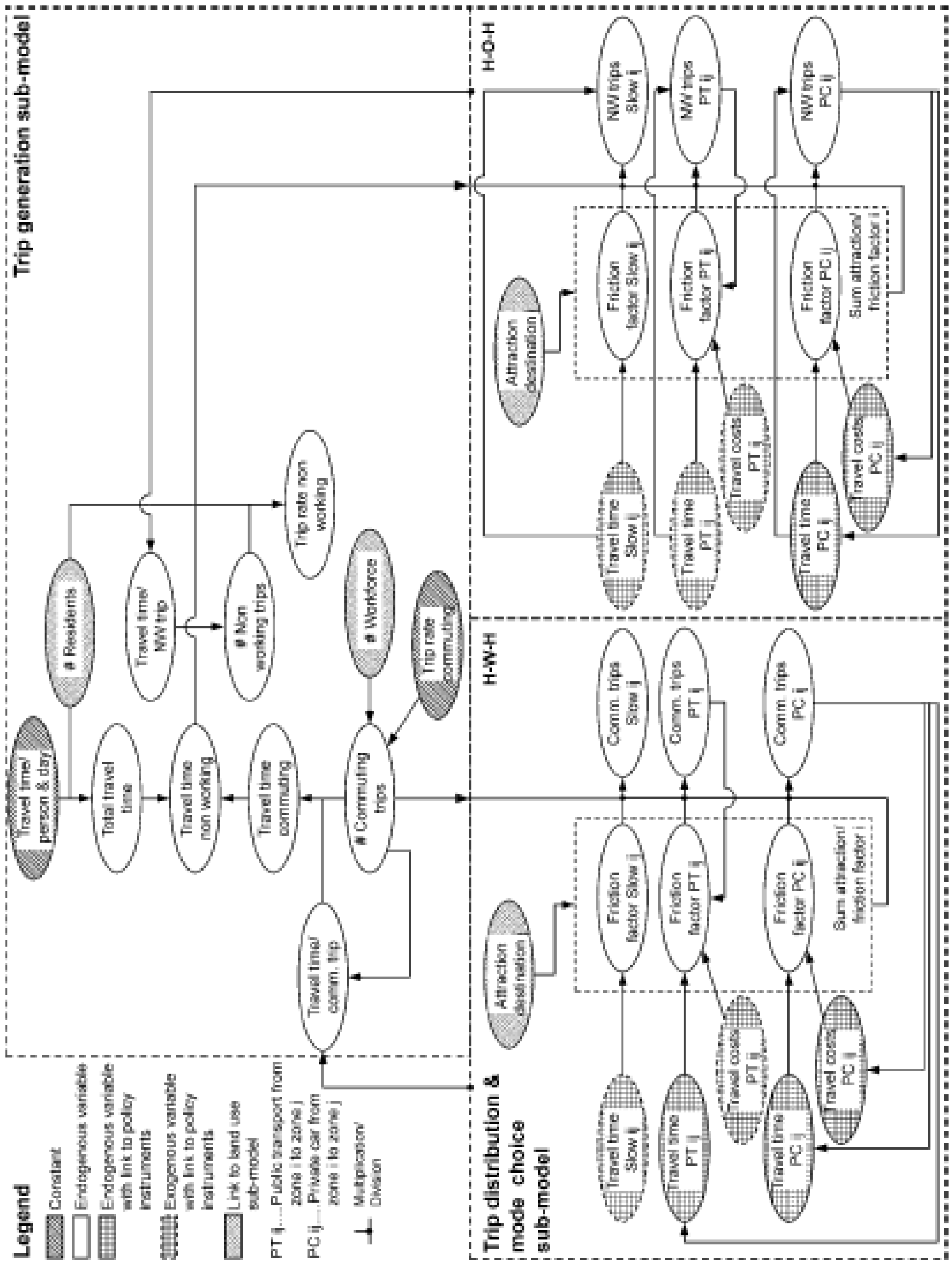

Figure 19 MARS Transportation Sub-model Diagram
Source: (Pfaffenbichler 2008)

5.1.2 Land use Sub-model

The land use sub-model consists of a residential and a workplace location model. The land use sub-models use general LOGIT or gravity type models. The ratio of the exponential function value of utilities and dis-utilities of an alternatives to the sum of all alternatives is used to distribute a potential to different locations[20]. Both the residential and workplace location models consist of four further sub-models: a development model, a willingness to move out model, a willingness to move in model and a supply/demand redistribution model. The first development model models the development of building stock while the others model the activities of households and businesses with the analysis zone.

- **Resident Location Model**—Number of residents and available housing units are exogenous inputs to the model. For each year, new housing units constructed is based upon: rent prices, land price, and land availability. The time lagged output of the development sub-model of the residential location model is the number of new housing units built. Subsequent sub-models estimate the moving out and moving in of residents based upon rent prices, available green land (e.g., environmental quality), and accessibility.
- **Workplace Location Model**—The workplace location sub-model consists of two parts: one for the production sector and one for the service sector. For both sectors, exogenous growth factors are determined (positive or negative)

[20] A detailed description is provided in (Pfaffenbichler 2008).

for each year. Based upon rent, land price, and land availability, workplaces either increase or decrease for each zone.

The residential and workplace sub-models do not operate simultaneously but rather in sequence. The residential location sub-model is run first based upon an initial exogenous input in terms of growth. Available land is first allocated to residential locations and once the sub-routines have finished, then the workplace sub-model is run (see Figure 20).

5.1.3 Time Series Iterations

The MARS model operates on single year iterations over 30 years. The process is shown in Figure 20. First, MARS starts with a transportation sub-model calculation of accessibility indicators. These are input into the household location sub-model. After the household location analysis, MARS calculates the availability of land, which serves as an input into the workplace location sub-model. The transportation sub-model passes results from the speed flow calculation over to the next iteration. The household location sub-model passes the spatial distribution of households to the transport sub-model of the next iteration. Information about new developed residences are passed within the household location sub-model to a time lagged iteration t+T. The workplace sub-model passes information about the spatial distribution of workplaces and the availability of land over to the transport and household location sub-model of the next iteration.

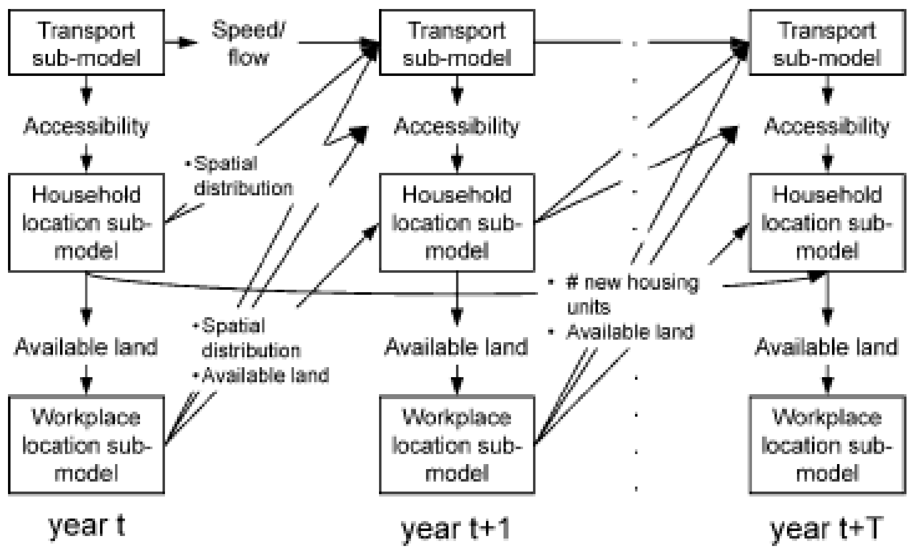

Figure 20 MARS Time Series Iterations
Source: (Pfaffenbichler 2008)

5.2 NETWORK DEVELOPMENT

In keeping with Hypothesis 2, the purpose of the detailed description of the network development is to indicate the tractability of obtaining the necessary data for the Washington DC MARS Model. Obtaining the required data to support a transportation and land use model is often seen as one of the largest barriers to their use (U.S. Government Accountability Office 2009). Thus, developing a transportation and land use model that does not require the collection of unique and specific data for a specific region, but one that can use readily-available data could be seen as an important aspect of using the model. To that end, readily-available sources of data were used to populate the Washington DC MARS Model with this section of the report serving as an archive for future replication of the MARS model in other areas of the U.S.

The first step in developing a MARS model is to identify individual MARS analysis zones that are consistent in terms of land use type and density which is the similar process used to develop traffic analysis zones in four step models (Pfaffenbichler, Günter Emberger, and Shepherd 2008). The Washington DC MARS Model network was developed based upon existing research conducted by the Washington Council of Governments (WashCOG), which serves as the federally-designated metropolitan planning organization (MPO) for the region. WashCOG conducts regular regional travel demand forecasting exercises. Data from the Round 6.1 Cooperative Forecasts were used to determine the individual MARS analysis zones based upon the traffic analysis zone network WashCOG used as well as the Regional Activity Centers and approved by WashCOG Board of Directors and Transportation Planning Board.

As seen Figure 21, the 2,191 traffic analysis zones and 59 regional activity centers and clusters were used to identify 97 individual MARS analysis zones. The MARS analysis zones were developed to maintain consistency as shown in Figure 22 (Fairfax County). The regional economic centers were first identified (numbered rectangles). Then, primarily residential areas were used to fill in the space between the regional activity centers (lettered rectangles). Finally, regional activity centers were combined as were the residential areas to create the 97 Washington DC MARS Model analysis zones. A list of the MARS analysis zones and the corresponding name are shown in Table 8.

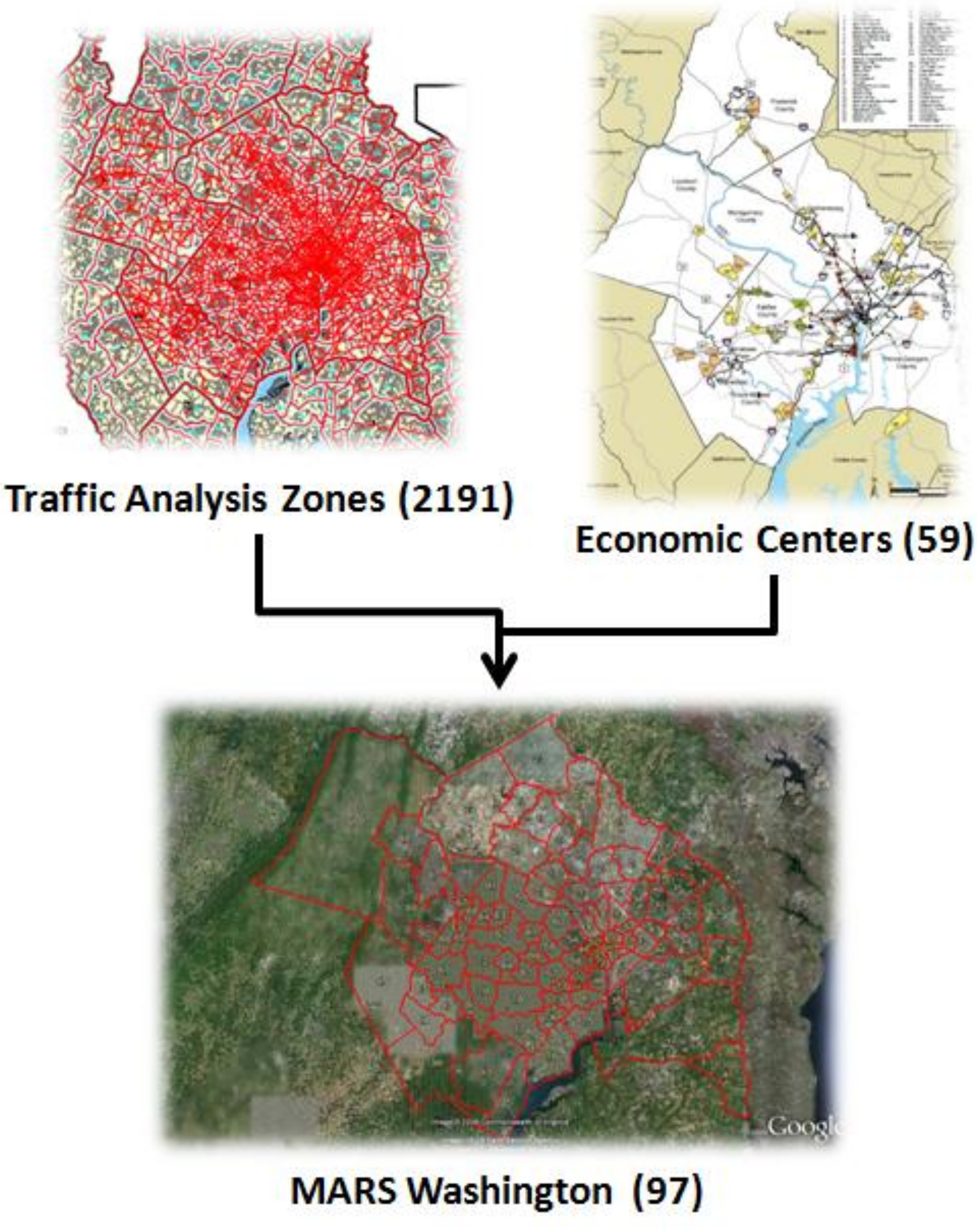

Figure 21 Washington DC MARS Model Analysis Zone Identification
Source: Metropolitan Washington Council of Governments and Google Earth

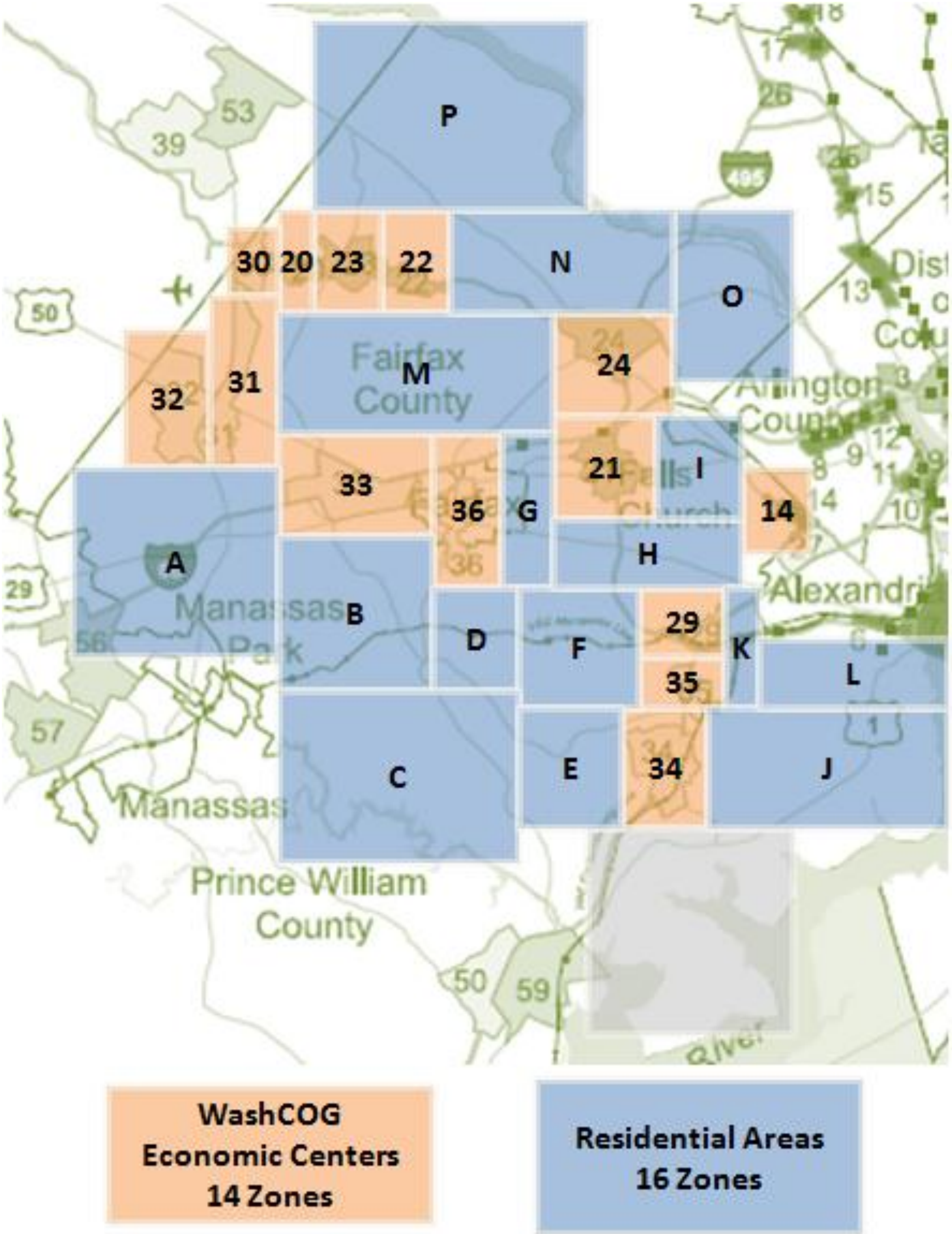

Figure 22 Washington DC MARS Model Analysis Zone Development
Source: Washington Council of Government and Author's Assessment.

Table 8 Washington DC MARS Model Analysis Zone Names

MARS Analysis Zone	Name	MARS Analysis Zone	Name
1	Downtown Washington	50	Rosslyn
2	Southwest/Navy Yard	51	The Pentagon
3	Georgetown	52	Pentagon City
4	Monumental Core	53	Crystal City
5	New York Avenue	54	North Arlington
6	Friendship Heights	55	South Arlington
7	NE DC	56	Bailey's Crossroads/Skyline
8	NW DC	57	Lake Barcroft
9	Embassy Row	58	Falls Church
10	Anacostia	59	Great Falls
11	Capitol Hill	60	McLean
12	East Capitol Street	61	Tysons Corner
13	Bethesda CBD	62	Vienna
14	Silver Spring CBD	63	Reston East
15	North Bethesda	64	Reston West
16	Rock Spring Park	65	Dulles East
17	Germantown	66	Dulles West
18	Rockville	67	Dulles Corner
19	Gaithersburg	68	Herndon
20	Glen Echo	69	Merrifield/Dunn Loring
21	Potomac	70	Beauregard Street
22	Western Montgomery	71	Beltway South
23	Northern Montgomery	72	Fairfax Center
24	Damsacus	73	Springfield
25	Olney	74	Engineering Proving Ground
26	Poolesville	75	Mount Vernon
27	North Potomac	76	Fort Belvoir
28	Wheaton	77	Lorton
29	White Oak	78	Burke
30	US 1 Green Line	79	Clifton
31	Greenbelt	80	Bull Run
32	New Carrollton	81	Centreville
33	Laurel	82	Wakefield
34	Largo Center	83	Bull Run-Sudley Area
35	National Harbor	84	City of Fairfax-GMU
36	Hyattsville	85	Western Loudoun

MARS Analysis Zone	Name	MARS Analysis Zone	Name
37	Bowie	86	Downtown Leesburg
38	Upper Marlboro	87	Corporate Dulles
39	Central Prince George's	88	Route 28 North
40	Suitland	89	Eastern Loudoun
41	Southern Prince George's	90	South Riding
42	Beltsville	91	Sterling
43	Seat Pleasant	92	Woodbridge
44	Capitol Heights	93	Potomac Mills
45	Eisenhower Avenue	94	Innovation
46	Old Town Alexandria	95	Gainsville
47	Alexandria	96	Central Prince William
48	Ballston/Virginia Square	97	Manassas
49	Clarendon/Courthouse		

The second step in developing a MARS model is to collect the necessary data describing the individual MARS analysis zones as well as the travel characteristics, in aggregate, among the analysis zones. Four categories of data are required: regional data, zonal data, passenger car data, and public transportation data. The following sub-sections describe in detail the manner in which the four categories of data were collected for the Washington DC MARS Model. The sub-sections include a discussion of where each individual data element was obtained and how it was calculated. Throughout the data collection process, the following data sources were used:

- **City-data.com**—The website *www.city-data.com* aggregates numerous data elements from different sources in a searchable database by geographic location. For each analysis zone, a single zip code was identified and used to lookup the necessary data element. These data are available for the entire U.S.

- **GMU Center for Regional Analysis (CRA)**—The CRA maintains a collection of data concerning the Washington, DC region. This includes business and residential data. Similar data is likely available for other regions in the U.S.
- **Google Maps**—Google Maps provides mapping and route directions all around the world. Google Maps allows users to enter data in multiple formats (e.g., address, lat/long, etc.) in order to get an origin and destination. Results include distance and travel time as well as travel time in peak periods if available. These data are available for the entire U.S.
- **Google Transit Feed Specification (GTFS)**—The GTFS defines a common format for public transportation schedules and associated geographic information (e.g., stop/station location). GTFS was initially developed by Google in conjunction with several transit agencies for Google Transit participation and is now released under the Creative Commons Attribution 2.5 License. Transit agencies must publish their transit schedules in the GTFS in order for it to appear as mode option within Google Maps. In addition, transit agencies must agree to the Creative Commons 2.5 License. These data are available for many transit properties throughout the U.S.
- **National Household Travel Survey (NHTS)**—The NHTS is conducted on a periodic basis by the Bureau of Transportation Statistics at the U.S.

Department of Transportation. For this research, the most recently available data were from 2001. These data are available for the entire U.S.

- **WashCOG Round 7.1 Cooperative Forecast**—This dataset provides a forecast of the number of Households, Residents (Household Population), and Employment Jobs (Industrial, Retail, Office, Institutional, and Other) by individual traffic analysis zone (TAZ).These values are forecasted for 5-year increments starting 2005 and ending in 2035. In preparing the Washington DC MARS Model analysis zones, each zone is an exclusive set of TAZs. Thus, each analysis zone includes a summation of forecasted Households, Residents and Employment Jobs. Similar data is likely available for other regions in the U.S.
- **U.S. Census Bureau**—The U.S. Census Bureau implements the decennial census as well as the American Community Survey (ACS). The decennial census collects basic data for U.S. resident every 10 years while the ACS collects more detailed data for a sampling of the population over time. ACS data are available in various time series including 1-year, 3-year, and 5-year data sets. Granularity of the data various for the time series due to privacy concerns. These data are available for the entire U.S.
- **U.S. Geological Survey (USGS) Land Cover Data Set**—The USGS division maintains a dataset consisting of land cover characteristics of the U.S.. The dataset is geo-located in a GIS database and classifies land based upon 28 different codes ranging from open water (11) to developed

land (21 through 24) to wetlands (90 through 99) at a resolution of $100m^2$. This data set was used to identify land use characteristics for the Washington, DC region. For purposes of this research, the following codes were used to characterize developed, undeveloped, and protected land:

- Developed: 21, 22, 23, and 24
- Undeveloped: 31, 41, 42, 43, 52, 71, 81, and 82
- Protected: 11, 90, and 95

These data are available for the entire U.S.

The MARS model includes a robust capability to enter and manipulate network model data in Excel. The MARS Data User Interface includes a set of linked worksheets accessible from a single Excel workbook as seen in Figure 23. The Excel file is linked to the MARS model constructed in the Vensim system dynamics modeling software package through scripting languages. The ability to use Excel makes MARS tractable to any person capable of using and understanding Excel worksheets and functions such as pivot tables, copy/paste commands, filtering, sorting, etc. This includes both the network input data (described in this section) as well as the output data from the MARS model which can be easily imported into Excel (described in Section 5.4).

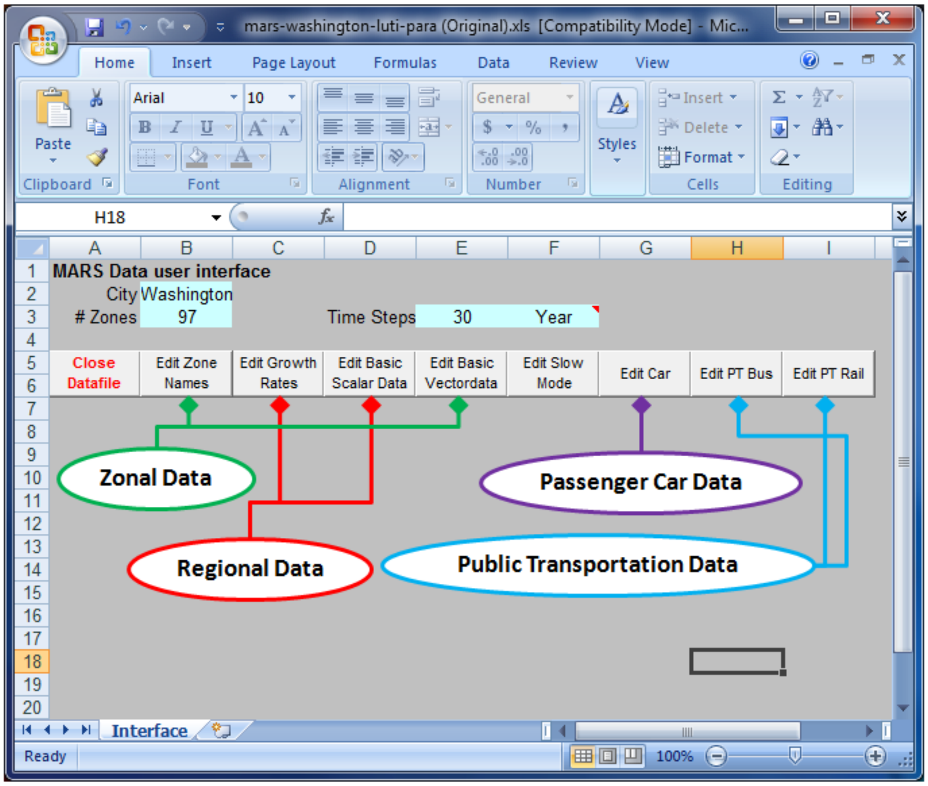

Figure 23 MARS Data User Interface

5.2.1 Regional Data

Regional data consists of eight data elements as listed in Table 9 below. The data were collected from a variety of sources that are readily available in other regions. Within the Washington DC MARS Model, these data elements are entered in the tab labeled *Growth* Rates (Figure 24) and *Basic Scalar Data* (Figure 25) both of which are accessible from the MARS Data User Interface screen. Collecting these data elements was straight-forward using readily available data.

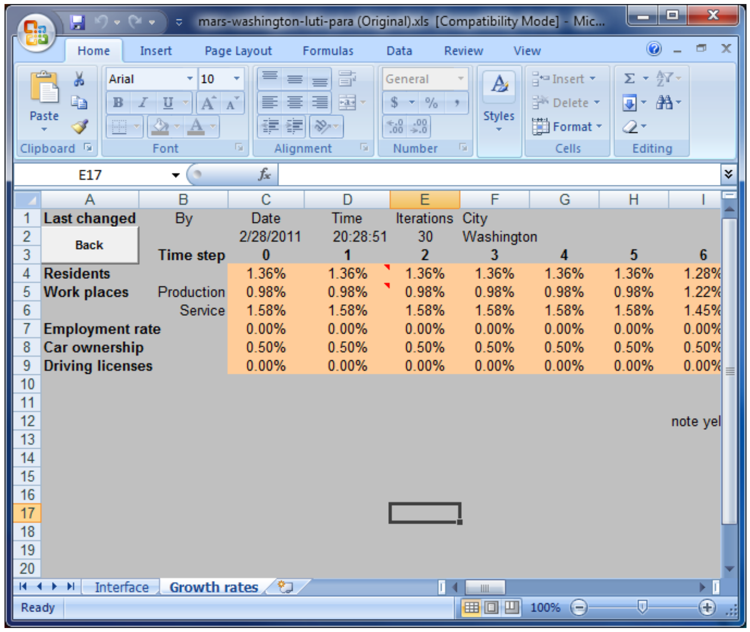

Figure 24 MARS Data User Interface: Growth Rates

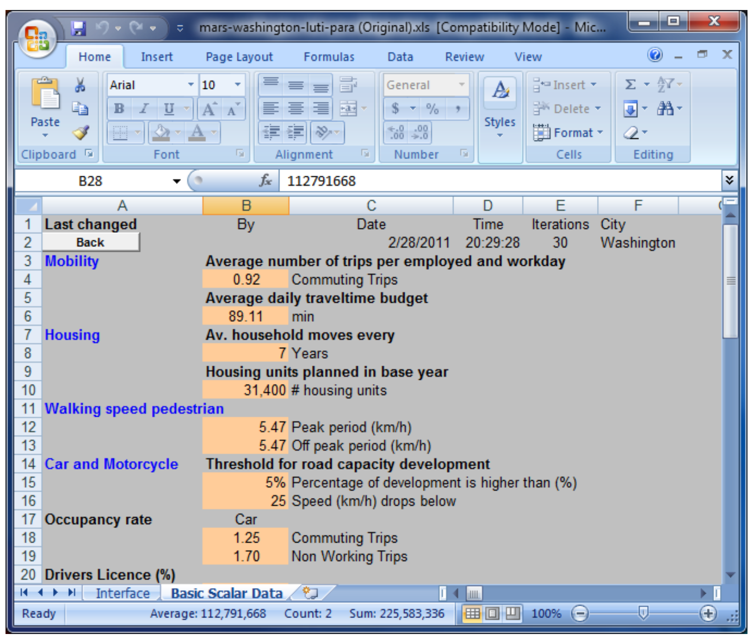

Figure 25 MARS Data User Interface: Basic Scalar Data

Table 9 Regional Data Elements

Data Element	Source	Value	Units
Average number of commuting trips	Estimate	0.92	Trips/person
Average daily travel time budget	NHTS	89.11	Minutes/person
Housing turnover rate	Estimate	7	Years
New housing units base year	GMU Center for Regional Analysis	31,400	Housing units
Average walking speed (peak and off-peak)	Estimate	3.4	kph
Vehicle occupancy rate: Commute	NHTS	1.25	Persons/vehicle
Vehicle occupancy rate: Non-commute	NHTS	1.7	Persons/vehicle
Drivers license (employed and non-employed)	Estimate	82	Percent

5.2.2 Zonal Data

Zonal data consists of 14 data elements as listed in Table 10 below. Within the Washington DC MARS Model, these data elements are entered in the tab labeled *Basic Vector Data* (Figure 26) accessible from the MARS Data User Interface screen. Following the table is a more detailed description on how each of the 14 data elements was calculated.

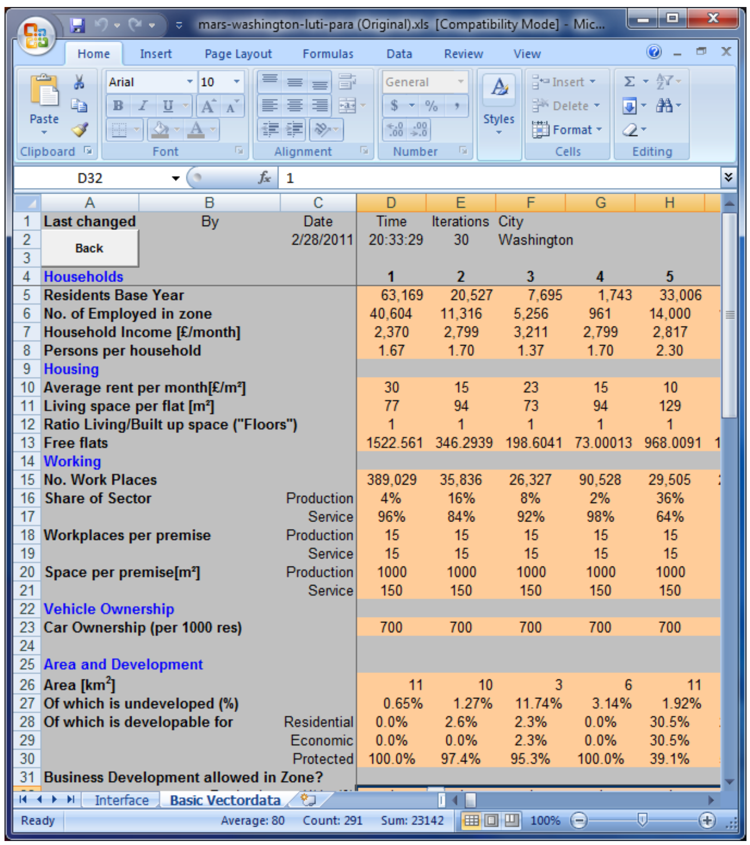

Figure 26 MARS Data User Interface: Zonal Data

Table 10 Zonal Data Elements

Data Element	Source	Units
Number of residents	WashCOG Round 7.1 Cooperative Forecast	Persons
Number of employed	WashCOG Round 7.1 Cooperative Forecast and U.S. Census (P43)	Persons
Average household income	City-data.com	Euro/month
Average household size	City-data.com	Persons/house
Average monthly housing cost	City-data.com	Euro/ m^2/month
Average house size	City-data.com	m^2
Number of empty housing units (base year)	U.S. Census	Housing units
Number of workplaces	WashCOG Round 7.1 Cooperative Forecast	Workplaces
Share of production sector and service sector jobs	WashCOG Round 7.1 Cooperative Forecast	Percentage
Area covered by each zone	WashCOG Round 7.1 Cooperative Forecast	km^2
Percent of land undeveloped	U.S. Geological Survey Land Cover Data Set	Percent
Percent of land developable for: residential, commercial, and protected	U.S. Geological Survey Land Cover Data Set and Visual Inspection	Percent
Production or service sector developed is allowed in a zone	Visual Inspection	Yes or no
Price of land	City-data.com	Euro/ m^2

- **Number of Residents**—WashCOG Round 7.1 Cooperative Forecast:

$$\sum_{MAZ}^{n} Residents$$

- **Number of Employed**—U.S. Census Bureau (Table P43):

$$Number\ of\ Residents \times \frac{Labor\ Force: Male + Labor\ Force: Female}{Total\ Population}$$

- **Average Household Income**—City-data.com:

$$\frac{Estimated\ Median\ Household\ Income}{12}$$

- **Average Household Size**—WashCOG Round 7.1 Cooperative Forecast:

$$\frac{\sum Residents}{\sum Households}$$

- **Average Monthly Housing Cost**—City-data.com:

$$\frac{Median\ Monthly\ Owner\ costs\ for\ Units\ with\ a\ Mortgage}{Average\ House\ Size}$$

- **Average House Size**—City-data.com:

$$\frac{Median\ Rooms\ (House) + Median\ Rooms\ (Apartment)}{2} \times 290$$

- **Number of Empty Housing Units**—U.S. Census Bureau: H8
- **Number of Workplaces**—WashCOG Round 7.1 Cooperative Forecast:

$$\sum_{MAZ}^{n} Employment$$

- **Share of Production Sector**—WashCOG Round 7.1 Cooperative Forecast:

$$\frac{\sum Industrial}{Number\ of\ Workplaces}$$

- **Share Service Sector Jobs**—WashCOG Round 7.1 Cooperative Forecast:

$$\frac{\sum Retail, Office, Institutional, and\ Other}{Number\ of\ Workplaces}$$

- **Area Covered by Each Zone**—WashCOG Round 7.1 Cooperative Forecast:

$$\sum_{MAZ}^{n} Acres$$

- **Percent of Land Undeveloped**—U.S. Geological Survey Land Cover Data Set:

$$\frac{\sum Undeveloped\ Land\ Values}{\sum Total\ Land\ Values}$$

- **Percent of Land Developable for: Residential, Commercial, and Protected**—

$$Protected = \frac{\sum Protected\ Land\ Values}{\sum Total\ Land\ Values}$$

$$Residential = Visual\ inspection\ of\ relevant\ county\ land\ use\ plans.$$

$$Commerical = \frac{1 - (Protected + Residential)}{Percent\ of\ Land\ Undeveloped}$$

- **Price of Land**— City-data.com:

$$\frac{Median\ house/condo\ value}{Lot\ size}$$

Collecting the required zonal data was straightforward for a majority of the data elements. A valuable data set that was available for the Washington, DC region is the WashCOG Round 7.1 Cooperative Forecast. This data set includes information concerning households, residents, and employment for each of the 2,191 TAZs which were aggregated to the 97 Washington DC MARS Model analysis zones. For any region maintaining an existing regional forecasting model, these data would likely be available. However, there is evidence calling into question the accuracy of these forecasts, especially at the individual zone level. In one analysis, population, households, and vehicles had errors up to 65 percent with employment errors of 154 percent (McCray, J. Miller, and Hoel 2009). Thus, it is important to know the inherent errors associated with these data sources.

There were three data elements that proved to be more difficult to collect in keeping with the intent of this research, which is to use readily-available data sources. First, the *Percent of Land Developable for: Residential, Commercial, and Protected* required a visual inspection of the Comprehensive Plans for each regional jurisdiction in order to get a sense of what type of land use was desired for the Washington DC MARS Model analysis zone. While most jurisdictions in the U.S. would likely have such a plan, it is not a guarantee. Thus, if a region wants to use the MARS model, it would have to find a way to estimate how developable land is intended to be used.

Second, visual inspection was also required for the data element *Production or Service Sector Development is Allowed in a Zone*. While this is a simple yes or no decision, it still required the visual inspection of the Comprehensive Plan for each jurisdiction and make a determination regarding the development of production and service sector businesses.

Finally, the *Price of Land* was a very difficult data element to calculate. In the Washington, DC region, as is likely the case for most regions in the U.S., it is difficult to estimate land values. Readily available data through websites such as www.zillow.com only report property values, which are a combination of land values and built improvements (structures) on the property. It is difficult to differentiate these values. In cases where land values can be separated from built improvements, there is no clear methodology that is consistently used among jurisdictions. Thus, even city/county tax records, if available, would not necessarily provide an accurate value. In order to maintain consistency among the Washington DC MARS Model analysis zones, the *Median House/Condo Value* available through city-data.com was used in combination with the lot size and building size was used as a proxy for land values. These data elements are available for other regions (thus enabling transferability of this research to other regions) and were fairly straightforward to collect.

5.2.3 Passenger Car Data

Passenger car data consists of six data elements as listed in Table 11 below. The data were either estimated based upon current conditions in the region (e.g., average parking costs in Downtown Washington versus Fairfax Center) or calculated using web-based mapping sources. Within the Washington DC MARS Model, these data elements are entered in the tabs labeled *Car_xxx* accessible from the MARS Data User Interface screen. A detailed description of how each data element was determined is provided following the table.

Table 11 Passenger Car Data Elements

Data Element	Source	Units
Parking cost: time	Estimate	Minutes
Parking cost: monetary	Estimate	Euros
Distance matrix among MARS analysis zones	Google Maps	km
Free-flow speed matrix among MARS analysis zones	Google Maps	kph
Peak-period speed matrix among MARS analysis zones	Google Maps	kph
Tolling charges among MARS analysis zones	Estimate	Euros

- **Parking Cost: Time**—The MARS model includes three separates concerning time associated with parking cost: walking from an origin to a car, the time associated with locating an available parking space, and the time required to walk from the car to the destination. These time costs can be estimated for each

Washington DC MARS Model analysis zone. Values of zero were used for most zones in the suburbs where parking is plentiful or freely available. Expert judgment of the researcher was used to estimate times for the analysis zones in the urbanized areas where finding a parking space can be more time consuming.

- **Parking Cost: Monetary**—Parking costs also include a monetary component. Average parking costs per stay were estimated by the researcher for the urbanized areas by analysis zone. Estimates were derived based upon out-of-pocket costs which are not necessarily the posted daily rates.
- **Distance Matrix Among MARS Analysis Zones**—The distance matrix is required in order to calculate travel times. The distance matrix includes a value between each analysis zone pair. Thus, with 97 analysis zones in the MARS Washington model, 9,409 separate values are required. Estimating these values by hand was not practical. In order to quickly and easily estimate these values, Google Maps was used since it provides routing information between two points. As seen in Figure 27, Google Maps returns three key pieces of information relevant to the MARS model: distance, average travel time, and travel time in traffic. Of concern here is the distance. In example shown in Figure 27, two lat/long coordinates representing MARS Washington analysis zones 1 and 58 (Downtown Washington and Falls Church, VA) were entered with a distance of 11.4 miles returned for the first suggested route.

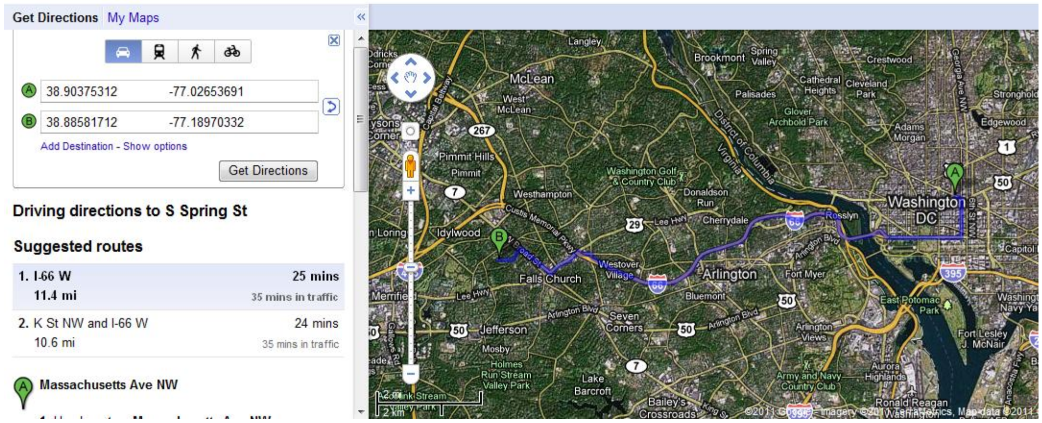

Figure 27 Google Maps Sreen Capture
Source: Google Maps. Accessed January 24, 2011.

In keeping with the intent of this research in using readily-available data, an automated routine was developed using the Python scripting language interfacing with the Google maps website (maps.google.com) that would capture key information returned from Google Maps[21]. First, the center of each MARS Washington analysis zone was determined. Second, using a lat/long coordinate for both the origin and destination analysis zone, a simple script was written to have Google Maps return a distance value between the lat/long coordinates. The value returned is not a straight line point-to-point measure, but the shortest path through the transportation network. Finally, the values returned by Google Maps were entered in to a 97x97 matrix of the analysis zones. Intra-zonal distances were also estimated for each MARS Washington analysis zone.

- **Free-flow Speed Matrix Among MARS Analysis Zones**—The free-flow speed matrix is required in order to calculate travel times. In similar fashion to the

[21] See Appendix 3 for the Python script that was used to extract the data from Google Maps. James Larkin assisted in the development of the script.

Distance Matrix Among MARS Analysis Zones, the free-flow speed matrix was created using the travel time not in traffic returned by Google Maps (25 minutes in Figure 27). The travel time was divided by the distance to calculate the free-flow speed. The travel times were calculated separately for both origin/destination pair. Thus, the free-flow speed between points A and B may be different than between points B and A.

- **Peak-period Speed Matrix Among MARS Analysis Zones**—The peak-period speed matrix is required in order to calculate travel times during the peak period. In similar fashion to the *Distance Matrix Among MARS Analysis Zones*, the peak-period speed matrix was created using the travel time in traffic returned by Google Maps (35 minutes in Figure 27). The travel time was divided by the distance to calculate the free-flow speed. Again, the travel times were calculated separately for both origin/destination pair. Thus, the free-flow speed between points A and B may be different than between points B and A
- **Tolling Charges Among MARS Analysis Zones**—Tolling charges are included to account for the total cost of traveling by car. Tolling charges are estimated based upon the researchers understanding of the Washington, DC region. Only two toll roads exist within the study area: Dulles Toll Road and the Greenway.

A major hurdle in using any transportation-based simulation model is the development of the transportation network. When first examining the use of the MARS model for this research, developing the transportation network appeared to be the most daunting task even with the simplification of the transportation network to a single link between each origin/destination pair. However, the use of web-based tools such as Google Maps and scripting languages significantly improved this aspect of building the model. In fact, since Google Maps covers all of the U.S., using the procedures documented here could be easily replicated in other regions.

One drawback of using Google Maps (or other mapping tools for that matter) is consistency in the results and a full understanding of how the data are calculated. There appears to be some inconsistency using the Google Maps when calculating a route between two lat/long coordinates. In some instances, the route between origin A and destination B is not the same using Google's Reverse Direction Feature. In some cases, the change in route makes sense in downtown areas consisting of one-way streets. In other cases, the difference did not make sense. The values that Google Maps returns concerning travel times are calculated using proprietary data collected by Google, which it does not readily share. While the travel times in free-flow conditions appears to be consistent, the travel times in peak-period conditions does change and it is difficult to know why this is so. Thus, when using Google Maps, it is important to keep an archive of the data collected for post-analysis purposes.

5.2.4 Public Transportation Data

Public transportation data consists of six data elements as listed in Table 12 below. The data were either estimated based upon current conditions in the region (e.g., average speed of MetroRail trains) or calculated using GTFS data available on the Washington Metropolitan Area Transportation Authority (WMATA) website. Within the

Washington DC MARS Model, these data elements are entered in the tabs labeled *PT_Rail_xxx* accessible from the MARS Data User Interface screen. A detailed description of how each data element was determined is provided following the table.

Table 12 Public Transportation Data Elements

Data Element	Source	Units
Station Distance Matrix	GTFS	km
Walk to Station Time	Estimate	Min
Train Headway Matrix	GTFS	km
Transfer Matrix	Estimate	Min
Train Speed Matrix	WMATA	kph
Station Fare Matrix	GTFS	Euros

- **Station Distance Matrix**—The GTFS was used in combination with Google Earth to determine transit network distances (not straight-line distances) between stations. The GTFS includes the latitude and longitude for each MetroRail station. These locations were entered in Google Earth whereby the measure function was used to trace the MetroRail track location between stations. These values were saved in an MS Excel spreadsheet where further analysis was conducted to create the Station Distance Matrix. In some analysis zones multiple MetroRail stations were available. In these instances the distances between stations was averaged to create a single value.

- **Walk to Station Time**—The walk time to stations is important to account for the amount of time required for an entire transit trip. The Walk to Station Time is an average time for each station origin and destination pair. These values were estimated based upon the researchers understanding and knowledge of the region.
- **Train Headway Matrix**—The GTFS was used to calculate average headways between trains for both the peak periods and off-peak periods.
- **Transfer Matrix**—The transfer matrix includes the average time it takes an individual to transfer from train to another train. This would include the walk time between trains (e.g., switch platforms) and the average wait time between trains. These values were estimated.
- **Train Speed Matrix**—Average train speeds between stations was estimated based upon existing performance data from WMATA. Average train speeds were estimated for different station types: suburban and urban. Train speeds were slower in the urban stations due to the closer spacing of stations in urban areas (e.g., Northwest DC).
- **Station Fare Matrix**—The GTFS was used to calculate fare charges between MetroRail stations. Because MetroRail uses both a time-of-day and distance-based rate, it was important to capture these costs for both the peak and off-peak periods.

It is important to note that the MARS model can account for both fixed-route transit (e.g., BRT, LRT, HRT) and bus service. For purposes of this research, only the

WMATA fixed-route rail service (MetroRail) was included in the analysis. The reason for this is two-fold. First, the Washington, DC region includes more than ten different transit agencies operating bus systems and it would be difficult to include all of these services in the Washington DC MARS Model given current resources. Second, not all of the regional operating agencies include their bus operating data in the GTFS format. GTFS greatly streamlined the process of developing the required distance, headway, and fare matrices required.

While the omission of bus service is important to note, the impact on the overall results of this research is not significant due to the spatial scale at which individual zones have been established. Rail transit trips are generally longer in nature and are more important to capture at the regional level. This was an important consideration between the MARS model developers and this researcher. Given this was the first application of MARS in the U.S., it was important to determine how transit trips would be accounted for in the model given the general lack of transit accessibility in the U.S. compared to where the MARS model has been applied elsewhere. However, future analysis of the MARS model in the U.S. will need to include bus trips.

The collection and assembly of the public transportation data was greatly facilitated by the GTFS data set. Without this data set and the web-based applications provided by Google at no charge, it is unlikely that the data could have been collected in such an efficient manner. Because the GTFS is becoming a *de-facto* standard used throughout the transit industry, the ability of other regions to have access to this data is very high.

5.3 CALIBRATION

Model calibration and validation are an important considerations of any simulation model, be it a sketch planning tool such as the MARS model or an agent-based microsimulation model. For purposes of this research, model calibration is defined as the process of estimating the model inputs and parameters such that the output of the model fits an observed data set. The process of model validation uses a calibrated model and compares model outputs with a secondary observed data set. Model validation is undertaken in Section 5.4, Reasonableness Checking.

The MARS model requires the calibration of the two sub-models: the transportation sub-model and the land-use sub-model. In keeping with the nature of this research, readily-accessible calibration data sets are used such that the approach of this research can be replicated in other regions of the U.S. For the transportation sub-model, the 2001 National Household Travel Survey (NHTS) data were used. For the land use sub-model, the Census Transportation Planning Products (CTPP) 3-year tabulations were used. Both of these data sets are readily available covering the entire U.S. The following sections document the process that was used to calibrate the transportation and land use sub-models for the Washington Region MARS Model.

5.3.1 Transportation Sub-model

Calibration of the Washington Region MARS transportation sub-model follows the same method as developed by Pfaffenbichler for the Vienna, Austria MARS model (Pfaffenbichler 2008). First, total trips are examined by purpose in terms of commuting trips (Home-Work-Home) and other trips (Home-Other-Home). Second, mode splits (total) are examined in terms of car and rail utilization. Finally, trip generation by individual MARS analysis zone is examined. The method developed by Pfaffenbichler is robust in nature and allows the analyst to adjust several different input variables to adjust the model to reflect that of the calibrated data set. In addition, a number of different parameter values can be further adjusted to better reflect real-world conditions. For purposes of this research, initial parameters developed for the Leeds, England MARS model were initially used and later adjusted in order to establish a calibrated Washington Region MARS model.

The observed data set which was used to calibrate the transportation sub-model is the 2001 NHTS. The NHTS data set provides data on personal travel behavior, trends in travel over time, and trip generation rates to use as a benchmark in reviewing local data, and data for various other planning and modeling applications (FHWA 2004). NHTS data has been collected on a periodic basis since 1969. The most recent collection period was 2009. The 2001 NHTS data set was used because it provided the necessary data at the required spatial scale (trip generation rates at the traffic analysis zone level). Future analysts will be able to use the 2009 NHTS data set as it is developed over the upcoming years.

The process of developing the necessary calibration data set required manipulation of the 2001 NHTS data set to create a 2005 NHTS Estimated data set. The 2005 NHTS Estimated data set was used to compare to the outputs of the Washington Region MARS model. In order to calculate the 2005 NHTS Estimated data set, the following process was used:

1. 2001 NHTS data set was downloaded for the required geographic regions covered by the Washington Region MARS Model at the TAZ level.
2. The personal trip rates per household for each 2001 NHTS TAZ were averaged over the Washington Region MARS model analysis zones such that 97 different trip generation values were estimated.
3. The trip generation rates were applied to the given number of households within each Washington Region MARS model analysis zone.
4. The percentage of commuting trips (PEAK) and other trips (OFFPEAK) were estimated for each Washington Region MARS Model analysis zone based upon the Trip Purpose for each TAZ in the 2001 NHTS data set. Both PEAK and OFFPEAK trips include work and non-work trips.

Using this procedure, Table 13 was produced and was used as the observed data set. Note that only the first 16 rows and last row are included in this table:

Table 13 2005 NHTS Estimate

MAZ	Name	Commuting (PEAK)	Other (OFFPEAK)
		2005 NHTS Estimate	2005 NHTS Estimate
1	Downtown Washington	23,585	50,620
2	Southwest/Navy Yard	6,481	13,909
3	Georgetown	3,507	7,528
4	Monumental Core	705	1,514
5	New York Avenue	8,519	18,285
6	Friendship Heights	8,035	17,246
7	NE DC	27,171	58,317
8	NW DC	20,743	44,519
9	Embassy Row	15,024	32,245
10	Anacostia	19,124	41,045
11	Capitol Hill	13,752	29,516
12	East Capitol Street	14,831	31,831
13	Bethesda CBD	43,929	88,159
14	Silver Spring CBD	48,932	98,198
15	North Bethesda	51,675	103,704
16	Rock Spring Park	4,093	8,213
…	…	…	…
97	Manassas	28,975	59,205

The first step in calibrating the transportation sub-model of the Washington Region MARS Model was to analyze the total trips produced. The initial model outputs were overestimating the total number of trips. Within the MARS model, the Regional Data variables *Average Number of Commuting Trips* and *Average Daily Travel Time Budget* were modified based upon the work of Lopes such that the total number of trips generated was within reason (Lopes 2010). In order to better model the Commuting and Other trips, the *Vehicle* occupancy rates were adjusted[22]. The final results of calibrating

[22] Final results of the calibration process are the following:
Average Daily Travel Time Budget = 89.11 minutes/person; *Average Number of Commuting Trips* = 0.92 per person; and *Vehicle Occupancy Rate* = 1.25 (commuting) and 1.70 (non-commuting)

the total trips produced by the model are seen in Table 14 below. The Washington Region MARS Model is underestimating both the total number of trips as well as the distribution of trips between purposes. Generally accepted guidelines are to consider calibration results reasonable if the difference is plus or minus 10 percent (Cambridge Systematics and FHWA Travel Model Improvement Program 2001). As seen in Table 14, the results are well within reason with a maximum difference on 4.3 percent.

Table 14 Calibration—Total Trips

	2005 NHTS Estimate	MARS Washington	Difference	Percent
Total	6,888,073	6,699,552	-188,521	-2.7%
Commuting (HWH)	2,305,585	2,206,419	-99,166	-4.3%
Other (HOH)	4,582,488	4,493,134	-89,355	-1.9%

The second step in calibrating the transportation sub-model of the Washington Region MARS Model was to analyze the mode split. While the MARS Model can accommodate up to four different modes (car, rail, bus, other), for purposes of this research, only the car and rail modes were considered. In addition, while the 2001 NHTS data set was useful in total trips, it did not provide sufficient data at the required geographic spatial scale to estimate public transportation trips by mode (rail versus bus). In this instance, the 2001 NHTS data set was supplemented with data collected by the American Public Transportation Association (APTA) called the Transit Ridership Report. The Transit Ridership Report is an aggregation of self-reported ridership data by mode that members of APTA report on a monthly basis. The value for the fourth quarter of 2005 for WMATA MetroRail service was used to estimate the mode split values as indicated in Table 15 below (APTA 2005)[23]. As seen in the table, the MARS model is overestimating the number of rail trips by 18.2 percent. The reason for the discrepancy is not clear since a number of different parameters were adjusted with similar results. One conclusion is that the MARS model may not have enough sensitivity to travel time, and selecting one mode over another is not as simple as which is the least cost, but which is more convenient or comfortable, a factor difficult to represent in a simulation model.

Table 15 Calibration—Mode Split

Total	2005 NHTS Estimate	MARS Washington	Difference	Percent
Car	5,891,873	5,521,924	-369,949	-6.3%
Rail	996,200	1,177,628	181,428	18.2%
Total	6,888,073	6,699,552	-188,521	-2.7%

The third step in calibrating the transportation sub-model of the Washington Region MARS Model was to analyze the total number of trips being produced by each MARS analysis zone. First, Commuting Trips were examined and are shown in Figure 28. Second, Other Trips were examined and are shown in Figure 29.

Regression analysis was used to determine how well the Washington DC MARS Model outputs fit with the 2005 NHTS Estimate and is an is an appropriate method to

[23] This is a single aggregate value reported by WMATA. WMATA does provide trips by rail station.

examine the conformity between calculated values (Washington DC MARS Model outputs) and observed values (2005 NHTS Estimate). In regression analysis, a good fit between observed value (x variable) and calculated value (y value) is characterized where the parameters for the equation of a line, $y = a + bx$, are:

a close to 0;

b close to 1; and

R^2 close 1.

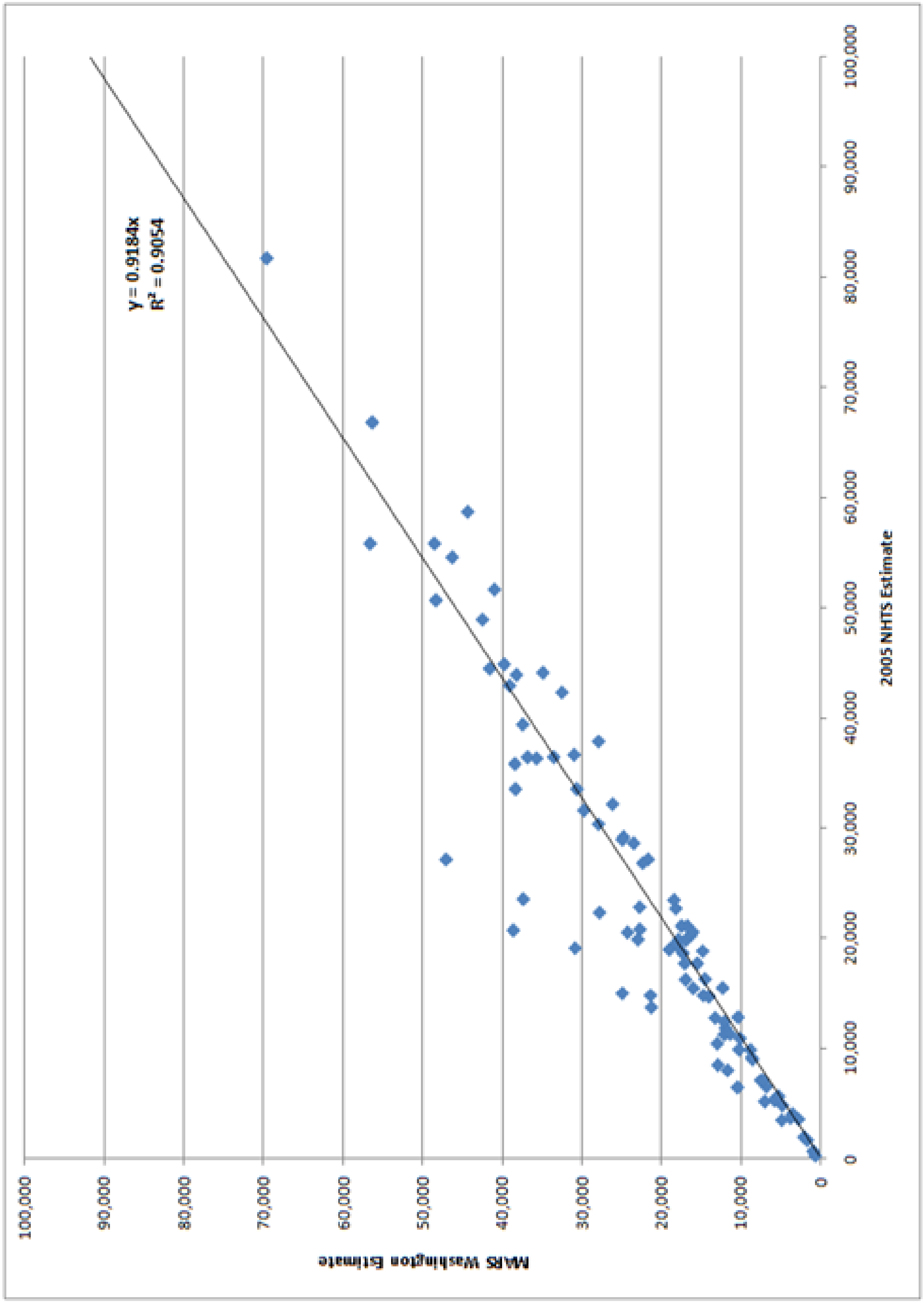

Figure 28 Calibration—Commuting Trips by Zone

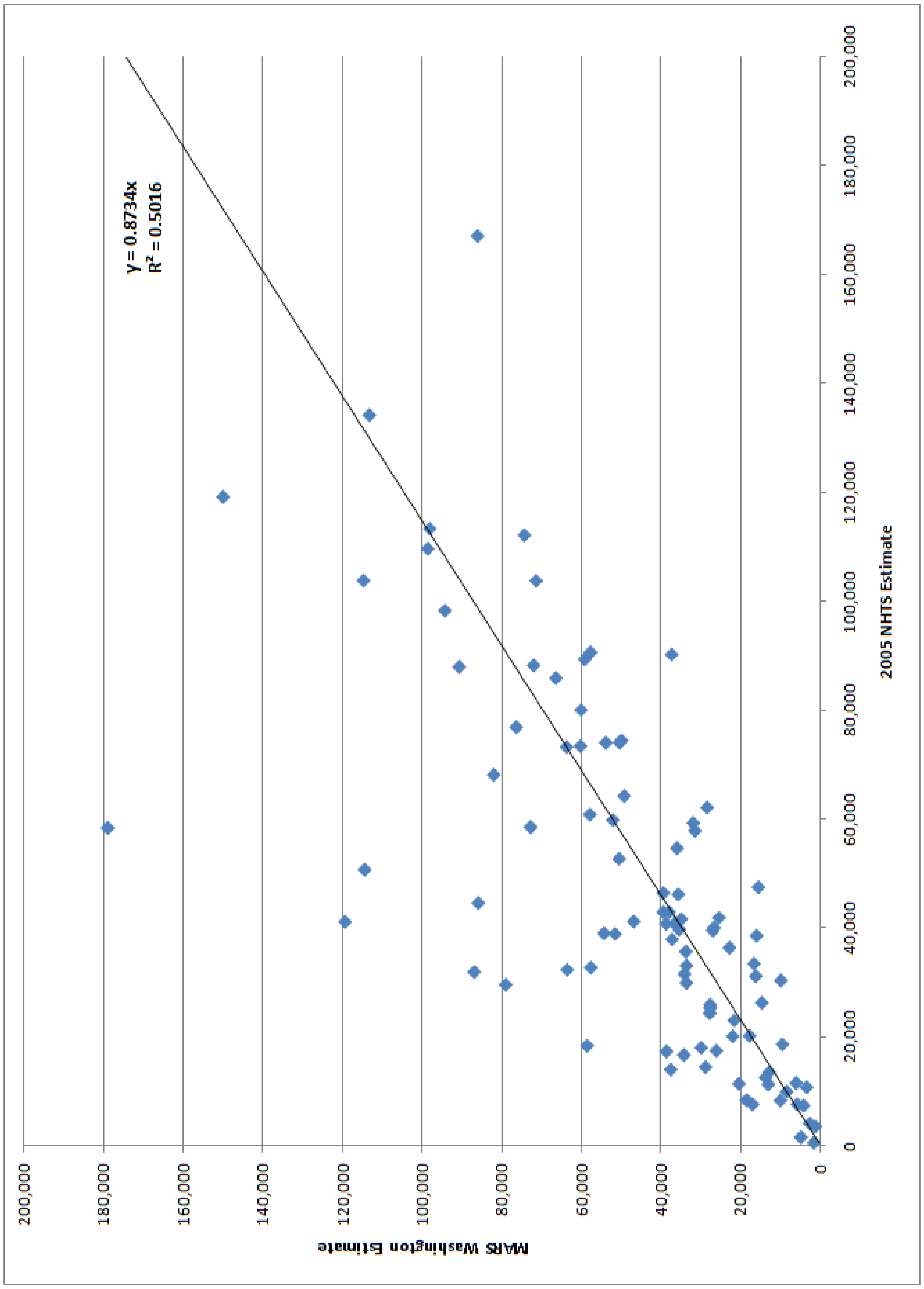

Figure 29 Calibration—Other Trips by Zone

As seen in Figure 28 and Figure 29, the Washington Region MARS model performs better at estimating the trips generated by zone for commute trips than for the other trips. For commuting trips, the regression analysis produced an R^2 value of 0.9054 indicating a strong correlation between the MARS Washington trips produced by zone and those of the 2005 NHTS Estimate. However, similar results were not obtained for the other trips, which had an R^2 value of 0.5051. One reason for the discrepancy in the accuracy of other trips being produced may lie within the NHTS data itself. Commuting trips are fairly easy to identify and indicate on a survey form. Other trips are more difficult to understand since a person does not necessarily travel neatly from home and to home, but rather does trip chaining (home-day care-grocery-cleaners-home). The NHTS data do not accurately represent these types of trips nor does the MARS model accurately represent these trips. Future refinement of the MARS model may need to focus on disaggregating other trips to better represent the types of trips being made since non-commute trips are inherently more variable than commuting trips.

5.3.2 Land Use Sub-model

Calibration of the Washington Region MARS land use sub-model follows a similar method as developed by Pfaffenbichler for the Vienna, Austria MARS model (Pfaffenbichler 2008). The number of residents is calibrated followed by the number of workers. The observed data set which was used to calibrate the land use sub-model is the CTPP 3-year tabulations.

The method used in this research is a modified approach since the observed data set is not available at desirable spatial scale. In order to use the CTPP 3-year tabulation data set to calibrate the Washington Region MARS model, the land use sub-model had to be calibrated at a larger spatial scale than desirable. Due to constraints associated with the analysis of the data, the 3-year tabulations are only available for a geographic region with a minimum population of 60,000 people. For example, the City of Falls Church, VA, (Washington Region MARS model analysis zone number 58) has a population of roughly 44,000 people. Thus, the CTPP 3-year tabulation is not available for the City of Falls Church. For this research, the land use sub-model was calibrated to the following eight geographic regions: District of Columbia, Montgomery County (Maryland), Prince George's County (Maryland), Arlington County (Virginia), Fairfax County (Virginia), Prince William County (Virginia), and Alexandria City (Virginia).

The first step in calibrating the land use sub-model was to examine residents. For this research, the number of residents estimated by the Washington Region MARS model for year 4 (2008) was compared with the CTPP 3-year tabulations. As seen in Table 16, the end result of the calibration process yielded acceptable results. In the future, more spatially disaggregate data will likely be available as the CTPP 5-year tabulations are created. However, these data will not likely yield better results. In fact, there will likely be more variability in the difference between the observed and model outputs.

Overall, the Washington Region MARS model overestimated the total number of residents in 2008 by 2.3 percent. For each of the geographic regions, the results of Washington Region MARS model were acceptable. The major concern is the overestimation of residents in Fairfax County and the underestimation of residents in Alexandria City. One reason for these discrepancies is the geographic boundaries of the

MARS analysis zones. It is important that the MARS analysis zones are developed knowing what data set will be used for calibration such that accurate an accurate data set can be developed. In this case, the MARS analysis zones did not follow the strict boundaries of Alexandria City in order to better capture the land use occurring in the analysis zone.

Table 16 Calibration—Residents

Location	CTPP (3-year Tab)	MARS Washington 2008	Difference	Percent
District of Columbia	588,375	581,841	-6,534	-1.1%
Montgomery County, Maryland	942,745	935,139	-7,606	-0.8%
Prince George's County, Maryland	825,925	850,593	24,668	3.0%
Arlington County, Virginia	204,890	193,368	-11,522	-5.6%
Fairfax County, Virginia	1,029,260	1,135,346	106,086	10.3%
Prince William County, Virginia	358,720	350,869	-7,851	-2.2%
Alexandria City, Virginia	140,655	127,692	-12,963	-9.2%
Loudoun County, Virginia	277,435	292,299	14,864	5.4%
Total	4,368,005	4,467,147	99,142	2.3%

The second step in calibrating the land use sub-model was to examine workers. The same data set as used for residents was used for workers. MARS separates Workers into two categories: production sector and service sector. The CTPP job codes that were used for both production sector and service sector jobs are summarized below. These jobs include both full- and part-time jobs since CTPP does not differentiate between a fully employed and partially employed person:

- **Production Sector Job Codes—**Construction; Manufacturing; and Wholesale Trade.
- **Service Sector Job Codes—**Retail Trade; Transportation and Warehousing, and Utilities; Information; Finance, Insurance, Real Estate and Rental and Leasing; Professional, Scientific, Management, Administrative, and Waste Management Services; Educational, Health and Social Services; Arts, Entertainment, Recreation, Accommodation and Food Services; Other Services (except Public Administration); Public Administration; and Armed forces.

Three separate analyses were conducted examining workers—all workers, production sector workers, and the service sector workers. The following three tables provide a summary of the calibration results. Table 17 provides a summary of all workers and shows that MARS Washington overestimates the total number of workers by 12.4%. Table 18 provides a summary of only the production sector workers and shows that MARS Washington overestimates the number of production sector workers by 9.3 percent. Finally, Table 19 provides a summary of only the service sector workers and shows that MARS Washington overestimates the number of service sector workers by 12.8 percent. As seen with these results, calibrating the land use sub-model in terms of workers was not ideal. Generally speaking, the Washington Region MARS model overestimates the number of workers for both the production and service sector. Part of the error likely comes from the discrepancies in terms of job classification for both the MARS input data and the CTPP data.

Table 17 Calibration—Workers (All)

Location	CTPP (3-year Tab)	MARS Washington 2008	Difference	Percent
District of Columbia	729,815	753,159	23,344	3.2%
Montgomery County, Maryland	466,250	514,618	48,368	10.4%
Prince George's County, Maryland	318,615	376,357	57,742	18.1%
Arlington County, Virginia	174,575	199,979	25,404	14.6%
Fairfax County, Virginia	589,560	718,671	129,111	21.9%
Prince William County, Virginia	117,520	146,187	28,667	24.4%
Alexandria City, Virginia	93,850	90,002	-3,848	-4.1%
Loudoun County, Virginia	121,255	135,473	14,218	11.7%
Sum	2,611,440	2,934,446	323,006	12.4%

.

Table 18 Calibration—Workers (Production Sector)

Location	CTPP (3-year Tab)	MARS Washington 2008	Difference	Percent
District of Columbia	42,685	60,457	17,772	41.6%
Montgomery County, Maryland	55,690	43,464	-12,226	-22.0%
Prince George's County, Maryland	54,655	44,144	-10,511	-19.2%
Arlington County, Virginia	12,265	24,574	12,309	100.4%
Fairfax County, Virginia	71,625	73,434	1,809	2.5%
Prince William County, Virginia	22,115	37,649	15,534	70.2%
Alexandria City, Virginia	9,830	9,572	-258	-2.6%
Loudoun County, Virginia	21,165	23,730	2,565	12.1%
Sum	290,030	317,023	26,993	9.3%

Table 19 Calibration—Workers (Service Sector)

Location	CTPP (3-year Tab)	MARS Washington 2008	Difference	Percent
District of Columbia	687,130	692,702	5,572	0.8%
Montgomery County, Maryland	410,560	471,154	60,594	14.8%
Prince George's County, Maryland	263,960	332,213	68,253	25.9%
Arlington County, Virginia	162,310	175,405	13,095	8.1%
Fairfax County, Virginia	517,935	645,237	127,302	24.6%
Prince William County, Virginia	95,405	108,538	13,133	13.8%
Alexandria City, Virginia	84,020	80,431	-3,589	-4.3%
Loudoun County, Virginia	100,090	111,743	11,653	11.6%
Sum	2,321,410	2,617,423	296,013	12.8%

5.3.3 Calibration Findings

Calibrating the Washington Region MARS model consisted of assessing the transportation and land use sub-models separately, using two different calibration data sets. The transportation sub-model was calibrated first using data from the 2001 NHTS in terms of total trips, model split, and trips by zone. The land use sub-model was calibrated second using data from the CTPP 3-year tabulation for 2006 to 2008 in terms of residents and workers (all, production sector, and service sector). Overall, the calibration of the Washington Region MARS model was successful. Both the transportation and land use sub-models were calibrated within a reasonable amount error given the nature of the MARS model.

However, the calibration was not perfect and further improvements could be made. First, the calibration process required two different data sets since no single data set existed. In addition, these data sets were from different time periods (2001 for the NHTS and 2006 to 2008 for the CTPP). A more robust calibration process would include either a single data set or two data sets from the same time period. Second, the Washington Region MARS model was overestimating the number of rail transit trips. One possible reason is the intangible effects of using rail transit which are not accounted for in a travel time and dollar cost value. While MARS does separate a trip into its different components (travel time, fare, parking cost, wait time, transfer time, etc.) there is an intangible component (e.g., ride smoothness, vehicle cleanliness, riders perception of the visual appeal of the system) which may need to be better accounted for in the MARS model. Finally, the land use sub-model could not be calibrated at the desired spatial scale (individual MARS analysis zones). However, once the CTPP 5-year tabulations (2006-2010) are released in early 2012, data will be available for geographic regions with a population as small as 20,000. This would facilitate calibrating the model at the desired spatial scale.

5.4 REASONABLENESS CHECKING

An important aspect of developing and deploying a computer modeling tool for transportation and land use planning is to validate the model and ensure that the results of the model in terms of its analytical capability are reasonable. Model validation can take on different definitions depending on the situation and whom one talks to. For purposes of this research, model validation is defined as using a calibrated model and comparing estimated model outputs with a secondary observed data set. In other words, one needs two independent data sets to perform both model calibration and validation. However, no secondary data source exists for the Washington Region MARS model since it uses 2005 as a base year and a 30-year time horizon to 2025. This is a common problem for most any large scale ITLUM tool.

An alternative approach, and one that is encouraged for system dynamics models, is to conduct reasonableness checking which builds confidence in the use of the model and examines the overall purpose and role of the model itself (Forrester 2001). Forrester suggested that a model should be judged not on its absolute validity but on its overall usefulness. In other words, it is more important that the model be used to create confidence in supporting a decision rather than necessarily identifying the correct decision[24]. Thus, it is more important to build and establish confidence when using a system dynamics model rather than establishing its absolute validity in predicting forecasts 10, 20, or 30 years into the future. To this end, model validation is concerned more appropriately with how the Washington Region MARS model performs in comparison to other models that are used to support decision making associated with transportation and land use policies.

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[24] Of course, it is critical that the model include a boundary of acceptability. A model that is consistently off by 50 percent is not useful. Thus, any model needs to be correct to some degree. The required “degree of correctness” of the model is often a function of the decision being supported (see Section 7.1)

One method to establish confidence in a model, and ensure the reasonableness of its outputs and functionality, is to compare the results of a calibrated model against those of an existing model that has been used to conduct similar forecasts. This is the approach undertaken in this research and uses a study published by the National Capital Region Transportation Planning Board (TPB) examining alternative land use and transportation scenarios as the existing (or baseline) model results (McAuslan and Ransome 2006). Using the TPB report as the baseline, this research compares the results of the Washington Region MARS model with that of the TPB report in terms of three different measures of effectiveness: land use (residents and workers), mode split, and vehicle travel. The purpose of this analysis not to determine if the results match absolutely, but whether there are similarities in terms of directionality (e.g., increase or decrease in residences), order of magnitude changes (e.g., 1 percent versus 10 percent change in mode split), and spatial location of the changes in the region. The Washington Region MARS model was used since it was successfully calibrated as discussed in Section 5.3.

5.4.1 Scenario Construction

In the TPB report, five different scenarios were analyzed using the existing regional travel demand model. For purposes of this research in conducting the reasonableness checking of the Washington Region MARS model, two of the five scenarios from the TPB report were examined. In addition, a third scenario was created but not examined in the TPB report related to road user charges. The three scenarios are described below and were chosen since they could be examined using the Washington

Region MARS model and also represent different aspects of the key policy tools driving metropolitan planning today (Section 2.2, Policy Tools Driving Metropolitan Planning):

1. **Transit Oriented Development for Rail (TOD-Rail)**—The Transit Oriented Develop for Rail scenario is designed to test the effects of concentrating more of the region's growth in areas that could be served by rail transit. The scenario that was constructed for the Washington Region MARS model focused only of rail since buses are not included in the model. The TBP model included additional commuter rail and BRT service as well. In the Washington Region MARS model this scenario was constructed by increasing land use densities in those MARS analysis zones that contained rail transit stations (zones 1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, 18, 28, 30, 34 ,36, 40, 43 ,44, 45 ,46, 47, 48, 49, 50, 51, 52, 53, 54, 58, 62, 69, and 73)
2. **Region Undivided (RU)**—The Region Undivided scenario is designed to test the effects of enabling workers to live closer to their jobs by assuming shifts in future job and household growth from the western portion of the region (Montgomery County, Maryland; Loudoun County and Fairfax County, Virginia) to the eastern portion of the region (Prince George's County, Maryland). In the Washington Region MARS model, this was accomplished by shifting job and residential growth to the MARS

analysis zones associated with Prince George's County (zones 30 through 44)

3. **Road User Charges (RUC)**—The Road User Charge scenario is not one of the five included in the TPB report. This scenario is designed to test the effects of increasing road user charges through a RUC fee for the entire region. This scenario includes two different sub-scenarios including a low and high user charge to assess the sensitivity of the Washington Region MARS model.

5.4.2 Comparison of MARS Washington Scenarios

Four different scenarios were analyzed using the calibrated Washington Region MARS model: TOD-Rail, RU, RUC-High, and RUC-Low. The calibrated Washington Region MARS model is considered the Baseline scenario. The comparison of the results is for the forecast year of 2025 which is consistent with the analysis of the TPB report. The results of the analysis are shown in Table 20. In the table, the values for each measure are shown in the top row with the percent difference calculated for each measure and scenario against the baseline scenario in the bottom row. For example, TOD-Rail scenario had a value of 125,395,955 for VMT which is a 5.7 percent reduction in VMT and 16.7 percent increase in transit trips compared to the baseline scenario. The following sub-sections discuss each scenario in more detail.

Table 20 Scenario Analysis Summary

Measure	Baseline	TOD-Rail	RU	RUC-Low	RUC-High
VMT	132,919,956	125,395,955	136,841,050	131,308,482	128,911,616
	-	-5.7%	2.9%	-1.2%	-3.0%
Trips	7,897,541	7,963,960	8,182,902	7,609,941	7,346,616
	-	0.8%	3.6%	-3.6%	-7.0%
Car	6,118,196	5,887,354	6,347,204	5,750,971	5,414,467
	-	-3.8%	3.7%	-6.0%	-11.5%
Transit	1,779,315	2,076,606	1,835,698	1,858,940	1,932,119
	-	16.7%	3.2%	4.5%	8.6%
Land Use	9,729,095	9,731,899	9,990,877	9,666,689	9,566,046
	-	0.0%	2.7%	-0.6%	-1.7%
Residence	5,694,728	5,699,691	5,777,691	5,634,746	5,539,689
	-	0.1%	1.5%	-1.1%	-2.7%
Workers	4,034,368	4,032,209	4,213,186	4,031,943	4,026,357
	-	-0.1%	4.4%	-0.1%	-0.2%

TOD-Rail

The results of the TOD-Rail scenario are generally what one would expect to see. In this scenario, land use development potential was increased in the analysis zones with rail stations. Overall, VMT is projected to decrease while the total number of trips will increase. Within the trips, the number of car trips will be reduced by 3.8 percent and the rail transit trips will increase by 16.7 percent. The other important component of this scenario is the location of where new development for houses and jobs is going to occur. Because this scenario favors development around transit stations, one would expect to see an increase in residences and employment in analysis zones with rail transit stations. As seen in Table 21, this is what occurs in the Washington Region MARS model. At the aggregate level, there is a five percent decrease in residences and employment locations in non-transit zones and an eight percent increase in zones with transit stations. At the disaggregate scale of individual analysis zones, the difference in land use changes is similar but not consistent in terms of the amount of change. Lower numbered zones (located closer to the Washington CBD) saw lower changes and higher numbered zones (located further away from the Washington CBD) saw larger changes[25].

Table 21 TOD-Rail Scenario: Land Use Changes

Zones	Baseline	TOD-Rail	Difference
Non-Transit	2,449,499	2,321,100	-5%
Transit	1,584,868	1,711,109	8%
1	388,112	387,926	0%
2	34,594	34,228	-1%
3	6,289	3,588	-43%
4	85,904	86,197	0%
5	29,340	29,462	0%
6	20,443	20,803	2%
7	43,900	44,144	1%
8	24,249	25,445	5%
10	26,147	27,003	3%
11	19,204	19,149	0%
12	17,081	19,753	16%
13	76,072	77,201	1%
14	43,215	43,621	1%
15	75,950	82,353	8%
18	76,788	80,855	5%
28	26,693	30,009	12%
30	42,862	46,568	9%
34	35,744	49,316	38%
36	38,263	39,676	4%
40	91,640	123,584	35%
43	23,977	27,420	14%
44	12,919	22,255	72%
45	12,534	14,263	14%
46	68,078	68,435	1%

[25] See Table 8 for a listing of zone names.

Zones	Baseline	TOD-Rail	Difference
47	10,792	11,632	8%
48	27,625	27,995	1%
49	17,233	17,540	2%
50	4,533	4,568	1%
51	23,408	23,437	0%
52	17,750	17,926	1%
53	17,155	17,486	2%
54	20,944	22,230	6%
58	24,984	28,375	14%
62	18,898	42,945	127%
69	55,368	64,186	16%
73	26,179	29,535	13%

Region Undivided

The Region Undivided scenario had different results than the TOD-Rail scenario. In the Region Undivided scenario, the projected increase in workers and residents was forecast to occur in the eastern portion of the region, primarily Prince George's County, Maryland. Overall, VMT and trips were projected to increase by 2.9 percent and 3.6 percent, respectively. An analysis of the land use changes is shown in Table 22. As seen in the table, the Region Undivided scenario projected a 2.7 percent increase in both residents and workers in the region with a significantly higher amount (27 percent) occurring in Prince George's County.

Table 22 Region Undivided Scenario: Land Use Changes

Region	Baseline	RU	Difference
District of Columbia	1,328,519	1,327,823	-0.1%
Montgomery County, Maryland	1,881,479	1,864,561	-0.9%
Prince George's County, Maryland	**1,741,198**	**2,139,529**	**22.9%**
Arlington County, Virginia	390,221	390,279	0.0%
Fairfax County, Virginia	2,719,242	2,601,194	-4.3%
Prince William County, Virginia	682,229	686,782	0.7%
Alexandria City, Virginia	250,841	251,053	0.1%
Loudoun County, Virginia	735,365	729,656	-0.8%
Sum	**9,729,095**	**9,990,877**	**2.7%**

Road User Charge

The Road User Charge scenario analyzed the effect that a simple road user fee would have on the transportation and land use system. In the MARS model, the road user fee was modeled as a single additional cost per car trip. The RUC-Low was $5 per trip and the RUC-High was $10 per trip. The results are what one would expect. Total VMT is projected to decrease for both the RUC-Low and RUC-High scenarios. In terms of trips, the total number of trips is projected to decrease, but the number of rail transit trips will increase due to the implementation of the road user charge. Regarding the sensitivity of the Washington Region MARS model to a road user charge, Table 23 shows the difference in VMT and Trips by mode due to a doubling of the road user charge from $5 to $10 per trip. As seen in the table, doubling the road user charge yields a 1.8 percent decrease in VMT, a 5.9 percent decrease in car trips, and a 2.9 percent increase in transit trips.

Table 23 Road User Charge Scenario: Sensitivity

Measure	RUC-Low	RUC-High	Difference
VMT	131,308,482	128,911,616	-1.8%
Trips	7,609,941	7,346,616	-3.5%
Car	5,750,971	5,414,467	-5.9%
Transit	1,858,940	1,932,119	3.9%

5.4.3 Validation of MARS Washington

Table 24 provides a summary of the comparison between the results of the TPB study and the Washington Region MARS model. In both cases the comparison is between the final forecasted year for each model (2030 for the TPB study and 2025 for the Washington Region MARS model). In the table, a shaded cell indicates a discrepancy between the directionality of the measure while underlining indicates a difference in the order of magnitude of the measured values. In general, the results of the Washington Region MARS model track well with the TPB study regarding the directionality of the values.

Table 24 Scenario Comparison: TPB versus MARS

Measure	TOD-Rail		Region Undivided	
	TPB	*MARS Washington*	*TPB*	*MARS Washington*
VMT	↓ by 0.8%	↓ by 5.7%	↓ by 1.0%	↑ by 2.9%
Mode Split	↑ transit trips by 8.8%	↑ transit trips by 16.7%	↑ transit trips by 7.9%	↑ transit trips by 3.2%
Land Use	↑ growth near transit stations	↑ growth in analysis zones with transit stations	↑ growth in Prince George's County	↑ growth in Prince George's County

In all but one instance (VMT measure for the Region Undivided scenario), the directions of the measured change are consistent. For both scenarios, the TPB study projected a decrease in VMT and an increase in mode split and land use. MARS estimated an increase in VMT for the Region Undivided scenario. In examining the land use changes of where residents and workers were locating, it was apparent that there were increases in the outer regions (Prince William and Loudoun County) resulting in additional VMT. It is likely that cost of land in the outer regions is less expensive and is a larger determinant of where new residents and workers choose to locate over the cost of transportation. Thus, there is no indication that because the two model results are not similar that one is either correct or incorrect. A more detailed analysis of the manner in which the TPB study model allocates land and distributes new development would need to be conducted to determine whether the process of land-use allocation is similar in both models.

Where there were significant differences was concerning the order of magnitude of the changes. For example, in the TOD-Rail scenario, the TPB study projected a 0.8 percent decrease in VMT with the Washington Region MARS model projecting a 5.7 percent decrease. At this point, there is no clear indication of why this is occurring. One possible explanation is the manner in which the Washington Region MARS model accounts for transit trips and the lack of sensitivity to the qualitative characteristics of the transit system (see previous discussion on model calibration). However, there is a likely explanation for the differences in the Region Undivided scenario due to the lack of bus transit system representation in the Washington Region MARS model. The TPB study included bus transit systems in the model and also included an increase in bus transit systems when running Region Undivided scenario. Thus, it makes sense that the TPB scenario would result in a larger increase in transit trips.

5.5 WASHINGTON, DC REGION CASE STUDY FINDINGS

Hypothesis 2 stated that, in part, a system dynamics-based integrated transportation and land use modeling tool can be tractably used to support the metropolitan planning decision making process. In order to test this hypothesis a case study approach was used by developing a Washington Region MARS model and then using the calibrated model to analyze four different scenarios. The case study included detailed documentation concerning the collection and calculation of the required data describing the Washington region for input into the MARS model. In addition, the case study documented the process of using the NHTS and CTPP data sets to calibrate both the transportation sub-model and land use sub-model, respectively. Finally, a high level validation exercise was conducted by analyzing different scenarios concerning the Washington Region and comparing them to a similar exercise undertaken by the Washington Council of Governments.

The results of the case study analysis provide moderate evidence (data were available, the model was calibrated and validated) with which to support, in part, Hypothesis 2 that the model can be tractably used. First, there is very good documentation concerning the development of the Washington Region MARS model using readily-available data sources. Most of the necessary data came from sources that other regions could access. However, some of the required data (e.g., land use characteristics) may not be readily available at the necessary spatial scales. Thus, more time and effort may be required in order to collect the necessary data. Second, calibration of the Washington Region MARS model was not perfect, but it was acceptable given the omission of bus transit trips. Calibration of the transportation sub-model for *commuting trips* was very good (R^2=0.9054), but not as good for the *other trips* (R^2=0.5016). Future efforts will need to focus on including bus transit trips in order to better calibrate *other trips*. In addition, the required data to calibrate the land use sub-model at the desired spatial scale were not available. Finally, the validation exercise was generally successful, but did show some discrepancies between the results of the TPB study and the Washington Region MARS model.

CHAPTER 6: MODEL TESTING

Traditionally, model testing pertaining to the development of transportation simulation models involved calibrating the overall operation of the model using actual data and then validating it to real-world conditions. As seen in Section 5.3, the MARS model was successfully calibrated to real-world conditions. In addition, Section 5.4 demonstrated a high-level validation exercise comparing the results of the Washington DC MARS Model to results obtained in the National Capital Region Transportation Planning Board scenario planning analysis *Regional Mobility and Accessibility Study: Alternative Land Use and Transportation Scenarios*. While the results of the calibration and validation exercises were successful, an equally important consideration in system dynamics modeling is to examine the overall purpose and role of the model itself (Abbas and Bell 1994). To this end, Forrester suggested that a model should be judged not solely on its absolute validity but some aspect of usefulness as well (Forrester 2001). In other words, the Washington DC MARS Model was deemed a valid model. However, this is not to suggest it is a useful model to support the decision-making process. This chapter is concerned with testing whether a valid Washington DC MARS Model could be useful within the metropolitan planning decision-making process.

For purpose of this research, model testing was conducted by way of an expert panel to determine how useful the Washington Region MARS Model could be in supporting the decision-making process. The results of the expert panel supports, in part, Hypothesis 2 that a system dynamics-based integrated transportation and land use modeling tool can serve as an improved modeling approach by decision makers involved with the metropolitan planning process to support policy development and visioning. Members of the expert panel completed a questionnaire regarding the Washington Region MARS Model on which content analysis was conducted.

As seen in Figure 30, Chapter 6 includes three separate sections. This first is a discussion concerning the implementation of the expert panel, including the questionnaire design, panel selection, and webinar meeting. Second, content analysis of the completed questionnaires was conducted to systematically analyze the expert panel's thoughts and opinions. Finally, some findings concerning the results of the model testing exercise using the expert panel are made.

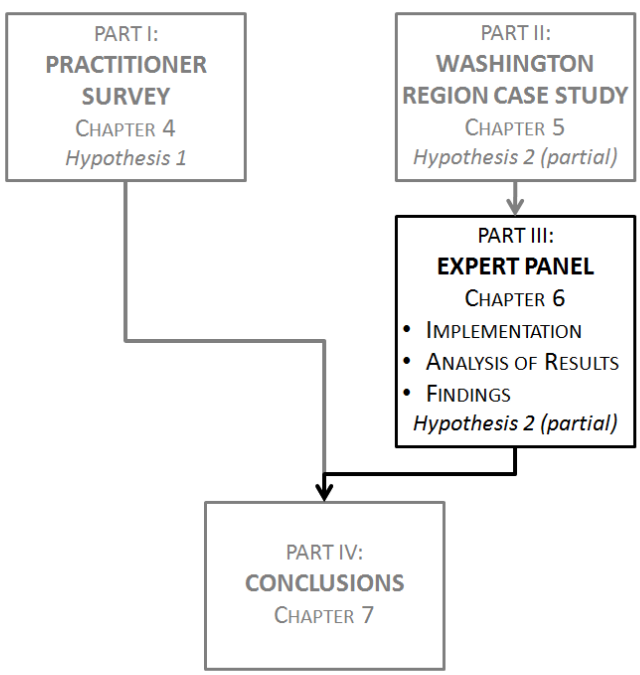

Figure 30 Chapter 6 Research Process

6.1 EXPERT PANEL IMPLEMENTATION

The expert panel was developed in accordance with the requirements of the George Mason University HSRB. Approval was received per protocol number 7196 on November 4, 2010. The implementation of the expert panel followed the basic structure defined by Seskin, *et. al.* and consisted of three steps (see Section 3.1.2). First, the questionnaire was designed. Second, the panel was selected and invitations sent out to serve on the panel. Panel members were identified based upon their role in either using transportation and land use models (analyst) or using the results from a transportation and land use model (decision maker). Panel members were not familiar with the MARS model. Finally, a webinar was held for the purpose of soliciting feedback from the panel concerning the Washington Region MARS Model. The following discusses each step in turn.

A six-question open-ended questionnaire was designed for the expert panel to fill out at the completion of the webinar meeting. The questionnaire was designed to assess the expert panel's opinion concerning the use of the Washington DC MARS Model in terms of the following three broad categories:

- Appropriateness of the model in supporting the metropolitan planning decision-making process.
- Resource requirements given the identified purpose of the model.
- Acceptability of the model boundaries and use given the identified purpose of the model.

As seen in Appendix 4, the questionnaire includes six broad questions concerning the strengths and weaknesses of the Washington Region MARS Model, such as areas for improvements, usefulness of the model's functionality in terms of the resource requirements, utility in addressing the four metropolitan planning decision-making categories, and general thoughts and opinions not accounted for in the previous questions. The questionnaire was designed such that content analysis could be conducted on the panel's answers and inferences could be made to support the hypothesis that a system dynamics-based integrated transportation and land use modeling tool can serve as an improved modeling approach by decision makers involved with the metropolitan planning process to support policy development and visioning.

The expert panel was selected such that a broad-based representation of the organizations involved in the metropolitan planning process was included. Necessary representation included individuals from federal and state governments, MPOs, and researchers. In addition, two separate roles that individuals play within the organizations were included: analysts (those conducting or overseeing the use and application of the models) and decision makers (those using the results of the models to make decisions). The two different roles were selected to account for expertise in developing and running models (Analyst) and using the results of the model in the decision-making process (Decision Maker). The analysts better understand the tractable nature of simpler modeling tools while the decision makers have a better understanding of how the results could be used. It was important to include both perspectives in the expert panel.

The expert panel is shown in Table 25 below. Due to requirements of the George Mason University HSRB, the list of names on the expert panel is anonymous. As seen in the table, the expert panel included representation from Federal (2), MPO (4), State (5), and Research (4) organization types. Also, the role of both analysts and decision makers are represented. Once the expert panel was identified, invitations were sent to the members to serve on the panel per the requirements of the George Mason University HSRB.

Table 25 Expert Panel Composition

ID	Organization Type	Role	Webinar Attended	Completed Questionnaire
1	Federal	Analyst	15-Feb	No
2	Federal	Decision Maker	14-Feb	Yes
3	MPO	Analyst	15-Feb	Yes
4	MPO	Analyst	15-Feb	No
5	MPO	Analyst	14-Feb	No
6	MPO	Decision Maker	14-Feb	Yes
7	State	Analyst	15-Feb	Yes
8	State	Analyst	15-Feb	Yes
9	State	Analyst	15-Feb	No
10	State	Decision Maker	15-Feb	Yes
11	State	Decision Maker	14-Feb	Yes
12	Research	Analyst	15-Feb	Yes
13	Research	Analyst	15-Feb	Yes
14	Research	Analyst	14-Feb	Yes
15	Research	Analyst	15-Feb	Yes

For purposes of this research, it was decided that a webinar (web-based seminar) would be held to inform the panel members of the Washington DC MARS Model and to also give them an opportunity to ask questions. The webinar format is a useful medium for gathering the expert panel members for a number of reasons. First, the expert panel is geographically diverse. Second, the expert panel includes a number of high-ranking professionals with busy schedules. Trying to schedule an in-person meeting would have been difficult, if not impossible. Thus, the webinar enabled an easy and convenient mechanism to bring the panel together in a cost and time efficient manner without sacrificing the ability to have an engaged discussion among the panel members. Two webinars were scheduled in order to accommodate panel members from the east coast and west coast of the U.S.—an afternoon session on February 14, 2011 and a morning session on February 15, 2011. Table 25 indicates the distribution of panel members between the two dates.

The webinar consisted of a presentation on the Washington Region MARS Model, demonstration of the model, and question/answer period. Since none of the expert panel members were familiar with the MARS model, read-ahead material was sent to them and the first part of the presentation included a overview of the model. The presentation is included in Appendix 5 of this report. Both webinars had durations of approximately 75 minutes and provided panel members with an overview of this research, a demonstration of the MARS model, and preliminary results. The presentation was e-mailed to panel members upon completion of the webinar along with the questionnaire. Follow-up e-mails and telephone calls were made to the panel members asking them to fill out the questionnaire. As seen in Table 25, eleven of the fifteen panel members completed the questionnaire. Follow-up e-mails were sent to those expert panel members who did not complete a questionnaire. The reason for not completing the questionnaire was due to the pressing nature of their current work load and not a feeling that the study was not valid.

6.2 CONTENT ANALYSIS OF EXPERT PANEL RESULTS

Content analysis of the completed expert panel questionnaires was conducted in order to better understand the appropriateness of the model, acceptability of the model boundaries, and the resource requirements of the model. Content analysis is an appropriate methodology to examine the completed questionnaires of the expert panel since it is a systematic research method for analyzing textual information in a standardized way that allows researchers to make inferences about the information (Krippendorff 2003). In content analysis, individual ideas or concepts must first be defined and then identified within the text be analyzed. There are two basic types of content analysis approaches: conceptual analysis and relational analysis. In conceptual analysis, a concept is first identified and then the number of its occurrences is analyzed. In relational analysis, individual concepts by themselves are not viewed as meaningful but rather the relationships among various concepts in a text. Content analysis does have drawbacks particularly concerning the conclusions reached by the inferential procedures. While reasonable conclusions can be made from the quantitative data generated, the question of proof may remain unanswered (Carney 1972).

This content analysis focused on conceptual analysis (as opposed to relational analysis) to better determine the existence and frequency of concepts in the completed expert panel questionnaires related to Washington Region MARS Model (Neuendorf 2001). The completed expert panel questionnaires are included in Appendix 6 and are identified based upon the ID column in Table 25. The completed expert panel questionnaires were analyzed based upon the three broad categories presented earlier. The analysis used simple visual inspection of the responses to extract points of similarity and differences. The sample size was small enough to permit this to be effective.

6.2.1 Appropriateness of the Washington Region MARS Model

Question 5 of the expert panel questionnaire directly asked the expert panel members their opinion of the appropriateness of the Washington Region MARS Model in supporting the four metropolitan planning decision-making categories (policy development, visioning, strategic analysis, and tactical assessments). Key words and phrases that were examined included mention of the four decision-making categories and phrases associated with the usability of the tool such as "ease of use", "flexibility", and "challenging" (e.g., difficult to use).

All of the respondents indicated that the modeling tool would be useful to support the policy development process while eight of the nine respondents indicated that the tool would be useful in supporting the visioning process. Some respondents indicated that the model's ability to run multiple alternatives quickly was a positive. And, the run time of 10 minutes for a single iteration was paramount to its ability to be used as a tool to test many different policy scenarios. Two of the respondents indicated that the tool would be invaluable as a sketch planning tool for quick alternative analysis such that it could be used during a community meeting (e.g., public participation) and run in real-time to generate results.

In addition to the direct response to Question 5 by the respondents, some of the discussions in other questions were useful in better understanding how the tool could be used. For example, respondents indicated that the model's visualization of the relationship between sub-models (e.g., transportation and land use) was an important consideration, making the model more transparent and accessible to both stakeholders and decision makers. Also, respondent number 6 indicated that "…policy makers will need tools that can support their decision making in a more sophisticated way—but on a *shoestring* [budget]" suggesting that the MARS model could serve in this capacity.

Another interesting insight taken from the responses was the overall usability of the tool in relation to the tool supporting the decision-making process. Nine of the respondents made reference to usability as an important factor in terms of data entry, manipulation, and presentation. Respondents used terms such as "ease of use", "flexibility and responsiveness", and "easily implementable" when justifying why the Washington Region MARS Model would be useful to support the decision making process. This suggests that not only is it important for a tool to support a specific decision-making category, but that the tool needs to be easily useable as well, regardless.

6.2.2 Required Resources of the Washington MARS Model

Question 4 of the expert panel questionnaire asked the expert panel members their opinion concerning the functionality of the Washington Region MARS model as it relates to the required resources. In analyzing this question, in addition to how respondents answered other questions, three key themes were examined: data requirements, resources (e.g., time, money and expertise), and run times. Nine of the eleven respondents indicated that the data requirements associated with the model are reasonable. Two specifically mentioned the ability to use Google as an integral source of the data. For example, Respondent 2 indicated that "…the ability these days to use Google is just terrific compared to past very laborious input processing." And, Respondent 10 said that they "…really like being able to tap into Google."

In this analysis, resource requirements focus on time, money and expertise required to build and run a model. Six of the nine respondents indicated that the resources required to run the MARS model were acceptable. Respondent 10 put it most succinctly when discussing the required resources saying "…the MARS Washington DC Model is a good tool to use for testing out multiple different scenarios because of its low data requirement, fast run times and high level outputs." In terms of money, none of the respondents made specific mention of funding as a critical indicator in using the MARS model. However, an important factor in collecting data is the availability of funding with which to collect the required data. In discussing the reasonableness of the required data for MARS, Respondent 7 offered an important insight concerning smaller urban and rural areas without the funding resources of large urban area and where transportation and land use data with which to build models are often lacking. Respondent 7 indicated that "…the use of readily available data is key especially if smaller urban and rural areas are using it." This suggests that due to the low resource requirements and use of the readily available data, the MARS Model could be a useful tool to promote.

The last factor in assessing the required resource of the model is the model run times. While demonstrating the Washington Region MARS Model during the webinar, there was a discussion of the validity of concerns associated with model run times given the consistent increase in computer processing power and subsequent decrease in model run times. The discussion ended with a consensus that the length of time it takes to run a model will always be an important consideration in choosing a model. And, it is important to consider the model run time not just in getting results of a particular policy scenario but also in the model calibration process where numerous runs will have to be made. In the completed questionnaires, five of the respondents indicated that the run times of the MARS model are important. Respondent 15 indicated that "The tool is built so as to keep run times minimal—this is an important strength." Respondent 3 indicated that the "Run time seems to be great…" and Respondent 7 said "the run time seemed appropriate."

6.2.3 Acceptability of the Boundaries and Use of the Washington MARS Model

Questions 1, 2, and 3 of the of the expert panel questionnaire asked the expert panel members their opinion concerning the acceptability of the model relative to its boundaries in terms of the model's strengths, weaknesses, and areas for improvement. The model boundary indicates which variables are endogenous to the model (calculated within the model or is an output of the model), exogenous to the model (input variables), and excluded from the model. The content analysis did not indicate any consistent theme of the respondents concerning the acceptability of the model. The following is summary of the highest frequency responses:

- Four of the respondents indicated that freight movements are an important consideration and which are specifically excluded from the MARS model.
- Four respondents indicated that the MARS model made an important contribution in addressing economic and market forces in a sketch planning tool.
- Three responses indicated the importance of MARS linking the land use model with the transportation model.
- Three respondents suggested the ability to analyze additional trips beyond the Home-Work-Home and Home-Other-Home treats during the peak and off-peak periods.
- Two respondents indicated that analyzing trips during the peak and off-peak periods was an important consideration that MARS addresses. This is because traditional planning models typically cover the morning and evening peak periods whereas MARS addressed travel over the entire day.

6.3 MODEL TESTING FINDINGS

Hypothesis 2 stated that, in part, a system dynamics-based integrated transportation and land use modeling tool can serve as an improved modeling approach by decision makers involved with the metropolitan planning process to support policy development and visioning. In order to test this hypothesis an expert panel was used to gather feedback and opinion on the use and applicability of the Washington Region MARS Model. The expert panel consisted of people from different organizations involved in the metropolitan planning decision-making process with different roles. A webinar was held in order to inform the expert panel regarding the MARS model and its use in the Washington, DC region as a case study. A questionnaire was designed to solicit feedback from the expert panel members. The questionnaire was designed to address three key areas: 1) appropriateness of the model; 2) required resources of the model; and 3) acceptability of the model use and boundaries.

The results of the expert panel survey provide strong evidence with which to support, in part, Hypothesis 2. First, a vast majority of expert panel survey respondents indicated that the MARS model could be used to support the policy development and visioning categories of the metropolitan planning decision-making process. For example, respondents indicated that the ability to run multiple scenarios very quickly was important and that the MARS model would not likely have the ability to do the detailed analysis required for other categories (e.g., strategic analysis and tactical assessments). Second, a majority of the respondents of the expert panel indicated that the resources required to run the model given its stated purpose of supporting policy development and visioning could serve as an improved modeling approach and fill an unmet need, in particular in communities with lesser resources such as smaller urban and rural areas. Finally, many of the expert panel respondents indicated that the transparency associated with the MARS model, ease of use, and short run times were important factors in choosing the model. These three factors are also consistent with the benefits of using a system dynamics model.

CHAPTER 7: CONCLUSIONS

This dissertation employed a mixed-method approach to address two hypotheses related to the application and use of an ITLUM tool to the support the metropolitan planning decision-making process. The mixed-method approach was invaluable in better understanding the complex phenomenon associated with the decisions that have to be made as part of the metropolitan planning process, the tractability of modeling tools supporting that process, and the usefulness of the results. Using a single method (e.g., survey, case study, or expert panel) would not have produced the robust and rich results presented here. The first hypothesis stated that decision makers involved with the metropolitan planning process desire a simplified ITLUM tool that can be used to support the policy development and visioning categories of the decision-making process. The second hypothesis stated that a system dynamics-based integrated transportation and land use modeling tool can be tractably used to serve as an improved modeling approach by decision makers involved with the metropolitan planning process to support policy development and visioning as compared to traditionally-used regional planning modeling tools. Chapter 7 provides concluding remarks concerning this research including hypothesis testing and findings, policy implications, and future research opportunities.

The two hypotheses presented in this research were supported using two survey methodologies and a case study approach. The two survey methodologies were used to gather feedback and opinion in order to support the hypotheses. The first was a cross-sectional survey used to collect opinion from a broad base of industry practitioners regarding the use and application of ITLUM tools in order to support Hypothesis 1. The second was an expert panel used to gather detailed thoughts and opinions on a specific simplified ITLUM tool in order to partially support Hypothesis 2. Second, a case study approach, using the Washington DC region as the case study location, was also used in order to partially support Hypothesis 2. The results of the hypothesis testing are shown in Table 26.

Table 26 Hypothesis Testing Results

Hypothesis	Methodology	Support	Evidence
1. Decision makers involved with the metropolitan planning process desire a simplified ITLUM tool that can be used to support the policy development and visioning categories of the decision-making process.	Practitioner Survey (Chapter 4)	Strong	1. Practitioners indicated it was important that ITLUM tools be used to support all four of the metropolitan planning decision-making categories. 2. Practitioners indicated that a scalable ITLUM tool is needed to support the decision-making categories 3. Practitioners indicated that a simplified ITLUM tool, one requiring less data, resources and functionality, are important features of an ITLUM tool that would be used to support the policy development and visioning.
2a. A system dynamics-based ITLUM tool can be tractably used.	Case Study (Chapter 5)	Moderate	1. Case study provided documented sources of necessary input data. 2. Case study showed that the calibration of the Washington Region MARS model was not perfect, but it was acceptable. 3. Case study demonstrated a validation exercise that was successful, but did show discrepancies between the results.

Hypothesis	Methodology	Support	Evidence
2b. A system dynamics-based ITLUM tool can serve as an improved modeling approach by decision makers involved with the metropolitan planning process to support policy development and visioning.	Expert Panel (Chapter 6)	Strong	1. Expert panel indicated MARS model could be used to support the policy development and visioning categories 2. Expert panel indicated resources required to run the MARS model could serve as an improved modeling approach and fill an unmet need 3. Expert panel indicated the transparency of the MARS model, ease of use, and short run times were important factors in choosing the model.

As seen in the table, this research provided strong support for Hypothesis 1 and 2b with moderate support for Hypothesis 2a. The practitioner survey was an important component of this research in demonstrating that decision makers are not necessarily concerned with using the "latest and greatest" in terms of ITLUM tools, but would rather use a tool that can more easily support the decisions that have to be made concerning transportation and land use policies. The case study was a critical component of this research that documented the development of the Washington Region MARS Model making the research transferable to other regions. The case study also demonstrated the use of the MARS model in terms of flexibility (analyzing different policy scenarios), scalability (using the model for analyses at different spatial scales), and accessibility (populating the model with readily available data). Finally, the expert panel confirmed that the MARS ITLUM tool could be used to support the metropolitan planning decision-making process in term of policy development and visioning and exhibited characteristics desired of this type of tool by the practitioner survey (a tool the required less data, resources and functionality, Figure 16).

However, this research did not show strong support for all of the hypotheses. As seen in Hypothesis 2a from Table 26, there was only moderate support suggesting the MARS model could be tractably used, essentially for two reasons. First, the calibration of the Washington Region MARS Model could be improved with better data. A central component of this research was to use readily-available data sources, thus both the NHTS and CTPP data were used to calibrate the transportation and land-use sub-models, respectively. More accurate data could provide better calibration results and this data will likely be available once the 5-year CTPP tabulations are produced in 2012 and the 2009 NHTS data set is finalized. Second, the notion of tractability needs to be tested as the MARS model is deployed in other regions and the process detailed in this research is replicated.

The central research question of this research was concerned with the opportunities and limitations of using a simplified ITLUM approach to support the metropolitan planning decision-making process. In the end, this research did show that decision makers want a simplified ITLUM tool to support the metropolitan planning decision-making process as it relates to policy development and visioning. And, the MARS ITLUM tool, a system dynamics model that uses readily available data, could serve in this capacity. While this research did leave out some important aspects of a transportation system (e.g., bus trips) these shortcomings could be readily addressed given additional resources. What an agency can do in terms of more fully developing a MARS model goes far beyond the resources available in this research.

7.1 FINDINGS

This research made significant contributions to the fields of transportation and land use modeling and the metropolitan planning decision-making process. First, this research assessed the utility that a simpler modeling tool has in supporting metropolitan planning decision making. Second, this research documented how one can build, calibrate, and test a simplified ILTUM tool using readily-available data such that the process can be replicated in other regions.

Besides the contributions this research has made, some additional findings can be stated concerning the evolution of computer modeling tools to support the decision-making process. As described previously, researchers have described the evolution of computer modeling tools in different ways. Miller, *et.al.*, and Wegener describe the evolution as consisting of two axis (land use models and transportation models) from simple to complex with the goal of developing tools that are, generally speaking, more complex in nature (E. Miller, Kriger, and Hunt 1998; Wegener 2004, 2). Mile, *et. al*., however, describes it slightly differently where model tool selection to support transportation planning is a trade-off between system complexity and spatial complexity (Mile and G. Emberger 2004). What is absent from these frameworks of model evolution is an inherent decision-making functionality that a computer modeling tool supports.

What this research showed is a definite connection among the computer modeling tools, the factor requirements associated with the computer modeling tools, and the decision-making process. The connection among these three concepts is best understood visually. As seen in Figure 31, the ***X*** axis represents the factor requirements of using a model which increase as one moves from conducting Policy Development to Tactical Assessments (see Figure 16). The ***Y*** axis represents model complexity which also increases in terms of spatial and temporal complexity as one moves from conducting Policy Development to Tactical Assessments (see Section 6.2.1, Appropriateness of the Washington Region MARS Model). Connecting the two axes are the decision-making categories starting with Policy Development (the blue line that includes low factor requirements and low model complexity) and ending with Tactical Assessments (the green line that includes higher factor requirements and model complexity). Traditionally, model development has moved on a trajectory from the lower left to the upper right with a desire to develop more complex models requiring more factors.

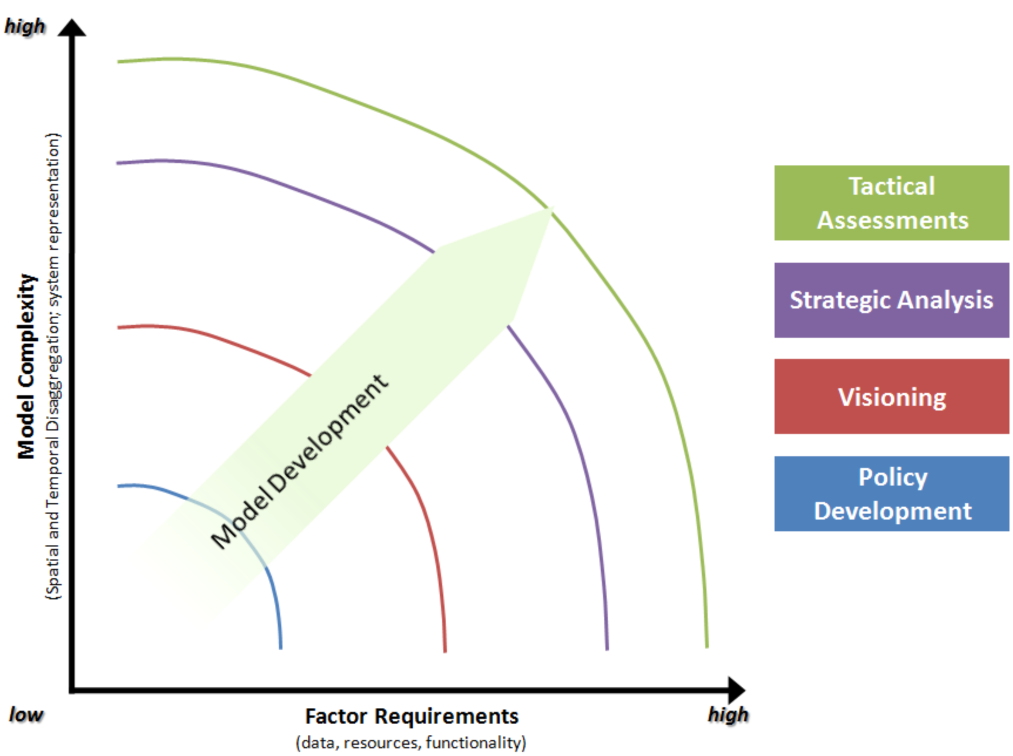

Figure 31 Model Complexity and Factor Requirements
Source: Author's Assessment

However, this research suggests that missing from this assessment are the decision-making categories. Figure 32 includes possible boundaries around the four decision-making categories based upon model complexity and the factor requirements. The assumption that model development should only consider pushing the boundaries in terms of increased complexity and factor requirements in the absence of how the tool supports decision making is wrong. As seen in Figure 32, the traditional belief has been that model development has pushed the boundaries in terms of model complexity and factor requirements. This can be seen with the development of the Strategic Highway Research Program (SHRP) II projects which are developing models with more complexity (integrating UrbanSim and TRANSIMS with activity based models) and factor requirements. The results are likely improved models that more accurately represent real-world conditions, but not necessarily better models that support the decision-making process nor are the results likely to be better and more accurate forecasts. In fact, what may be occurring is that a void is being created whereby all decision-making categories are not being addressed in terms of tool development. As seen in Figure 32, what this research suggests is that the void could be filled with a simpler modeling tool such as MARS that is designed to support a decision-making category based upon the needs of that decision maker and not the desire of pushing the boundary of model development.

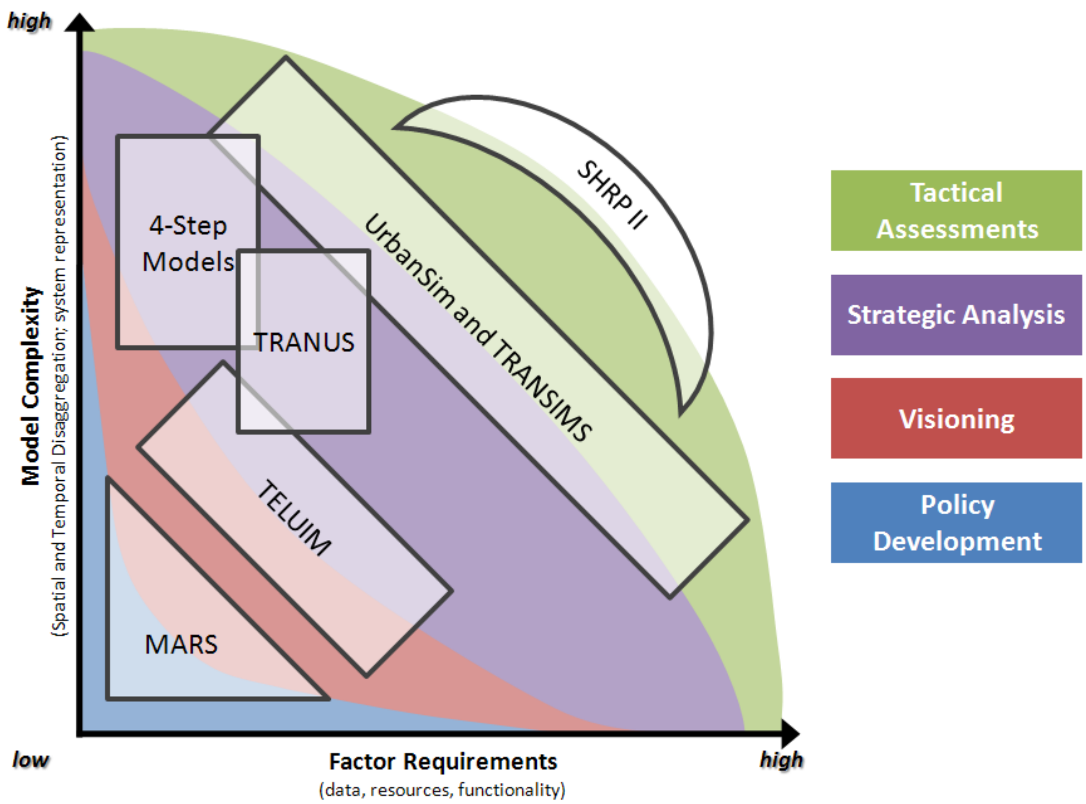

Figure 32 Model Complexity, Factor Requirements, and Decision Making
Source: Author's Assessment

7.2 Policy Implications

This research revealed a number of policy implications relating to the use and application of ITLUM tools to support metropolitan planning. First, model development should focus on a spectrum of tools to support the range of decision-making categories. And, more specifically, ITLUM tool development needs to be addressed within the context of uncertain futures. The literature review associated with this research demonstrated that current travel demand models are not accurate in predicting with certainty conditions 10, 20, or 30 years in the future. However, the case study analysis demonstrated the ability to populate a simple model and generate results similar to that of a complex model. Thus, model development should not focus on more complex computer modeling tools that may accurately predict the future (which significant evidence shows they cannot), but less complex tools that can assist decision makers in knowing which data elements cause the most uncertainty to enable more robust decision making. Robust decision making is a decision-making process that explicitly identifies uncertainty as an important component and includes formal mechanisms of accounting for uncertainty (Ullman 2006). Computer models play an integral role in robust decision making.

Second, readily available data sources can be used to populate and run models. A significant hurdle to model development is the acquisition of input data as well as calibration and validation data. This research showed that using existing and open data sources is technically feasible, which could either reduce the cost of applying existing models or encourage the development of new models since data can be more easily acquired. Also, the availability of useable data sources may further enable the policy development and visioning categories of the decision-making process to be more data-driven and transparent.

Third, this research reinforces the notion that modeling tools only serve to support the decision-making process and do not define it. The first question that analysts and decision makers must ask is not what modeling assets do I have or what is the best model available, but rather what decision needs to be made and how can a modeling tool be best used to support the decision, if at all.

7.3 FUTURE RESEARCH

This research revealed four areas that are in need of further research. However, the suggestion for future research needs to be weighed against the desire to create a better modeling tool. As Respondent 15 of the expert panel said: "*Any time we get a new tool there is the inevitable push to enhance and refine it and it turns into a much bigger investment than realized. If this is envisioned as a sketch planning tool, one of the challenges would be to not try and turn it into something more.*" That being said, there are areas for future research as indicated below:

- **Model Refinement**—The calibration and validation of the Washington Region MARS model was not perfect and additional analysis needs to occur to better calibrate the model. In addition, the calibration of the transit trips needs to be assessed as well as the inclusion of bus trips in the overall model. Given the accelerated deployment of use of the GTFS, entering bus-based transit data should be easier.
- **Replication**—An important consideration of this research was to document the process of developing the Washington Region MARS model such that it can be replicated in other areas. Future research should test the ease of replicating the process documented here to other regions in the U.S. with a focus on smaller urban and rural regions.
- **Model Comparison**—This research described similar models to MARS. Future research needs to concentrate on comparing these similar models (e.g., TELUM and Tranus) with each other using the same data set and

assessing how the models compare to each other in terms of data requirements, functionality, and outputs.

- **Visualization**—One of the features that is lacking in MARS is an integrated visualization component. Future research could focus on taking the outputs of MARS and developing scripts and routines to automate the visualization of the data.

APPENDIX 1
PRACTITIONER SURVEY INSTRUMENT

Survey on Integrated Transportation and Land Use Modeling Tools

Dear Survey Participant:
Thank you for contributing to this survey regarding transportation and land use modeling tools. The purpose of this survey is to better assess what role integrated transportation and land use modeling (ITLUM) tools can play in the metropolitan planning decision-making process. Recent surveys indicate that many jurisdictions and metropolitan planning organizations are looking at implementing ITLUM tools. However, there are a number of ITLUM tools available to practitioners ranging from simple sketch planning tools to complex microscopic simulation tools. There are benefits and limitations to using any type of ITLUM tool. Selecting a specific tool to use is often a tradeoff among many different factors. The purpose of this survey is to gather expert opinion on the use and application of ITLUM tools as it relates to the metropolitan planning decision-making process.

This survey is part of Matthew Hardy's doctoral dissertation research that he is completing in the School of Public Policy at George Mason University. An informed consent form is available here.

This survey should take no longer than 15 minutes to complete.

Please complete the survey by January 7, 2011. Should you have any questions, please contact Matthew Hardy at (202) 624-3625 or mhardy@aashto.org.

1) Demographic Data: Please indicate what type of organization you currently work for:

- ❍ State DOT
- ❍ MPO (small: population of less than 200,000)
- ❍ MPO (medium: population of 200,000 to 1,000,000)
- ❍ MPO (large: population of greater than 1,000,000)
- ❍ Consultant
- ❍ Academia/Researcher
- ❍ Other (please specify)

If you selected other, please specify

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2) Indicate your perception on the importance of using computer modeling tools to support decision-making with regards to transportation and land use policies.

- ❍ No Opinion
- ❍ Not Important
- ❍ Somewhat Important
- ❍ Important
- ❍ Very Important
- ❍ Critically Important

Additional comments

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3) Indicate your perception on the importance of considering the effects of transportation and land use policies together in an integrated fashion.

- ❍ No Opinion
- ❍ Not Important
- ❍ Somewhat Important
- ❍ Important
- ❍ Very Important
- ❍ Critically Important

Additional comments

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4) Indicate your perception on the importance of considering transportation and land use policies in an integrated fashion at the following spatial scales.

	Spatial Scale					
	No Opinion	Not Important	Somewhat Important	Important	Very Important	Critically Important
Neighborhood	❍	❍	❍	❍	❍	❍
Corridor	❍	❍	❍	❍	❍	❍
County	❍	❍	❍	❍	❍	❍
Multi-County	❍	❍	❍	❍	❍	❍
Region	❍	❍	❍	❍	❍	❍
Statewide	❍	❍	❍	❍	❍	❍

5) Computer modeling tools operate in many different ways. Some tools are equilibrium models that show results as a snapshot in the future (e.g., 30 years out) while others are dynamic simulation models which track transportation and land use changes over a certain time period (e.g., every year for the next 20 years). With this in mind, indicate your perception on the importance of knowing the effects of transportation and land use policies dynamically over a certain time period.

- ❍ No Opinion
- ❍ Not Important
- ❍ Somewhat Important
- ❍ Important
- ❍ Very Important
- ❍ Critically Important

Additional comments

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6) Computer modeling tools are sometimes referred to as "black boxes" meaning data is entered and outputs are calculated but there is little knowledge by the analyst or practitioner on how the computer modeling tool operates and how the calculations are being made. With this in mind, indicate your perception on the importance of transparency in knowing how the computer modeling tool is making its calculations.

❍ No Opinion
❍ Not Important
❍ Somewhat Important
❍ Important
❍ Very Important
❍ Critically Important

Additional comments
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Questions 7 through 9 focus specifically on the metropolitan planning decision-making process. This process is defined as consisting of the following four decision-making categories. Please use the definitions provided below when considering questions 7 through 9.

- Policy Development—Often involves exploring potential outcomes in a broad-based manner as a way of screening a large number of alternatives to identify strategies that are worthy of more investigation.
- Visioning—A concerted effort undertaken by the government to engage stakeholders in the planning process in order to elicit feedback regarding various transportation and land use policies and scenarios. Also referred to as scenario planning.
- Strategic Analysis—Includes the identification, consideration, and analysis of alternative transportation systems (e.g., no-build versus light rail transit) or land use policies (e.g., high density versus low density growth).
- Tactical Assessments—It is the design, construction, and operation of a specific project identified as part of the strategic analysis (e.g., construction of the Silver Line or redevelopment of a specific Silver Line station in Tysons Corner).

7) Indicate the importance you believe that computer modeling tools should have in supporting the following four metropolitan planning decision-making categories.

	ITLUM Tools Supporting Metropolitan Planning Decision-Making					
	No Opinion	Not Important	Somewhat Important	Important	Very Important	Critically Important
Policy Development	❍	❍	❍	❍	❍	❍
Visioning	❍	❍	❍	❍	❍	❍
Strategic Analysis	❍	❍	❍	❍	❍	❍
Tactical Assessments	❍	❍	❍	❍	❍	❍

8) Indicate your perception on the required level of detail of the outputs of an analysis tool in order for a computer modeling tool to be capable of supporting the following four metropolitan decision-making categories.
High would be results at the individual parcel or vehicle level while Low would be results aggregated to a regional level.

	ITLUM Tools Level of Detail Required					
	No Opinion	Low (region)	Low-Medium (county)	Medium (multiple TAZ)	Medium-High (TAZ)	High (parcel)
Policy Development	❍	❍	❍	❍	❍	❍
Visioning	❍	❍	❍	❍	❍	❍
Strategic Analysis	❍	❍	❍	❍	❍	❍
Tactical Assessments	❍	❍	❍	❍	❍	❍

9) Indicate your perception on the overall number of transportation and land use policy scenarios one might have to consider for each of the following four metropolitan decision-making categories.

	Policy Scenarios to Consider for Decision-Making					
	No Opinion	Low (1)	Low-Medium (5-10)	Medium (15-20)	Medium-High (25-30)	High (30+)
Policy Development	❍	❍	❍	❍	❍	❍
Visioning	❍	❍	❍	❍	❍	❍
Strategic Analysis	❍	❍	❍	❍	❍	❍
Tactical Assessments	❍	❍	❍	❍	❍	❍

Questions 10 through 13 focus on the different modeling factors that must be considered when ultimately deciding on which computer modeling tool to use to support the metropolitan planning decision-making process. There are many different factors that one must consider including the data requirements needed to run the model, the resources available with which to run the model (e.g., time and funding), required functionality (e.g., the measures the modeling tool calculates), and the expertise required to run the modeling tool. Questions 10 through 13 ask you to rate your perception of these four modeling factors as they relate to the process of ultimately selecting and using a specific modeling tool per individual transportation and land use policy scenarios for each of the four metropolitan planning decision-making categories. Each question uses a five point scale.

10) Indicate your perception on the data requirements necessary for a particular modeling tool in regards to the four metropolitan planning decision-making categories.
A "1" would indicate that a rough estimation is sufficient while a "5" would indicate detailed data is necessary.

	Data Requirements for a Particular Modeling Tool					
	No Opinion	1 (rough estimation)	2	3	4	5 (detailed)
Policy Development	❍	❍	❍	❍	❍	❍
Visioning	❍	❍	❍	❍	❍	❍
Strategic Analysis	❍	❍	❍	❍	❍	❍
Tactical Assessments	❍	❍	❍	❍	❍	❍

11) Indicate your perception on the resources required to run a particular modeling tool in regards to the four metropolitan planning decision-making categories.
A "1" would indicate that lower resources are sufficient while a "5" would indicate a higher degree of resources are necessary.

	Resources Required to Run a Particular Modeling Tool					
	No Opinion	1 (low)	2	3	4	5 (high)
Policy Development	❍	❍	❍	❍	❍	❍
Visioning	❍	❍	❍	❍	❍	❍
Strategic Analysis	❍	❍	❍	❍	❍	❍
Tactical Assessments	❍	❍	❍	❍	❍	❍

12) Indicate your perception on the functionality that is required of a particular modeling tool in regards to the four metropolitan planning decision-making categories.
A "1" would indicate that less functionality is sufficient while a "5" would indicate more functionality is necessary.

	Functionality Required for a Particular Modeling Tool					
	No Opinion	1 (less)	2	3	4	5 (more)
Policy Development	❍	❍	❍	❍	❍	❍
Visioning	❍	❍	❍	❍	❍	❍
Strategic Analysis	❍	❍	❍	❍	❍	❍
Tactical Assessments	❍	❍	❍	❍	❍	❍

13) Indicate your perception on the expertise that is required by an analyst in order to run a particular modeling tool in regards to the four metropolitan planning decision-making categories.
A "1" would indicate that a lower level of expertise is sufficient while a "5" would indicate a higher level of expertise is necessary.

	Expertise Required by an Analyst					
	No Opinion	1 (low)	2	3	4	5 (high)
Policy Development	❍	❍	❍	❍	❍	❍
Visioning	❍	❍	❍	❍	❍	❍
Strategic Analysis	❍	❍	❍	❍	❍	❍
Tactical Assessments	❍	❍	❍	❍	❍	❍

14) Please use this space to provide any additional comments or insights.

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15) As part of my dissertation work, I will be holding a webinar in early 2011 on the use and application of a simplified sketch planning ITLUM Tool. The tool is called the Metropolitan Activity Relocation Simulator (MARS) and is a system dynamics-based model. It was first developed and used in Vienna, Austria. My research will develop a MARS model using the Washington, DC region as a case study. If you are interested in learning more about this tool and participating in this webinar, please fill out the following information so that I may contact you in the future.

Name (first and last)	___________________________________
Organization	___________________________________
E-mail Address	___________________________________
Telephone	___________________________________

Thank you for contributing to this survey regarding integrated transportation and land use modeling tools. If you have any additional questions please contact Matthew Hardy at mhardy@aashto.org.

APPENDIX 2
STATA RESULTS OF PRACTITIONER SURVEY

Table 2

Q1_Organization	Q2_Importance 1	2	3	4	5	Total
Large MPO	0	0	5	9	6	20
Medium MPO	0	2	4	4	6	16
Small MPO	0	5	10	7	1	23
State DOT	1	8	6	17	5	37
Total	1	15	25	37	18	96

Fisher's exact = 0.034

Table 3

Q1_Organization	Q3_Integration 2	3	4	5	Total
Large MPO	0	3	9	8	20
Medium MPO	0	1	5	10	16
Small MPO	1	4	12	6	23
State DOT	5	8	15	9	37
Total	6	16	41	33	96

Fisher's exact = 0.227

Table 4a

Q1_Organization	Q4_Integrattion_Spatial Scale_Neighborhood 1	2	3	4	5	Total
Large MPO	3	5	4	0	8	20
Medium MPO	1	2	5	0	8	16
Small MPO	2	6	9	6	0	23
State DOT	1	5	5	14	11	36
Total	7	18	23	20	27	95

Fisher's exact = 0.000

Table 4b

Q1_Organization	Q4_Integration_Spatial Scale_Corridor 2	3	4	5	Total
Large MPO	1	7	3	9	20
Medium MPO	1	2	5	8	16
Small MPO	2	5	9	7	23
State DOT	0	3	20	14	37
Total	4	17	37	38	96

Fisher's exact = 0.044

Table 4c

Q1_Organization	Q4_Integration_Spatial Scale_County 1	2	3	4	5	Total
Large MPO	0	1	6	6	7	20
Medium MPO	0	0	1	11	4	16
Small MPO	0	0	5	14	3	22
State DOT	2	1	14	13	7	37
Total	2	2	26	44	21	95

Fisher's exact = 0.106

Table 4d

Q1_Organization	Q4_Integration_Spatial Scale_Multi-County 1	2	3	4	5	Total
Large MPO	1	1	3	4	11	20
Medium MPO	0	1	3	7	5	16
Small MPO	0	1	8	14	0	23
State DOT	1	4	14	13	5	37
Total	2	7	28	38	21	96

Fisher's exact = 0.002

Table 4e

Q1_Organization	Q4_Spatial Scale_Region 1	2	3	4	5	Total
Large MPO	0	1	4	5	10	20
Medium MPO	0	1	2	6	7	16
Small MPO	2	0	12	9	0	23
State DOT	2	5	7	17	5	36
Total	4	7	25	37	22	95

Fisher's exact = 0.000

Table 4f

Q1_Organization	Q4_Spatial Scale_Statewide 0	1	2	3	4	5	Total
Large MPO	1	3	4	5	3	4	20
Medium MPO	0	2	1	4	4	4	15
Small MPO	0	2	4	12	5	0	23
State DOT	0	4	9	12	4	8	37
Total	1	11	18	33	16	16	95

Fisher's exact = 0.253

Table 5

Q1_Organization	Q5_TLU_Dynamically 0	1	2	3	4	5	Total
Large MPO	0	3	1	8	2	6	20
Medium MPO	1	0	0	8	4	3	16
Small MPO	0	0	2	14	6	1	23
State DOT	0	0	5	14	13	3	35
Total	1	3	8	44	25	13	94

Fisher's exact = 0.027

Table 6

Q1_Organization	Q6_Transparency 1	2	3	4	5	Total
Large MPO	0	0	5	8	7	20
Medium MPO	0	2	4	4	6	16
Small MPO	0	4	6	10	3	23
State DOT	2	4	6	14	11	37
Total	2	10	21	36	27	96

Fisher's exact = 0.541

Table 7a

Q1_Organization	Q7_ITLUM_Policy 1	2	3	4	5	Total
Large MPO	1	2	6	6	5	20
Medium MPO	0	3	1	7	5	16
Small MPO	0	9	8	6	0	23
State DOT	1	6	11	14	4	36
Total	2	20	26	33	14	95

Fisher's exact = 0.041

Table 7b

Q1_Organization	Q7_ITLUM_Visioning 1	2	3	4	5	Total
Large MPO	2	0	7	7	4	20
Medium MPO	0	1	2	6	7	16
Small MPO	0	5	6	10	2	23
State DOT	1	9	8	14	5	37
Total	3	15	23	37	18	96

Fisher's exact = 0.080

Table 7c

Q1_Organization	Q7_ITLUM_Strategic 2	3	4	5	Total
Large MPO	0	4	11	4	19
Medium MPO	0	0	7	9	16
Small MPO	1	6	10	6	23
State DOT	3	11	15	8	37
Total	4	21	43	27	95

Fisher's exact = 0.121

Table 7d

Q1_Organization	Q7_ITLUM_Tactical 1	2	3	4	5	Total
Large MPO	2	4	3	5	6	20
Medium MPO	0	2	3	4	7	16
Small MPO	1	4	6	8	4	23
State DOT	1	5	14	11	6	37
Total	4	15	26	28	23	96

Fisher's exact = 0.602

Table 8a

Q1_Organization	Q8_Detail_Policy 0	1	2	3	4	5	Total
Large MPO	1	1	1	8	6	3	20
Medium MPO	0	4	3	4	5	0	16
Small MPO	0	2	7	10	4	0	23
State DOT	0	8	8	8	8	1	33
Total	1	15	19	30	23	4	92

Fisher's exact = 0.137

Table 8b

Q1_Organization	Q8_Detail_Visioning 0	1	2	3	4	5	Total
Large MPO	1	2	2	8	5	2	20
Medium MPO	0	0	2	6	7	1	16
Small MPO	0	3	3	10	7	0	23
State DOT	0	3	11	8	9	2	33
Total	1	8	18	32	28	5	92

Fisher's exact = 0.431

Table 8c

Q1_Organization	Q8_Detail_Strategic 1	2	3	4	5	Total
Large MPO	0	1	7	9	3	20
Medium MPO	1	0	5	10	0	16
Small MPO	0	1	6	12	4	23
State DOT	2	1	10	13	7	33
Total	3	3	28	44	14	92

Fisher's exact = 0.717

Table 8d

Q1_Organization	Q8_Detail_Tactical Assessments 0	1	2	3	4	5	Total
Large MPO	2	0	1	2	9	6	20
Medium MPO	0	0	0	1	11	4	16
Small MPO	0	1	4	4	5	9	23
State DOT	0	1	1	4	14	12	32
Total	2	2	6	11	39	31	91

Fisher's exact = 0.216

Table 9a

Q1_Organization	Q9_Scenarios_Policy 0	1	2	3	4	5	Total
Large MPO	2	0	11	3	1	3	20
Medium MPO	2	1	10	0	2	1	16
Small MPO	1	2	11	6	3	0	23
State DOT	0	1	19	6	7	3	36
Total	5	4	51	15	13	7	95

Fisher's exact = 0.230

Table 9b

Q1_Organization	Q9_Scenarios_Visioning 0	1	2	3	4	5	Total
Large MPO	2	0	11	4	1	2	20
Medium MPO	1	0	9	2	3	1	16
Small MPO	1	0	14	7	1	0	23
State DOT	0	2	15	10	6	3	36
Total	4	2	49	23	11	6	95

Fisher's exact = 0.445

Table 9c

Q1_Organization	Q9_Scenarios_Strategic 0	2	3	4	5	Total
Large MPO	2	9	5	3	1	20
Medium MPO	1	10	2	3	0	16
Small MPO	0	19	3	1	0	23
State DOT	0	19	11	5	2	37
Total	3	57	21	12	3	96

Fisher's exact = 0.201

Table 9d

Q1_Organization	Q9_Scenarios_Tactical 0	1	2	3	4	5	Total
Large MPO	3	0	11	3	2	1	20
Medium MPO	2	1	8	1	4	0	16
Small MPO	1	1	16	2	2	1	23
State DOT	0	3	18	6	6	1	34
Total	6	5	53	12	14	3	93

Fisher's exact = 0.565

Table 10a

Q1_Organization	Q10_Data_Policy 0	1	2	3	4	5	Total
Large MPO	0	3	1	4	4	7	19
Medium MPO	1	3	4	3	3	2	16
Small MPO	0	7	11	5	0	0	23
State DOT	0	7	14	8	3	2	34
Total	1	20	30	20	10	11	92

Fisher's exact = 0.004

Table 10b

Q1_Organization	Q10_Data_Visioning 1	2	3	4	5	Total
Large MPO	1	4	4	5	5	19
Medium MPO	3	3	8	2	0	16
Small MPO	8	5	8	1	1	23
State DOT	4	11	14	4	2	35
Total	16	23	34	12	8	93

Fisher's exact = 0.069

Table 10c

Q1_Organization	Q10_Data_Strategic 1	2	3	4	5	Total
Large MPO	0	0	0	7	12	19
Medium MPO	0	1	2	8	5	16
Small MPO	1	4	4	11	3	23
State DOT	1	4	10	12	8	35
Total	2	9	16	38	28	93

Fisher's exact = 0.023

Table 10d

Q1_Organization	Q10_Data_Tactical 0	1	2	3	4	5	Total
Large MPO	2	0	0	1	0	16	19
Medium MPO	0	0	0	1	4	11	16
Small MPO	0	3	1	3	7	9	23
State DOT	0	0	2	6	8	20	36
Total	2	3	3	11	19	56	94

Fisher's exact = 0.013

Table 11a

Q1_Organization	Q11_Resources_Policy 0	1	2	3	4	5	Total
Large MPO	0	1	1	6	3	9	20
Medium MPO	1	4	4	1	3	3	16
Small MPO	0	6	7	6	3	0	22
State DOT	0	8	10	5	9	3	35
Total	1	19	22	18	18	15	93

Fisher's exact = 0.005

Table 11b

Q1_Organization	Q11_Resources_Visioning 1	2	3	4	5	Total
Large MPO	1	1	7	2	9	20
Medium MPO	1	6	5	2	2	16
Small MPO	4	5	8	4	1	22
State DOT	5	10	6	10	5	36
Total	11	22	26	18	17	94

Fisher's exact = 0.039

Table 11c

Q1_Organization	Q11_Resources_Strategic 1	2	3	4	5	Total
Large MPO	0	0	2	5	13	20
Medium MPO	0	1	3	6	6	16
Small MPO	1	0	8	9	4	22
State DOT	1	1	9	15	9	35
Total	2	2	22	35	32	93

Fisher's exact = 0.127

Table 11d

Q1_Organization	Q11_Resources_Tactical 0	2	3	4	5	Total
Large MPO	2	1	1	3	13	20
Medium MPO	0	1	0	7	8	16
Small MPO	1	1	5	8	7	22
State DOT	0	3	5	8	19	35
Total	3	6	11	26	47	93

Fisher's exact = 0.161

Table 12a

Q1_Organization	Q12_Functionality_Policy 0	1	2	3	4	5	Total
Large MPO	3	1	0	2	4	10	20
Medium MPO	2	0	7	2	2	3	16
Small MPO	0	6	6	8	1	2	23
State DOT	0	1	10	10	5	4	30
Total	5	8	23	22	12	19	89

Fisher's exact = 0.000

Table 12b

Q1_Organization	Q12_Functionality_Visioning 0	1	2	3	4	5	Total
Large MPO	4	0	1	3	5	7	20
Medium MPO	0	0	5	4	6	1	16
Small MPO	0	4	6	8	3	2	23
State DOT	0	0	9	7	8	7	31
Total	4	4	21	22	22	17	90

Fisher's exact = 0.005

Table 12c

Q1_Organization	Q12_Functionality_Strategic 0	1	2	3	4	5	Total
Large MPO	3	0	0	1	2	14	20
Medium MPO	0	0	2	1	9	4	16
Small MPO	0	0	3	7	8	4	22
State DOT	0	1	2	7	10	10	30
Total	3	1	7	16	29	32	88

Fisher's exact = 0.001

Table 12d

Q1_Organization	Q12_Functionality_Tactical 0	1	2	3	4	5	Total
Large MPO	4	0	1	1	1	13	20
Medium MPO	0	0	2	1	7	6	16
Small MPO	0	2	4	4	6	7	23
State DOT	0	1	3	5	5	17	31
Total	4	3	10	11	19	43	90

Fisher's exact = 0.021

Table 13a

Q1_Organization	Q13_Expertise_Policy 1	2	3	4	5	Total
Large MPO	0	1	3	6	10	20
Medium MPO	1	2	3	3	7	16
Small MPO	2	3	5	6	6	22
State DOT	1	9	8	5	10	33
Total	4	15	19	20	33	91

Fisher's exact = 0.572

Table 13b

Q1_Organization	Q13_Expertise_Visioning 1	2	3	4	5	Total
Large MPO	0	0	3	7	10	20
Medium MPO	0	1	3	5	7	16
Small MPO	1	1	6	7	7	22
State DOT	4	1	11	9	10	35
Total	5	3	23	28	34	93

Fisher's exact = 0.725

Table 13c

Q1_Organization	Q13_Expertise_Strategic 1	3	4	5	Total
Large MPO	0	1	4	15	20
Medium MPO	0	1	5	10	16
Small MPO	1	2	8	11	22
State DOT	1	4	14	16	35
Total	2	8	31	52	93

Fisher's exact = 0.755

Table 13d

Q1_Organization	Q13_Expertise_Tactical 0	1	3	4	5	Total
Large MPO	1	0	1	2	15	19
Medium MPO	0	0	1	5	10	16
Small MPO	1	1	3	3	13	21
State DOT	0	0	3	10	21	34
Total	2	1	8	20	59	90

Fisher's exact = 0.533

APPENDIX 3
GOOGLE MAPS PYTHON SCRIPT

```
import os
import re
import urllib2
import time
import random

#*********************************************************************
class location:

    def __init__(self,name,lat,lon):

        self.name = name
        self.lat = lat
        self.lon = lon

        self.spd = {}
        self.TT = {}
        self.dis = {}
        self.congTT = {}
        self.congspd = {}



    def setspd(self,loc,value):
        self.spd[loc] = value

    def setdis(self,loc,value):
        self.dis[loc] = value

    def setTT(self,loc,value):
        self.TT[loc] = value

    def setcongTT(self,loc,value):
        self.congTT[loc] = value

    def setcongspd(self,loc,value):
        self.congspd[loc] = value

#*********************************************************************

def loadfile(file):

    global locs

    for line in open(file):
        # skip header
        if 'Centroid_ID' in line:
            continue

        #Add location to file
        lineval = line.split(',')
        locs.append(location(lineval[0].strip(), lineval[1].strip(), lineval[2].strip()))


#*********************************************************************
def getGoogleTT(lat1, lon1, lat2, lon2):

    baseURL = r"http://maps.google.com/maps?f=d&source=s_d&saddr="
    URL = "%s%s,+%s&daddr=%s,+%s" % (baseURL,lat1,lon1,lat2,lon2)

    #print URL

    #get website
    response = urllib2.urlopen(URL)
    html = response.read()

    #find the first location
    p1 = r"<div class=dditd id=dditd>(.*?)<\/div>"
    reg = re.compile(p1, re.DOTALL)
    text = reg.findall(html)

    #get Distance and Travel time
    p = r"<div><b>(\d+.\d).*?about <b>(\d+) mins"
    reg = re.compile(p,re.DOTALL)
    r = reg.findall(text[0])

    dis = r[0][0]
```

```
    TT= r[0][1]
    spd = (float(dis)/float(TT)) * 60

    #get congestion time hours
    p2 = r".*?up to (\d+) hour.*?"
    reg2 = re.compile(p2,re.DOTALL)
    r2 = reg2.findall(text[0])

    #get congestion time mins
    if len(r2)>0:
        #get congestion time mins
        p3 = r".*? hour (\d+) mins.*?"
    else:
        #get congestion time mins
        p3 = r".*?up to (\d+) mins.*?"

    reg3 = re.compile(p3,re.DOTALL)
    r3 = reg3.findall(text[0])

    #if congestion time given
    if len(r3)>0:
        #if hour value given
        if len(r2)>0:
           hrtomins = (int(r2[0]) * 60 )
           conTT = str(int(r3[0]) + hrtomins)
        else:
           conTT = r3[0]
        conspd = (float(dis)/float(conTT)) * 60
    else:
        conTT = ' '
        conspd = ' '

    print "dis=%s  TT=%s  spd = %s conTT=%s conspd=%s " % (dis,TT,str(spd), conTT, str(conspd))

    return dis,TT, str(spd)[:5], conTT, str(conspd)[:5]



#*************************************************************************
def readFile(filename):


    fp = "(\d+)to(\d+).*?"
    freg = re.compile(fp,re.DOTALL)
    fdata = freg.findall(filename)

    toval = fdata[0][0]
    fromval = fdata[0][1]

    f = open(filename)
    text =   f.readlines()
    #print text[0]
    f.close()

    if 1==1:

        #get Distance
        p = r"<div><b>(\d+.\d).*?about"
        reg = re.compile(p,re.DOTALL)
        r = reg.findall(text[0])

        dis = r[0]

        #get Travel time if Hours
        p2 = r"<div><b>.*?about <b>(\d+) hour.*?"
        reg2 = re.compile(p2,re.DOTALL)
        r2 = reg2.findall(text[0])

        if len(r2)>0:
            #get congestion time mins
            p3 = r".*? hour (\d+) min.*?"
        else:
            #get congestion time mins
            p3 = r".*?about <b>(\d+) min.*?"

        #get Travel time mins
        reg3 = re.compile(p3,re.DOTALL)
```

```
        r3 = reg3.findall(text[0])

        #if hour value given
        if len(r2)>0:
             hrtomins = (int(r2[0]) * 60 )
             TT = str(int(r3[0]) + hrtomins)
        else:
             TT = r3[0]
        spd = (float(dis)/float(TT)) * 60


        #get congestion time hours
        p4 = r".*?up to (\d+) hour.*?"
        reg4 = re.compile(p4,re.DOTALL)
        r4 = reg4.findall(text[0])

        if len(r4)>0:
            #get congestion time mins
            p5 = r".*?up to \d+ hour (\d+) min.*?"
        else:
            #get congestion time mins
            p5 = r".*?up to (\d+) min.*?"

        reg5 = re.compile(p5,re.DOTALL)
        r5 = reg5.findall(text[0])

        #if congestion time given
        if len(r5)>0:
            #if hour value given
            if len(r4)>0:
               hrtomins = (int(r4[0]) * 60 )
               conTT = str(int(r5[0]) + hrtomins)
            else:
               conTT = r5[0]
            conspd = (float(dis)/float(conTT)) * 60
        else:
            conTT = ' '
            conspd = ' '

    else:
        print "Error"
        print text[0]

    return dis,TT, str(spd)[:5], conTT, str(conspd)[:5], toval, fromval

#************************************************************************
def printdata(outfile):


    f = open(outfile, 'w')

    #create header line
    header = ' ,'
    for loc in locs:
        header = header + loc.name + ","
    header =  header[:-1] + "\n"

    f.write("DISTANCE (miles)\n")
    f.write(header)

    #Print Distance
    for loc in locs:
        s = ''
        s = str(loc.name)
        print "Writing Distance for %s" %  (loc.name)
        for loc2 in locs:
                s = s +  "," + str(loc.dis[loc2.name])
        f.write(s + "\n")


    f.write("\n\nFREEFLOW TRAVEL TIME (mins)\n")
    f.write(header)

    #Print Freeflow TT
    for loc in locs:
        s = ''
        s = str(loc.name)
```

```
        print "Writing FF for %s" %  (loc.name)
        for loc2 in locs:
                s = s +  "," + str(loc.TT[loc2.name])
        f.write(s + "\n")

    f.write("\n\nFREEFLOW SPEED (mph)\n")
    f.write(header)

    #Print FF Speed
    for loc in locs:
        s = ''
        s = str(loc.name)
        print "Writing Spd for %s" %  (loc.name)
        for loc2 in locs:
                s = s +  "," + str(loc.spd[loc2.name])
        f.write(s + "\n")


    f.write("\n\nCONGESTED TRAVEL TIME (mins)\n")
    f.write(header)

    #Print Congested TT
    for loc in locs:
        s = ''
        s = str(loc.name)
        print "Writing Congested TT for %s" %  (loc.name)
        for loc2 in locs:
                s = s +  "," + str(loc.congTT[loc2.name])
        f.write(s + "\n")

    f.write("\n\nCONGESTED SPEED (mph)\n")
    f.write(header)

    #Print congestion spd
    for loc in locs:
        s = ''
        s = str(loc.name)
        print "Writing congestion spd for %s" %  (loc.name)
        for loc2 in locs:
                s = s +  "," + str(loc.congspd[loc2.name])
        f.write(s + "\n")


    f.close()



#*************************************************************************


def main (filename):

    #load input file
    loadfile(filename)

    os.chdir(r"C:\Data\Projects\Docstuff\Hardy\files")


    #test print
##    for loc1 in locs:
##
##        for loc2 in locs:
##           if loc1.name != loc2.name:
##               loc1.setdis(loc2.name, '23')
##               loc1.setTT(loc2.name, '18')
##               loc1.setspd(loc2.name, '23.4')
##               loc1.setcongTT(loc2.name, '34.2')
##               loc1.setcongspd(loc2.name, '12.2')
##           else:
##               loc1.setdis(loc2.name, ' ')
##               loc1.setTT(loc2.name, ' ')
##               loc1.setspd(loc2.name, ' ')
##               loc1.setcongTT(loc2.name, ' ')
##               loc1.setcongspd(loc2.name, ' ')


##    values = []
```

```
##    values = readFile("97to1.html")
##    print values
##    locs[0]


    #file load
    print "Loading Data..."

    files = os.listdir(r"C:\Data\Projects\Docstuff\Hardy\files")
    files.sort()

    for f in files:
        if '.html' in f:
            #print "Loading file %s" % (f)
            values = []
            values = readFile(f)
            #print "loc1=%s   loc2=%s" % (values[5],values[6])
            #print "dis=%s  TT=%s  spd = %s conTT=%s conspd=%s " %
(values[0],values[1],values[2],values[3],values[4])
            if values[5] != values[6]:
                locs[int(values[5])-1].setdis(values[6], values[0])
                locs[int(values[5])-1].setTT(values[6], values[1])
                locs[int(values[5])-1].setspd(values[6], values[2])
                locs[int(values[5])-1].setcongTT(values[6], values[3])
                locs[int(values[5])-1].setcongspd(values[6], values[4])

    #load data blanks for same to and from
    for loc1 in locs:
          for loc2 in locs:
              if loc1.name ==  loc2.name:
                loc1.setdis(loc2.name, ' ')
                loc1.setTT(loc2.name, ' ')
                loc1.setspd(loc2.name, ' ')
                loc1.setcongTT(loc2.name, ' ')
                loc1.setcongspd(loc2.name, ' ')

    #print "loc len %d" % len(locs)
    #for loc in locs:
    #   print "ID %s TT len %d" % (loc.name, len(loc.TT))


    printdata('data.csv')


    #Get TT from Google
##    for loc1 in locs:
##        if int(loc1.name)>3:
##            for loc2 in locs:
##                if loc1.name != loc2.name:
##                    values = []
##                    values = getGoogleTT(loc1.lat, loc1.lon, loc2.lat, loc2.lon)
##                    print "dis=%s  TT=%s  spd = %s conTT=%s conspd=%s " %
(values[0],values[1],values[2],values[3],values[4])
##                    loc1.setdis(loc2.name, values[0])
##                    loc1.setTT(loc2.name, values[1])
##                    loc1.setspd(loc2.name, values[2])
##                    loc1.setcongTT(loc2.name, values[3])
##                    loc1.setcongspd(loc2.name, values[4])

#**********************************************************************

if __name__=='__main__':

    os.chdir(r"C:\Data\Projects\Docstuff\Hardy")

    locs = []

    main('MAZ_Centroids.csv')
```

APPENDIX 4
EXPERT PANEL QUESTIONNAIRE

Dear Expert Panel Participant:

Thank you for agreeing to help evaluate the MARS Washington DC Integrated Transportation and Land Use Model. The following questions are designed to generate feedback assessing the utility and practical value of the model that was presented. Please fill out your answers and return to me by February 25, 2011. Should you have any questions, please contact me at (202) 624-3625 or mhardy@aashto.org.

Demographic Data

Name:

Organization:

Job Description:

Question 1: What did you find to be the strengths of the MARS Washington DC Model?

Question 2: What did you find to be the weaknesses of the MARS Washington DC Model?

Question 3: What do you see as some areas of improvement for the MARS Washington DC Model?

Question 4: What are your thoughts on the functionality of the MARS Washington DC Model (e.g., data requirements, run time, outputs, etc.)?

Questions 5 is concerned with the use of models in supporting the metropolitan planning decision-making process. This process is defined as consisting of the following four decision-making categories:

- *Policy Development*—Often involves exploring potential outcomes in a broad-based manner as a way of screening a large number of alternatives to identify strategies that are worthy of more investigation.
- *Visioning*—A concerted effort undertaken by the government to engage stakeholders in the planning process in order to elicit feedback regarding various transportation and land use policies and scenarios. Also referred to as scenario planning.
- *Strategic Analysis*—Includes the identification, consideration, and analysis of alternative transportation systems (e.g., no-build versus light rail transit) or land use policies (e.g., high density versus low density growth).
- *Tactical Assessments*—It is the design, construction, and operation of a specific project identified within as part of the strategic analysis (e.g., construction of the Silver Line or redevelopment of a specific Silver Line station in Tysons Corner).

Given these decision-making categories, what is your opinion regarding the utility of using the MARS Washington DC Model to support the metropolitan planning decision-making process?

Question 6: Overall, what is your opinion on the MARS Washington DC Model and its usefulness in supporting the decision-making process?

APPENDIX 5
EXPERT PANEL WEBINAR PRESENTATION

Expert Panel Presentation

Assessing the Application and Use of an Integrated Transportation and Land Use Modeling Tool to Support Metropolitan Planning Decision Making

Matthew Hardy

February 14 and 15, 2011

1

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Outline

- Research Overview
  - Motivation
  - Initial Findings
- MARS ITLUM Tool Overview
  - System Dynamics
  - MARS Model Development
- MARS Washington
  - Network Development
  - Data Requirements
  - Calibration
  - Outputs
- Demonstration
- Summary and Q&A

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RESEARCH OVERVIEW

3

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Motivation

1. Transportation and land use are key drivers in metropolitan planning.
2. Metropolitan planning is a complex and interconnected process.
3. Many policies operate on very different spatial and temporal scales.
4. The role and number of stakeholders is increasing.
5. Organizations rely on the use of computer modeling tools to assess alternatives.

4

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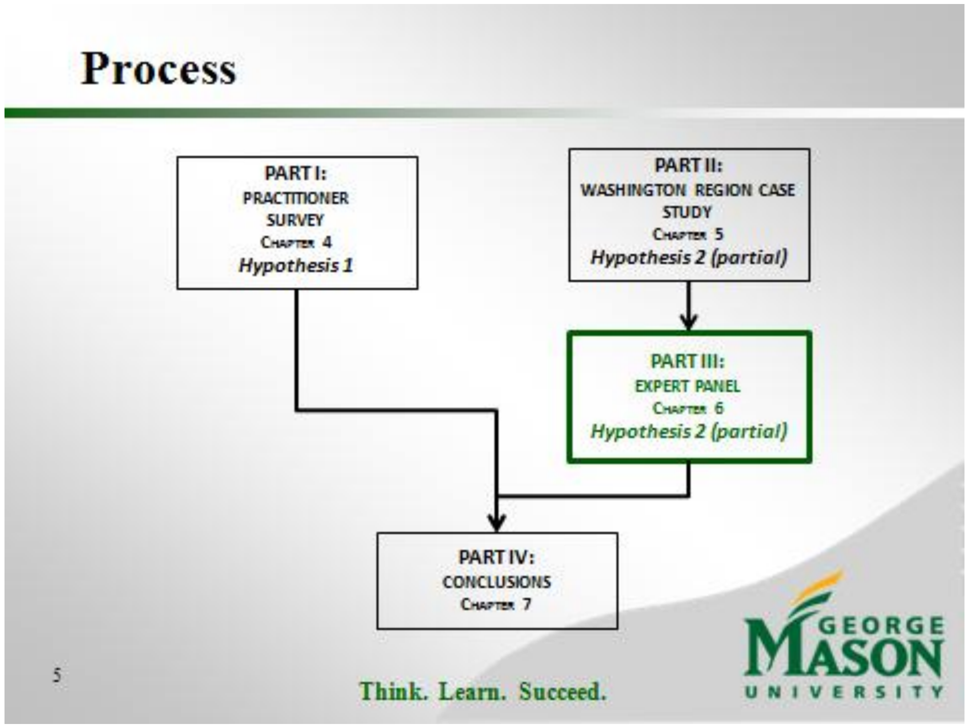
Process
PART I:
PRACTITIONER SURVEY
CHAPTER 4
Hypothesis 1
PART II:
WASHINGTON REGION CASE STUDY
CHAPTER 5
Hypothesis 2 (partial)
PART III:
EXPERT PANEL
CHAPTER 6
Hypothesis 2 (partial)
PART IV:
CONCLUSIONS
CHAPTER 7
5
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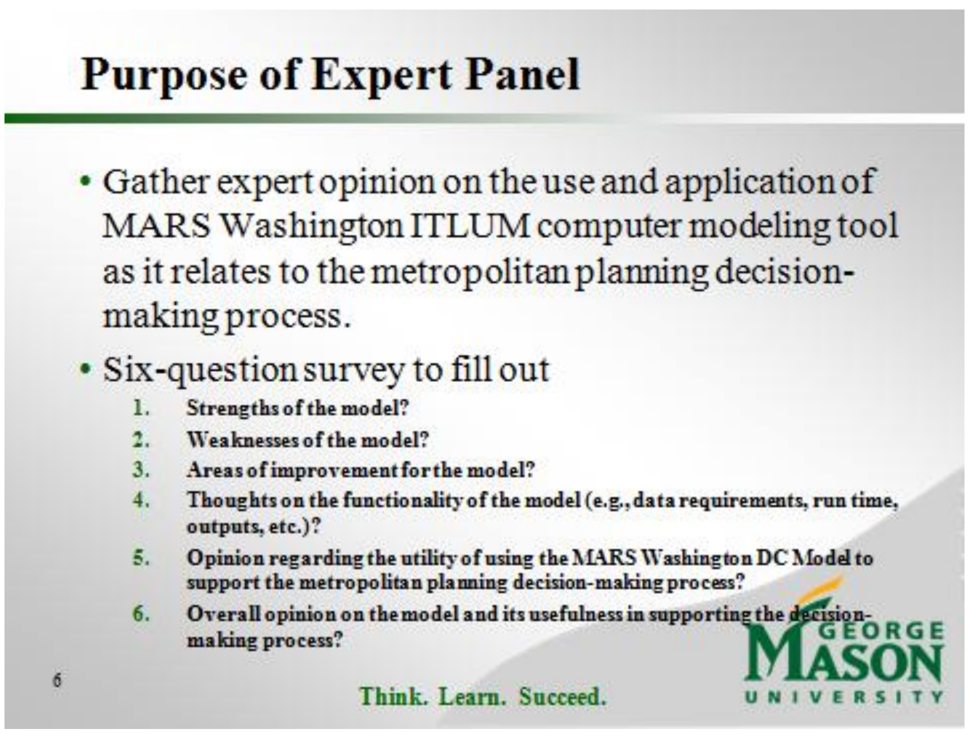
Purpose of Expert Panel
• Gather expert opinion on the use and application of MARS Washington ITLUM computer modeling tool as it relates to the metropolitan planning decision-making process.
• Six-question survey to fill out
1. Strengths of the model?
2. Weaknesses of the model?
3. Areas of improvement for the model?
4. Thoughts on the functionality of the model (e.g., data requirements, run time, outputs, etc.)?
5. Opinion regarding the utility of using the MARS Washington DC Model to support the metropolitan planning decision-making process?
6. Overall opinion on the model and its usefulness in supporting the decision-making process?
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ITLUM Tools

ITLUM Tool	Applications	Approach	Purpose	Spatial Scale	Temporal Scale	Data	Resource Availability	Functionality	Expertise
MARS	• Leeds, England • Madrid, Spain • Vietnam	Hybrid System Dynamics	• Policy Development • Visioning	Large Zones (3-20 km^2)	1 year time step	Low	Low	Medium	Medium
TELUM	• 50+ planning organizations in the U.S.	Spatial Interaction	• Policy Development • Strategic Analysis	Large Zones (3-20 km^2)	5 year time step	Medium	Medium	Low	Medium
TRANUS	• Sacramento, CA • Baltimore, MD • State of Oregon	Hybrid Microsimulation	• Strategic Analysis	Small Zones (1-5 km^2)	1 year time step	Medium	Medium	Medium	High
UrbanSim	• Eugene-Springfield, OR • Portland, OR • State of Utah • Oahu, HI	Hybrid Microsimulation Cellular Automata	• Policy Development • Strategic Analysis	150 m^2 grid	1 year time step	High	High	High	High
TRANSIMS	• Portland, OR • Dallas, TX	Hybrid Microsimulation Cellular Automata Agent-based	• Strategic Analysis	7.5 m^2 grid	1 second time step	High	High	High	High

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Metropolitan Planning Decision Making

- Decision Categories
  - Policy Development
  - Visioning
  - Strategic Analysis
  - Tactical Assessments
- *Sussman, et. al. (2005)*:
  - Decisions that need to be supported *should drive* tool selection.
  - Tool complexity and sophistication *should not drive* tool selection.

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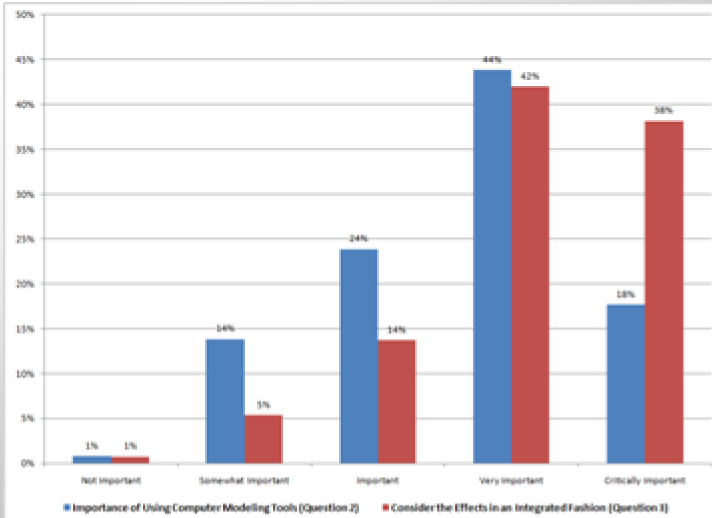
Practitioner Survey



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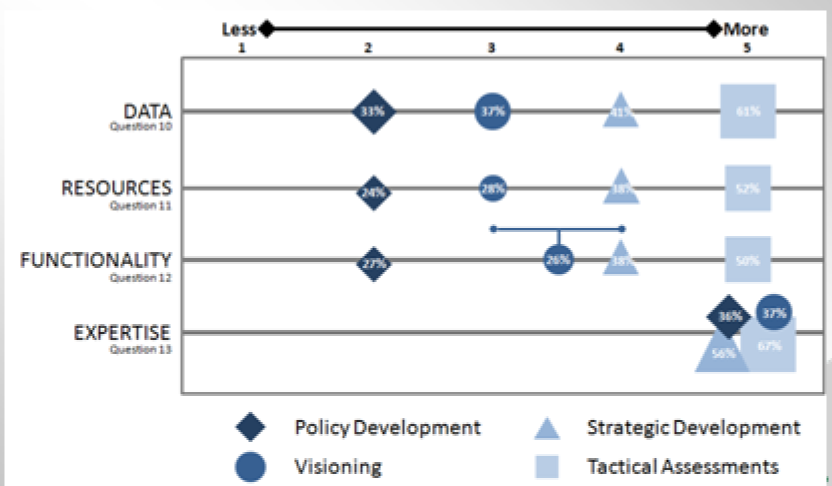
Practitioner Survey



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MARS ITLUM TOOL OVERVIEW

11

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System Dynamics

- Developed by Forester in 1950s
  - Initially developed to better understand business dynamics
- Models relationships of systems over time.
  - Useful for policy analysis and design
- Five benefits:
  1. Treats a problem as *holistic*.
  2. Includes *feedback loops* such that policy effects can be assessed over time.
  3. Represents *counterintuitive* behavior.
  4. Comprises *long-term and short-term* tradeoffs.
  5. Allows for many policy scenarios to be *rapidly assessed*.

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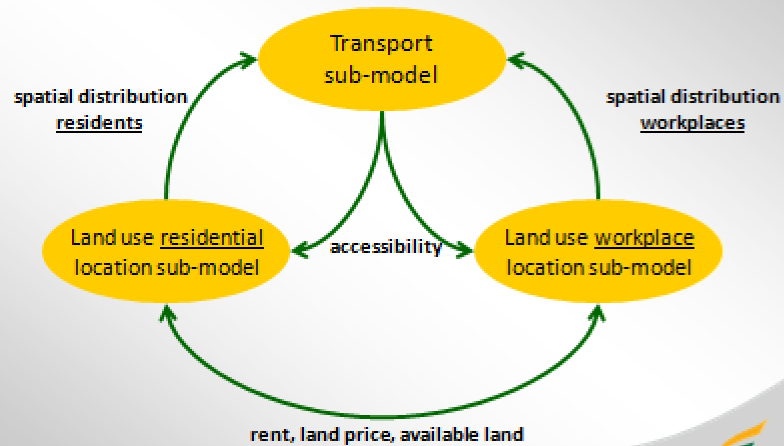
MARS Model Development



13

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Boundary Table

Endogenous	Exogenous	Excluded
Number of Trips	Growth Rate	Freight Transport
Private Vehicle	Service Sector	Route Choice
Transit	Production Sector	GDP
Bike/Pedestrian	Residents	Ageing
Distribution of Trips	Car Ownership Growth Rates	
Mode Share	Household Income	
Private Vehicle Speeds	Household Size	
Accessibility	Households Moving	
Fuel Consumption	Technological Improvements	
New Housing Units	Policy Instruments	
Available open Space	Transportation Network Data	
Rent		
Land Price		
Distribution of Households Moving		
Out of a Zone		
In to a Zone		
Distribution of Workplaces		
Service Sector		
Production Sector		

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Transportation Sub-Model

- Trip Generation
  - HWH (Commute Trips)
  - HWO (Other Trips)
    - Based upon total travel time budget
- Trip Distribution
  - Gravity Model Approach
- Mode Split
- No Assignment Component

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Land Use Sub-Model

- Resident Location
  - Development: How many new residential location are to be built
  - Move Out: How many existing residents move out
  - Move In: How many new residents move in
- Work Place Location
  - Businesses settle where the availability of land is high, the accessibility is high and the land price is low.
  - The development of new building land (for businesses) takes place where accessibility has recently increased.
  - When businesses may choose between equally available sites, differences in land price are more important than differences in accessibility.

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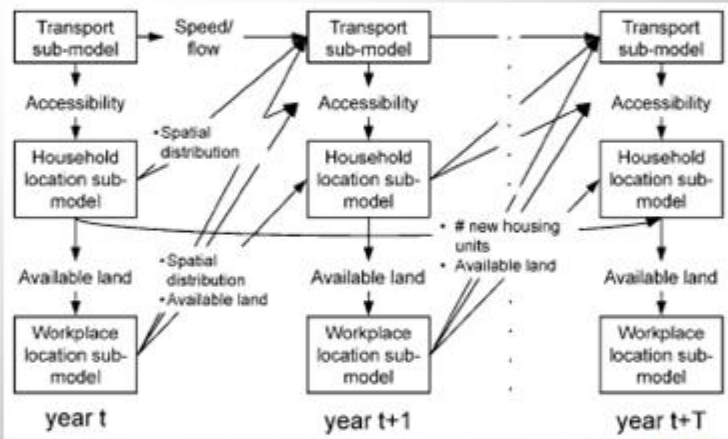
Time Series Iterations



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MARS WASHINGTON

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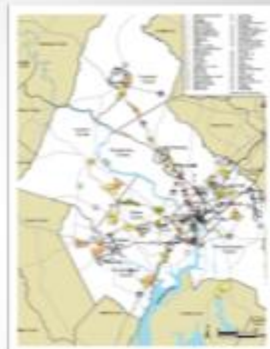
Network Development

Traffic Analysis Zones



Economic Centers

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Network Development

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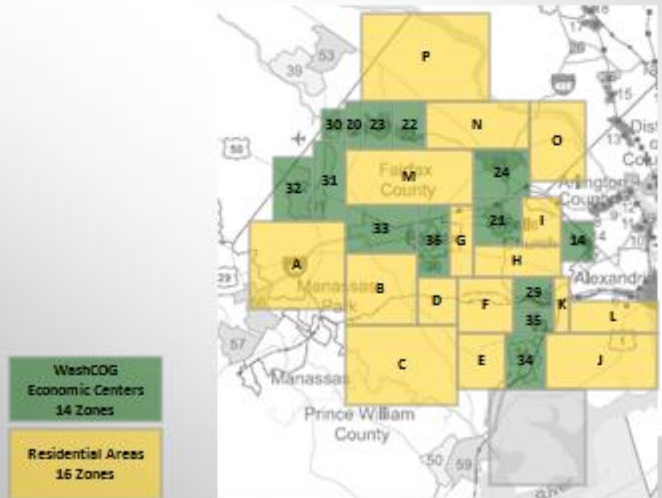
Network Development



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Data Sources

- City-data.com
- GMU Center for Regional Analysis (CRA)
- Google Maps
- Google Transit Feed Specification (GTFS)
- National Household Travel Survey (NHTS)
- WashCOG Round 7.1 Cooperative Forecast
- U.S. Census Bureau
- U.S. Geological Survey (USGS) Land Cover Data Set

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Data Requirements

- Regional Data
- Zonal Data
- Passenger Car Data
- Public Transportation Data

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Regional Data

Data Element	Source	Units
Average number of commuting trips	Estimate	Trips/person
Average daily travel time budget	NHTS	Hours/person
Housing turnover rate	Estimate	Years
New housing units base year	GMU Center for Regional Analysis	Housing units
Average walking speed (peak and off-peak)	Estimate	kph
Vehicle occupancy rate: Commute	NHTS	Persons/vehicle
Vehicle occupancy rate: Non-commute	NHTS	Persons/vehicle
Drivers license (employed and non-employed)	Estimate	Percent

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Zonal Data

Data Element	Source	Units
Number of residents	WashCOG Round 7.1 Cooperative Forecast	Persons
Number of employed	WashCOG Round 7.1 Cooperative Forecast and U.S. Census (P43)	Persons
Average household income	City-data.com	Euro/month
Average household size	City-data.com	Persons/house
Average monthly housing cost	City-data.com	Euro/ m^2/month
Average house size	City-data.com	m^2
Number of empty housing units (basic year)	U.S. Census	Housing units
Number of workplaces	WashCOG Round 7.1 Cooperative Forecast	Workplaces
Share of production sector and service sector jobs	WashCOG Round 7.1 Cooperative Forecast	Percentage
Area covered by each zone	WashCOG Round 7.1 Cooperative Forecast	km^2
Percent of land undeveloped	U.S. Geological Survey Land Cover Data Set	Percent
Percent of land developable for: residential, commercial, and protected	U.S. Geological Survey Land Cover Data Set and Visual inspection	Percent
Production or service sector developed is allowed in a zone	Visual inspection	Yes or no
Price of land	City-data.com	Euro/ m^2

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Passenger Car Data

Data Element	Source	Units
Parking cost: time	Estimate	Minutes
Parking cost: monetary	Estimate	Euros
Distance matrix among MARS analysis zones	Google Maps	km
Free-flow speed matrix among MARS analysis zones	Google Maps	kph
Peak-period speed matrix among MARS analysis zones	Google Maps	kph
Tolling charges among MARS analysis zones	Estimate	Euros

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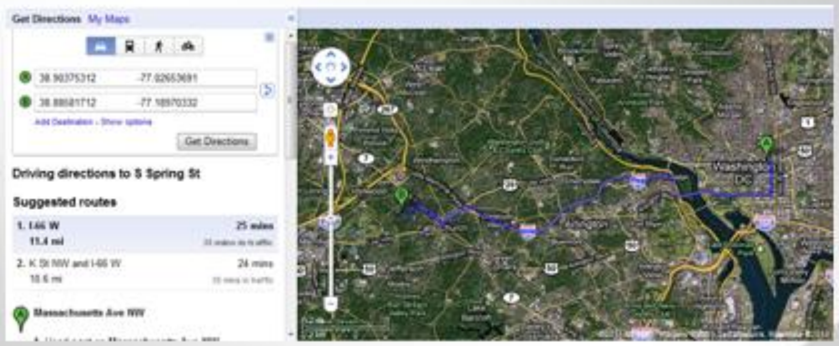
Google Maps



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Public Transportation Data

Data Element	Source	Units
Station Distance Matrix	GTFS	km
Walk to Station Time	Estimate	Min
Train Headway Matrix	GTFS	km
Transfer Matrix	Estimate	Min
Train Speed Matrix	WMATA	kph
Station Fare Matrix	GTFS	Euros

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Calibration

- NHTS 2001 Data
  - Total Trips
  - Mode Split
  - Trips by MARS Analysis Zone
- CTPP 2006-2008 tabulations
  - Still analyzing

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Total Trips

	NHTS*	MARS Washington	Difference	Percent
Total	6,888,073	6,699,552	-188,521	-2.7%
Commuting (HWH)	2,305,585	2,206,419	-99,166	-4.3%
Other (HOH)	4,582,488	4,493,134	-89,355	-1.9%

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Mode Split (Total)

Total	NHTS*	MARS Washington	Difference	Percent
Car	5,891,873	5,521,924	-369,949	-6.3%
Rail	996,200	1,177,628	181,428	18.2%
Total	6,888,073	6,699,552	-188,521	-2.7%

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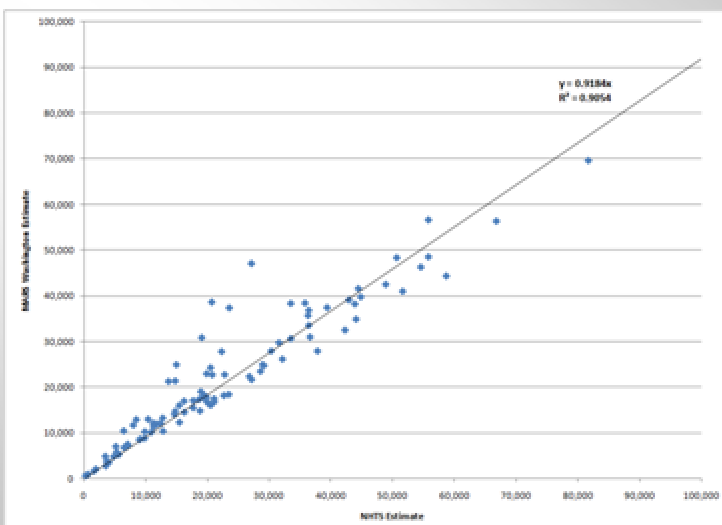
Commute Trips



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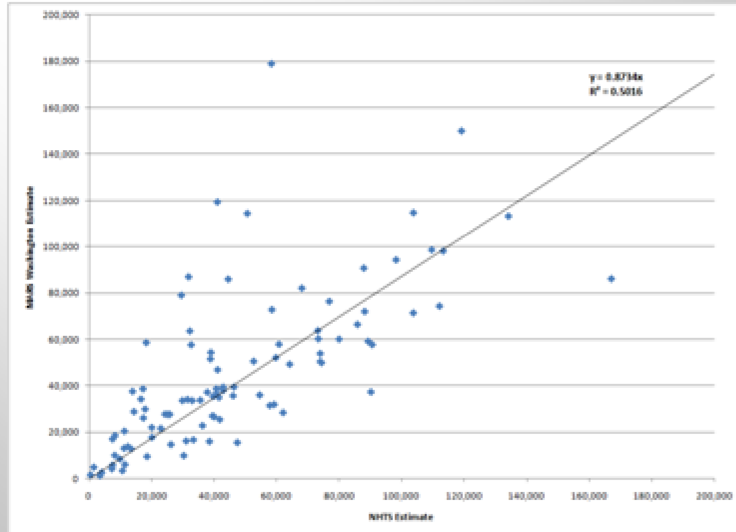
Other Trips



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Outputs

- Land Use Changes
  - Residents and Work places
- Transportation System Utilization
  - VMT: Peak and Off-peak
- Mode Share
  - Car
  - Public Transportation
- Revenue
  - Parking Fees
  - Gas Tax
  - Road User Charging

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DEMONSTRATION

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SUMMARY AND Q&A

- The intent is to develop a tractable ITLUM tool
  - Use readily available data
  - Does not require significant resources
  - Functionality
  - Support Policy Development and Visioning categories
- Expert panel being used to assess the application and use
  - Please fill out the questionnaire
  - Completely anonymous
  - Return to me Wednesday, February 23
- Questions…?

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APPENDIX 6
EXPERT PANEL RESPONSES

ID: 2

Question 1: Strengths
Seems best as sketch planning tool.

Question 2: Weaknesses
Seems softest on economic factors

Question 3: Areas for Improvement
Have to think more. Mostly about the way land uses are distributed , need more input

Question 4: Functionality
All seem good and the ability these days to use google is just terrific compared to past very laborious input processing

Question 5: Utility in Decision Making
As I said as a sketchplanner yes. The other purpose of such a model that doesn't fit the four areas (derived from my experience as Chief of Data Collection and Analysis at COT) is to be able to say that the plans developed by planners/political types will/will not achieve the goals enunciated for the region by politicians/planners.   Example: Montgomery Co should have high density development around transit facilties!!! MODEL WILL TELL YOU THAT WITH YOUR PRESENT POLICIES/PLANS/ACTIONS YOU WON'T GET THERE FROM HERE.

Question 6: Concluding Thoughts and Opinion
Can be very useful. Stay with it.

ID: 3

Question 1: Strengths
Without knowing the model in detail, it is kind of difficult to assess the model. However, it seems that the model has strength in visualization and simplifying model's complexity…..

Question 2: Weaknesses
I should know more about Vensim on this…… I would like to assess more if the model is available to me……

Question 3: Areas for Improvement
N/A

Question 4: Functionality
Run time seems to be great….. Just 10 minute for 1 interation (right?)

Question 5: Utility in Decision Making
It will be a good tool for especially strategic analysis…

Question 6: Concluding Thoughts and Opinion
This can be a great tool for policy testing, if many of policy factors can be properly coded in the model.

ID: 6

Question 1: Strengths

- It combines land use and transportation factors
- Data needed are available to many communities that might be interested in using it
- Data can be entered into model efficiently
- Model inputs and process can actually be diagramed – in a way that planners and policymakers could understand (or at least see what's in – or not in – the "black box")
- Includes market factors (rent/land price/available land)
- Could provide good support for policy development/testing and visioning

Question 2: Weaknesses

Not sure I know enough to identify. Would be great to understand more about how the info not included like freight and route choice do or don't affect. Also to know if the problems with the data alignment for some factors affects outcome.

Question 3: Areas for Improvement

Don't feel that I know enough to suggest improvements.

Question 4: Functionality

MARS tool looks like it has good possibilities for usefulness for a wide variety of communities. The need for these tools will only become more acute. The decision making process is not going to become more simple. Decisions about where to spend scarce resources will only become more complex as situations become more complex and as public opinions and opportunities to participate in decision making processes increase. In short – policy makers will need tools that can support their decision making in a more sophisticated way – but on a "shoestring".

Question 5: Utility in Decision Making

It is hopeful. It should be tried out by some communities to track its utility. Also – It would be helpful to have the analysis of various tools available to communities so that they become aware of them, can choose a tool that most meets their needs, and can approach the tool choice with some good information.

Question 6: Concluding Thoughts and Opinion

Work should continue on the tools as well as opportunities to inform those of us "in the trenches" about what is available and useful.

Great project Matt – and excellent presentation (although a bit rushed for those of us less familiar with the complexities of models and modeling).

ID: 7

Question 1: Strengths

Strengths include the holistic approach, the linkages among the 3 submodels, the fact that readily available data that is fairly easy for anyone to obtain can be used, 4 modes included in the transportation submodel (auto, rail, bus, ped/bike), 30 year time horizon, price, and features that can be changed to test the effects of policy decisions (e.g., parking costs, fares, frequency, fuel price).

Question 2: Weaknesses

Weaknesses include use of metric scale and euros, some learning curve, lack of visualization (graphical interface), not clear if other demographic data can be included (such as population age, low-income, minority, etc), compatibility with land use scenario planning tools (such as Community Viz, Envision, etc.) and possibly the limitations of TAZs (which may not be an issue b/c large metro areas probably already use a more robust model and MARS would be more applicable in smaller urban or rural areas).

Question 3: Areas for Improvement

Part of the answer to this question is to address the weaknesses. For a larger metro area, may want to be able to have more TAZs. This model would probably not work very well for the _______ metro area with that limitation. In addition, while the data is there and can be readily put into an excel spreadsheet, it isn't very public friendly if you wanted to use the outputs in a visual way to inform the public.

Question 4: Functionality

Seems like a very functional model. The run time seemed appropriate, the use of readily available data is key especially if smaller urban and rural areas are using it. The study I'm working on is to create tools, including a land use/transportation scenario planning model, for use in rural areas of ___________, this could be very beneficial.

Question 5: Utility in Decision Making

I think this tool can support the process. The only downside is the lack of visualization for sharing with stakeholders, which could make the visioning piece difficult. Easy to understand graphics to illustrate the model's inputs, outputs and scenarios is almost a must to engage the public. It seems this model is better suited for smaller MPOs. Also, I'm not exactly clear on how the model could work at the project level unless you were able to somehow input the project to see it how it affects the system. In thinking about this further, I'm not really clear how you change the network to assess different transportation system scenarios at both the strategic analysis and tactical assessment levels. For example, a scenario planning exercise to evaluate a more auto oriented system vs. transit or the no build vs. build. How does the model reflect land use changes with transportation system changes and vice versa. I know the inputs can be tweaked to show greater development in an area and what that does to traffic (VMT, etc), but not sure when it's scenarios for the transportation system.

Question 6: Concluding Thoughts and Opinion

I am very interested in learning more about this model for our own work in __________. I think it could be a very useful tool in decision-making if a few of the downsides were worked out, namely metrics/euros conversion and graphical interface capabilities. Plus, I would need to understand better how the relationship between land use decisions and transportation decisions get expressed within the model. I apologize, if this was demonstrated during the presentation and I'm forgetting.

ID: 8

Question 1: Strengths
My immediate positive reaction to this model is based upon its low-data appetite and that the data necessary to drive the model can be easily obtained and is free or very low-cost. In working with small communities with limited planning resources, this would be a valuable asset.

Question 2: Weaknesses
One concern when reviewing the inputs needed for the model, but could be a deterrent to users, is the requirement for the data to be "Euro-centric" with costs & values being reported in euros and distance in metric units. How adaptable is this? In rural communities, "trip-chaining" is a fairly common behavior as commuters will make a trip into town for work then conduct their errands as part of that commute. I believe that it was presented that this model did not react well to tracking "trip-chaining"?

Question 3: Areas for Improvement
If "freight" could be included in the model in the future, this would be helpful. This is an issue which is weighing heavy on the minds of the small communities in our region for two reasons: a) The impacts of pass-through truck traffic on these communities which are located on major freight networks, b) The impacts of truck traffic generated from the development of distribution centers within in these communities.

Question 4: Functionality
I found the higher than expected number of "rail trips" with this model to be intriguing, especially in light of one fellow participant's comments that the model may not be sensitive to "modal choice" behavior patterns, especially with the American traveler. Of course, the small and rural communities with whom I work do not have rail as a viable mode choice and this would not be a factor to skew their model outputs. The appeal of this model (the low-cost or free resources available for inputs, its user friendliness, & its performance with smaller sets of TAZs) outweighs this one anomalous output.

The incorporation of Google Maps in the determination of travel times seems very user-friendly and lends itself to visualizations which can be easily communicated to the public and local officials. If I understood correctly, these travel times also included transit waiting times, the times used in locating parking space, etc.

Question 5: Utility in Decision Making
From my understanding of the outputs, this model seems to best utilized in regards to the development of transportation policies (especially of those mentioned concerning parking fees, fuel taxes, and road user charges), and also in the plotting out the impacts

of land use/transportation scenarios for communities. Because of the mode share and VMT outputs, this mode may react well in strategic analysis of alternative systems, but I am uncertain as to how it would address the more focused assessments of specific projects.

Question 6: Concluding Thoughts and Opinion

The simplicity and relative ease of the model appears to make the case that this is a tool which could be useful, especially to smaller MPOs. For evaluations of transportation policies possible scenarios, this tool reacts well. I am uncertain of its use in evaluation of specific project alternatives.

ID: 10

Question 1: Strengths
Ease of use.

Question 2: Weaknesses
Hard to translate results into "sustainability". Unsure of validity of projections.

Question 3: Areas for Improvement
See #2

Question 4: Functionality
Seems fine for what it is. Really like being able to tap into Google, etc.

Question 5: Utility in Decision Making
Seems a useful tool. So useful, that it might be used by advocacy groups, etc to stimulate discussion on alternative futures…

Question 6: Concluding Thoughts and Opinion
Helps formulate the questions. Not sure it has the rigor to substantiate big ticket decisions.

ID: 11

Question 1: Strengths

Its strengths seem to be using data from readily available sources, aggregation of the data and ease of use. This will allow flexibility and responsive application of the model.

Question 2: Weaknesses

It may not allow as detailed analyses as other models but it would provide more opportunities for alternatives analyses because of its simplicity and ease of use. Assuming the NHTS is capturing the data, it does not explain "other" trips as accurately it does commuting trips. Why is that?

Question 3: Areas for Improvement

It was not apparent how much peak hour analyses could be done using the model and how it could explain "other" trips. Since most of the peak hour trips would probably be commuting trips, this may not be that much of an issue because it explains commuting trips with a higher correlation.

Question 4: Functionality

It seemed to be very functional and the ability to use data from multiple sources was a strength. Also its explanation of "commuting" trips was a strength because they would be consuming the peak hour capacity.

Question 5: Utility in Decision Making

The model seems to be capable of the first three decision-making categories and its simplicity would allow for multiple analyses to be done. At a project level it is not apparent how much detailed analyses of designs or modal tradeoffs could be done and how precise they might be. At such a grand scale as the Washington MPO, trying to do something at that level with zones being combined may be too much to ask of a model of this type. For tactical assessments at the scale you suggest above, like Tyson's Corner, the model looks like it might be helpful. Land uses for non-work purposes might be more difficult to analyze since the model does not seem to explain non-commuting trips as well.

Question 6: Concluding Thoughts and Opinion

It looks like it would be useful to do analyses for policy, visualization and strategic decision making on modal investments, particularly for commuting purposes.

ID: 12

Question 1: Strengths

Overall the strengths of the MARS Washington DC Model are its ability to return large amounts of broad output data in a short period without requiring substantial amounts of hard to obtain data to run. This makes the MARS Washington DC Model ideal for running multiple scenarios quickly to determine which scenario maybe the best to evaluate further. Also the low data requirements and low level of expertise required to run the software make it a good model choice for organizations that may not have the resource and funding for larger scale planning models.

Question 2: Weaknesses

One of the largest weaknesses of the MARS Washington DC Model is it lack of detail strategic analysis. The light weight approach that the MARS Washington DC Model allows it to have low data requires but what you lose is detail in the results. For large scale planning projects that have lots of detail the MARS model can give you a general idea of what is happening but most likely a more detail model would be required to get useable results.

Question 3: Areas for Improvement

To improve the use of the MARS DC Model I would look at creating more automatic methods to pull in its data. With improved tools to gathering, cleaning, preparing, and entering the data into the MARS DC model it can be used in a much broader format. This is especially true for generating and modifying the network in the model.

Question 4: Functionality

I think the MARS Washington DC Model is a good tool to use for testing out multiple different scenarios because of its low data requirements, fast run times and high level outputs.

Question 5: Utility in Decision Making

- Policy Development – The MARS DC model is very good for this because of its ability to run multiple alternatives quickly.
- Visioning – The MARS DC Model would be good to give stokehold broad policy information over many different scenarios.
- Strategic Analysis – I don't think the MARS DC Model has the detail to do this type of Analysis.
- Tactical Assessment - The MARS DC Model does not have the detail for this type of analysis.

Question 6: Concluding Thoughts and Opinion

I believe the MARS DC Model if used properly can be an effective Model in supporting decision-making process. The models low data requirements and low level of expertise requirement make it possible for small organization to use it will out a lot of training or cost. Also the high availability of the data inputs helps to reduce the cost of running the model. The MARS DC model should be used as a scenario evaluation model for best results.

ID: 13

Question 1: Strengths
Seems to be reasonably applicable without huge investments in data collection and modeling resources. Like that it accounts for non-work trips (becoming an increasing proportion of total trips). And, it seems applicable to most metro areas via use of generally available data – ability to define subarea geography and transportation measures.

Question 2: Weaknesses
Not much, given that best uses will likely be for policy analysis at a macro scale. Too bad freight movements are excluded.

Question 3: Areas for Improvement
Freight movements? Does the model have a bias re: auto vs rail (something in the webinar about that)

Question 4: Functionality
Looks to be very functional in those measures…appears to enable rapid assessment of policy scenarios.

Question 5: Utility in Decision Making
It appears that policy changes are fairly easy to specify and then to analyze with the model…the proof of that would be in hypothesizing some policy options and see if the results make intuitive sense. Could you apply the model to a reasonable case study policy set to show the outputs and therefore the utility of using the model?

Question 6: Concluding Thoughts and Opinion
It looks like a winner…not too difficult to get the data or specify policies or run. Seems like it would be a good very useful to apply in an-going policy planning function…e.g., questions from a transportation policy board such as "what if we did x and y – and then be able to respond with a fairly reliable sense of the implications of x and y.

ID: 14

Question 1: Strengths
Fascination as to how far the modeling community has come in being able to use tools and data bases to build a credible useful tool with a relatively modest level of effort. Seemingly well targeted to contemporary topics of concern to policy makers.

Question 2: Weaknesses
While not unique to this model, it implies a level of understanding of key phenomenon relating to transportation and land use as well as travel behavior that I feel are far more nuanced than the models imply.

Question 3: Areas for Improvement

Question 4: Functionality
Geographic precision is a very sensitive issue and one that challenges data availability and computational time requirements but more is better and as data and processing power allow, greater geographic precision will be much appreciated.

Question 5: Utility in Decision Making
I see these types of tools as more relevant as learning tools and concept testing but would be reluctant to use for the project level analyses implied by the strategic analysis and Tactical assessments examples. The most challenging issues is our understanding of the power/accuracy of the transportation behavior and land use relationships and our understanding of the policies or investments required to have the respective impacts implied in the scenarios. Specifically, the land use scenarios are very informative but we often don't have a particularly good idea of what policies (rules, pricing, etc.) would be required to make them materialize.

Question 6: Concluding Thoughts and Opinion
Part of assessing its value is understanding how it fits in the suite of tools that they use for the various applications. I was very impressed with what you put together and could see it as a useful tool for education and scenario evaluation. Any time we get a new tool there is the inevitable push to enhance and refine it and it turns into a much bigger investment than realized. If this is envisioned as a sketch planning tool, one of the challenges would be to not try and turn it into something more.

I am increasingly skeptical of the connection between policy analysis and decision making. My observations are that most policy decisions are based on existing perceptions and understandings of the policy makers and their values. I haven't seen many policy makers seeking out analysis but rather using any analysis to justify their positions or to meet compliance requirements. Things like support for smart growth or transit or livability tend not to be nuanced based on specific analysis.

However, tools like this could inform perceptions not in the context of a particular decision but in general. Thus, these informed persons might subsequently be making decisions that would be more knowledgeable because they had developed a better understanding of the phenomenon.

ID: 15

Question 1: Strengths

- The tool is computer based, practical, and applicable for large and small areas alike.
- The tool can be used for decision making effectively at a systems level to answer questions.
- Considers and models land use along with transportation models.
- The tool perhaps has highest applicability in small and medium communities.
- The tool is inexpensive, the data requirements are not cumbersome, and easy to use.

Data requirements:

- The model uses readily available local sources of data.
- The algorithm in python to extract google times and distances is in itself a very good contribution.
- The model innovatively uses NHTS and CTPP for calibration.

Model Strengths

- An enormous amount of time is spent in traditional models for network coding, but eliminating assignment and looking at the production and distribution alone, the model is simplified and easily implementable.
- **Model recognizes the relatively high importance of affordability (land prices) compared to transportation costs.**

Question 2: Weaknesses

- Assignment and consequent validation is a very important part of the modeling process, however this is inherent in the concept of a simplified decision making tool.

Question 3: Areas for Improvement

- It would be useful to model carpools separately.
- For most areas, bus trips are the predominant share of transit, would be useful to have some inclusion of bus trips, but the difficulties in modeling these for a metropolitan region like Washington, DC with many separate transit systems is quite hard. It might be good to consider the National Transit Database as an alternative to collecting data from individual operators.

Question 4: Functionality

- The model uses readily available local sources of data.
- The algorithm in python to extract google times and distances is in itself a very good contribution.
- The model innovatively uses NHTS and CTPP for calibration.

- The outputs are laid out in a matrix format that allows several decision making queries.
- The tool is built so as to keep run times minimal --- this is an important strength.

Question 5: Utility in Decision Making

The presentation showed how the model could be used in "comparative" analysis, it will be invaluable as a sketch planning tool for quick alternative analysis.

Question 6: Concluding Thoughts and Opinion

This is a very important effort and should be presented at the Census and the NHTS conferences. The utility for small and medium communities is high.

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Matthew Hardy was raised in Fairfax, VA. He earned a B.S. in Urban Systems Engineering in 1997 and a M.S. in Transportation Policy, Operations and Logistics in 2004 both from George Mason University. He currently works as the Program Director for Planning and Policy at the American Association of State Highway and Transportation Officials (AASHTO). Previously, he was a Principal, Transportation Analysis at Noblis and a Transportation Engineer at Castle Rock Consultants. He was selected to be an Eno Transportation Fellow in 2009.

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