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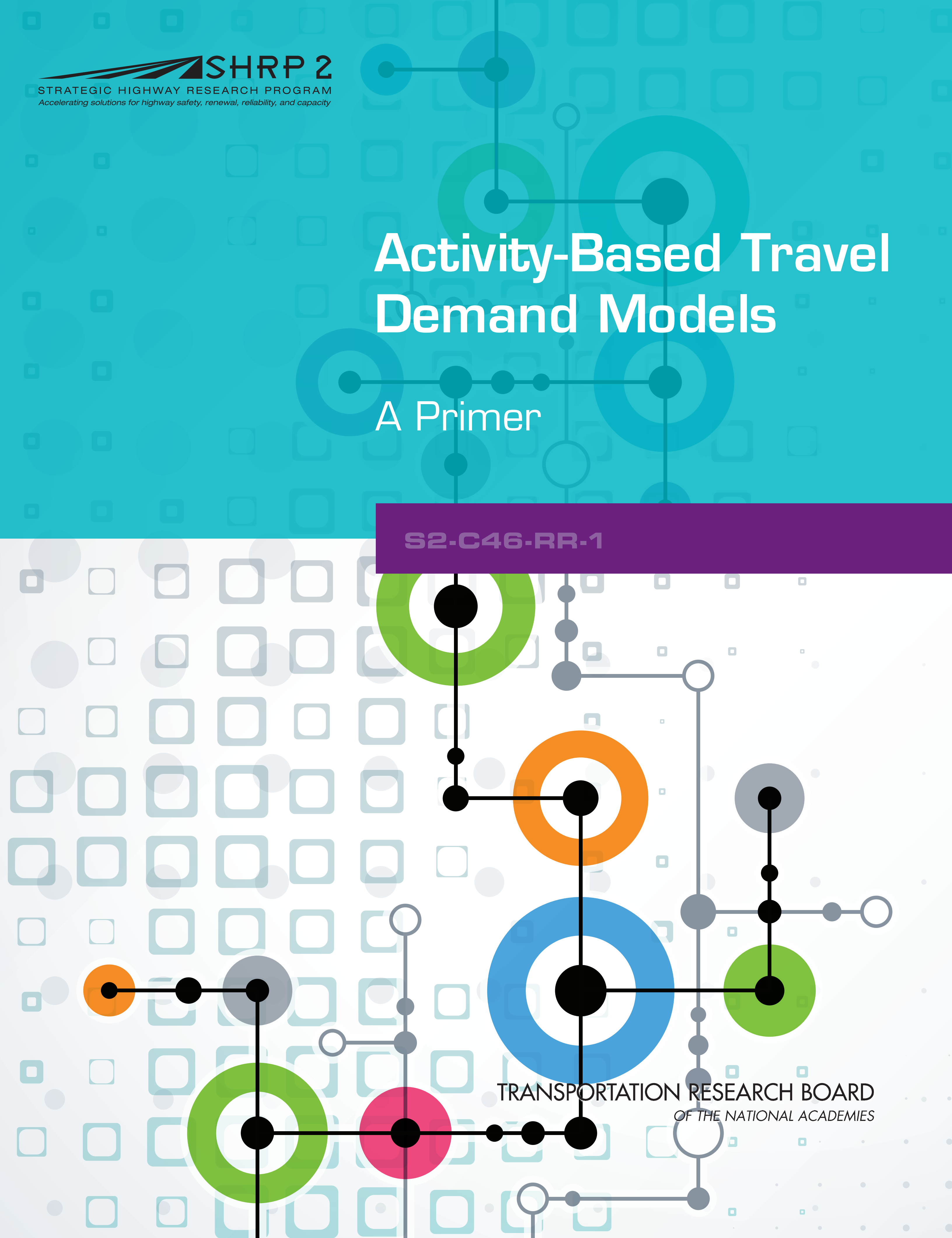

Activity-Based Travel Demand Models

A Primer

S2-C46-RR-1

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THE SECOND STRATEGIC HIGHWAY RESEARCH PROGRAM

Activity-Based Travel Demand Models: A Primer

SHRP 2 Report S2-C46-RR-1

Joe Castiglione, Mark Bradley, and John Gliebe
Resource Systems Group, Inc.
White River Junction, Vermont

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THE SECOND STRATEGIC HIGHWAY RESEARCH PROGRAM

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FOREWORD

Jo Allen Gause
SHRP 2 Senior Program Officer, Capacity

This publication is a guide for practitioners that describes activity-based travel demand model concepts and the practical considerations associated with implementing them. Activity-based travel demand models portray how people plan and schedule their daily travel. This type of model more closely replicates actual traveler decisions than traditional travel demand models and thus may provide better forecasts of future travel patterns.

The guide is composed of two parts. Part 1 is intended to help managers, planners, and hands-on practitioners and modelers make informed decisions about activity-based model development and application. Part 2 examines the practical issues that transportation agencies face in migrating from traditional to "advanced" travel demand models, in which activity-based models are linked with regional-scale dynamic network assignments.

Transportation decision makers confront difficult questions about how local and regional transportation will perform years into the future. Travel models are created to support decision making by providing information about the impacts of alternative transportation and land use policies, as well as demographic and economic trends. A wide array of travel models is used in transportation planning, from simple sketch-planning models that produce rough "order of magnitude" information to trip-based travel models that use individual person trips as the fundamental unit of analysis. Trip-based travel models, often referred to as 4-step models, have been used for decades to support regional, subregional, and project-level transportation analysis and decision making.

Activity-based models share a number of similarities with traditional trip-based models. However, activity-based models incorporate some significant advances over 4-step trip-based models. These advances include the explicit representation of realistic constraints of time and space, as well as the linkages among activities and travel both for an individual person and across multiple people in a household.

Many transportation agencies are considering moving forward with new activity-based models. The skills required to build, test, and implement an activity-based model, however, are limited to a relatively small number of departments of transportation and metropolitan transportation agencies. The first part of this guide is intended as a resource to answer management and implementation questions such as

- Do I need an activity-based model?
- What resources do I need to start building an activity-based model?
- How long does activity-based model development take?
- How can I get a model that runs in a decent amount of time?

Part 1 of the guide addresses three audiences:

- Chapter 1 is for managers and directors who make decisions about which models an agency will use.
- Chapter 2 provides modeling and planning managers with a technical road map for developing an activity-based model.
- Chapter 3 is for hands-on practitioners or modelers and focuses on concepts and algorithms for activity-based models.

The second part of the guide discusses potential benefits and issues in adopting integrated dynamic model systems in which activity-based model systems are linked with regional-scale dynamic network assignment models. Developing and applying advanced integrated dynamic models is an area of emerging research and practice. Part 2 also describes four regional integrated dynamic model system development efforts that are currently under way.

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INTRODUCTION

In order to support informed decision making, transportation agencies have been increasingly developing and experimenting with activity-based travel demand models that describe how people plan and schedule their daily travel. Activity-based models more closely replicate actual traveler decisions and thus may provide better forecasts of future travel patterns. While there have been recent successes implementing practical activity-based models, these have been limited mostly to larger metropolitan planning organizations (MPOs) and a few state departments of transportation (DOTs). This guide has been developed to help directors, managers, and planners make informed decisions about forecasting model development and application. The guide is composed of two parts. Part 1 is a primer intended to provide a practical overview of activity-based model development and application. Part 2 discusses issues in linking activity-based models to dynamic network assignment models.

The first part comprises three chapters. The first chapter is for managers or directors who make decisions about what travel demand models an agency will use and begins with a brief introduction to the motivation and practice of developing and applying travel models. Chapter 1 also provides a pragmatic assessment of activity-based model development considerations, both technical and institutional, and examines how activity-based models are integrated with other forecasting tools.

The second chapter provides a technical road map for developing an activity-based model system for modeling or planning managers. Chapter 2 identifies development strategies that agencies have used and discusses each aspect of the model development process, including

- designing the modeling system to address key policy considerations;
- specifying temporal, spatial, and typological resolutions;
- identifying activity-based model subcomponents and the relationship between the activity-based model and other forecasting tools;

- developing data;
- implementing the models and model system linkages; and
- applying the model system.

The third chapter presents and explains key activity-based model concepts. The intended audience for this section is modelers who have some familiarity with traditional trip-based concepts. The demand-and-supply model framework is examined, discrete choice models are explained, and activity-based concepts are presented.

The second part is a discussion of issues in adopting integrated dynamic model systems. The purpose of this element is to examine the benefits, barriers, and practical issues that MPOs, state DOTs, and other transportation agencies face in migrating from traditional to advanced travel demand forecasting models in which activity-based models are linked with regional-scale dynamic network assignment models. This information is included in the activity-based model primer because activity-based models are a core component of integrated dynamic model systems, and developing and applying dynamic model systems is an area of significant emerging research and practice.

Part 1

ACTIVITY-BASED TRAVEL DEMAND MODELS: A PRIMER

1

MOVING TO ACTIVITY-BASED TRAVEL DEMAND MODELS

1.1

WHY DO WE MODEL TRAVEL?

Transportation decision makers confront difficult questions and must make informed choices. How will the national, regional, or even local transportation system perform 30 years into the future? What policies or investments could influence this performance? How will economic, demographic, or land use changes affect transportation system performance? Will travel demand management strategies or intelligent transportation systems alleviate congestion? Will a new transit investment attract riders? Given a set of desired outcomes, decision makers must identify capital investments and policies that will achieve these objectives. Travel models are created to support decision making by providing information about the impacts of alternative transportation and land use investments and policies, as well as demographic and economic trends. Travel models produce quantitative information about travel demand and transportation system performance that can be used to evaluate alternatives and make informed decisions.

1.2

WHAT IS A TRAVEL MODEL?

A travel model is an analysis tool that provides a systematic framework for representing how travel demand changes in response to different input assumptions. Travel models may take many different forms. Some travel models seek to comprehensively represent multiple, interrelated aspects of regional travel behavior, such as what activities people engage in, where and when these activities occur, and how people get to these activities. Other models are more limited in scope, addressing a smaller transportation market such as airport-related travel, travel within a corridor or a particular district of a city. The type of travel model that is appropriate to use is dependent on the particular questions being asked by decision makers. The following sections identify some broad types of models used in transportation planning, though it should be noted that these model types are not strictly defined and that there is a continuum of capability and detail across these model types.

1.2.1

Sketch-Planning Models

Sketch-planning models are the simplest types of travel models. These tools are designed to produce rough estimates of travel demand where order-of-magnitude information is all that is required. These models are typically simple and easy to implement, require less data, and often are implemented using common desktop software tools such as spreadsheets and geographic information systems (GISs). However, although these tools are less expensive to develop and apply, they may not provide the level of detail required to analyze certain types of policy and investments decisions, and may not provide detailed output information. As a result, sketch-planning models may be appropriate for specific targeted analyses, but cannot inform large-scale longer-term policy and investment decision making.

1.2.2

Strategic-Planning Models

Strategic-planning models are often narrow in scope but incorporate significant detail in specific areas of analysis. These models often are used when there is a desire to analyze many scenarios quickly and implemented using basic software and hardware tools; these models are less expensive to develop and apply. Strategic-planning models are useful for testing a wide range of large-scale policy and investment alternatives but may be less appropriate for analyzing detailed project alternatives.

1.2.3

Trip-Based Models

Trip-based travel models have evolved over many decades. As their name suggests, trip-based models use the individual person trip as the fundamental unit of analysis. Trip-based models are widely used in practice to support regional, subregional, and project-level transportation analysis and decision making. Trip-based models are often referred to as "4-step" models because they commonly include four primary components. The first trip generation components estimate the numbers of trips produced by and attracted to each zone (these zones collectively represent the geography of the modeled area). The second trip distribution step connects where trips are produced and where they are attracted to. The third mode choice step determines the travel mode, such as automobile or transit, used for each trip, while the fourth assignment step predicts the specific network facilities or routes used for each trip.

Table 1.1 displays key travel questions and answers for trip-based and activity-based models.

1.2.4

Activity-Based Models

Activity-based models have become more widely used in practice. Activity-based models share some similarities to traditional 4-step models: activities are generated, destinations for the activities are identified, travel modes are determined, and the specific network facilities or routes used for each trip are predicted. However, activity-based models incorporate some significant advances over 4-step trip-based models, such as the explicit representation of realistic constraints of time and space and the linkages among activities and travel,

TABLE 1.1. KEY TRAVEL QUESTIONS AND ANSWERS

Key Travel Questions	Trip-Based Model Components	Activity-Based Model Components
What activities do people want to participate in?	Trip generation	Activity generation and scheduling
Where are these activities?	Trip distribution	Tour and trip destination choice
When are these activities?	None	Tour and trip time of day
What travel mode is used?	Trip mode choice	Tour and trip mode choice
What route is used?	Network assignment	Network assignment

for an individual person as well as across multiple persons in a household. These linkages enable them to more realistically represent the effect of travel conditions on activity and travel choices. Activity-based models also have the ability to incorporate the influence of very detailed person-level and household-level attributes and the ability to produce detailed information across a broader set of performance metrics. These capabilities are possible because activity-based models work at a disaggregate person-level rather than a more aggregate zone-level like most trip-based models.

1.3

HOW DO WE USE TRAVEL MODELS?

Travel models are used to provide objective assessments of the advantages and disadvantages of different alternatives. These alternatives may include capital investments, policies, land use configurations, socioeconomic and demographic assumptions, and many other factors. By running the travel model with different sets of input assumptions representing these alternatives, analysts can evaluate differences between alternatives using a broad range of metrics and can help answer decision makers' key questions.

1.4

WHY USE AN ACTIVITY-BASED TRAVEL MODEL?

Activity-based models can be used to evaluate alternative investments and policies that are difficult to test using traditional trip-based or sketch-planning models. For example, activity-based models often provide much more robust capabilities and sensitivities for evaluating pricing scenarios. Because activity-based models typically function at the level of individual persons and represent how these persons travel across the entire day, the model is more sensitive to pricing policies that may vary by time of day, which involve more complex tolling schemes. Another critical advantage of activity-based models is that they produce more detailed performance metrics, such as how travel benefits (or disbenefits) accrue to different populations, which can be used to support equity analyses. In addition, activity-based models can produce all of the trip-based model measures used to support regional planning, regional air quality, transit, and transportation demand management forecasting.

Table 1.2 broadly summarizes and compares some of the key features of the continuous spectrum of model types from simple sketch-planning models to detailed activity-based models. Sketch-planning models often have lower levels of spatial and temporal resolution, while activity-based models often incorporate moderate to high levels of spatial resolution (such as parcels) and temporal resolution (such as half-hours). Activity-based models also incorporate the highest levels of person and household detail in this continuum of model types. Strategic-planning models and activity-based models can have moderate to high levels of policy sensitivities, although trip-based models

TABLE 1.2. COMPARISON OF MODEL TYPES

Model Type	Spatial/ Temporal Detail	Person/ Household Detail	Policy Sensitivity	Run Time	Cost
Sketch Planning	Low	Low	Low	Low	Low
Strategic Planning	Low–Moderate	Low–High	Moderate–High	Low	Low
Trip-Based	Low–Moderate	Moderate	Moderate	Moderate	Moderate
Activity-Based	Moderate–High	High	Moderate–High	Moderate	Moderate

and activity-based models generally have longer run times and greater development, application, and maintenance times and costs.

1.5

ACTIVITY-BASED TRAVEL MODELS

1.5.1

Activity-Based Travel Model Definition

A fundamental premise of activity-based travel models is that travel demand derives from people's needs and desires to participate in activities. In some cases these activities may occur within their homes, but in many cases these activities are located outside their homes, resulting in the need to travel. Activity-based models are based on behavioral theories about how people make decisions about activity participation in the presence of constraints, including decisions about where to participate in activities, when to participate in activities, and how to get to these activities. Because they represent decisions and the resulting behavior more realistically, activity-based models are often better at representing how investments, policies, or other changes will affect people's travel behavior.

Activity-based models are distinguished from trip-based models by a number of features. Activity-based models represent each person's activity and travel choices across the entire day, considering the types of activities the individual needs to participate in and setting the priorities for scheduling these activities (such as prioritizing work activities over shopping activities). As any individual's schedule becomes filled, the time available to participate in and travel to additional activities diminishes.

1.5.2

Deficiencies of Trip-Based Models

1.5.2.1

Independence Assumptions

Transportation policy and investment questions have become more complex. Decision makers are no longer confronted only with questions about how and where to expand transportation system capacity, but they also must consider questions about how to best manage the existing transportation system. Trip-based models are not able to provide information to address these policy questions because they assume that all trips are made independently. They do not recognize that the locations, travel modes, and timing of travel made by an individual are interrelated. In addition, they lack details on individual travelers and their coordination with other household members.

For example, a region may wish to evaluate tolling alternatives that vary by time of day and price on a critical facility that is significantly congested during peak periods. Tolls are to be used to manage congestion by influencing travelers' choices regarding when, and possibly how and where, they travel. Because trip-based models do not consider the entire tour, or series of linked trips made by an individual, they would not be sensitive to a toll on the return home from work. Similarly, because trip-based models usually do not include sensitivity to time of day and scheduling choices, they cannot show how a midday toll may result in increased evening traffic or the impacts of many other policies with time-of-day characteristics. Because trip-based models rely on aggregations of persons and households, they are limited in their ability to represent how different people may respond to different toll changes, depending on their travel purpose, income, and other factors. Trip-based models typically have high numbers of nonhome-based trips, which do not include important information such as trip purpose, traveler income, or relation to other trips in the person's day; this factor limits the sensitivity of trip-based models to many transportation policy and investment alternatives. In addition, trip-based models are often insensitive to how overall demand levels are influenced by the accessibility to opportunities for shopping, eating, and various social and recreational activities.

1.5.2.2
Aggregation Bias

Aggregation bias refers to the assumption that group characteristics are shared by all the individuals who are members of that group. Trip-based models use aggregations of households that share the same attribute values to make forecasts, the idea being that all households of the same type behave similarly. For example, one such aggregation would be all households with two persons, one worker and one automobile, living within a particular transportation analysis zone. A trip-based model would predict the number of daily trips of various types for these households using a common rate.

There is tremendous diversity in how different types of persons and households make travel decisions depending on factors such as income, transit accessibility, competition with other household members for vehicles, travel times by detailed time of day, and many other influences. The use of average values applied to aggregate populations across aggregate spatial zones and time periods distorts a model's sensitivity to investment and policy alternatives. Although it may be theoretically possible to incorporate additional detail in trip-based models through the use of additional market segmentation (such as including more household income categories), zones or time periods, it is practically challenging because the aggregate trip-based model's reliance on two-dimensional origin–destination (O-D) or production–attraction matrices causes model run times, storage, and memory requirements to increase exponentially as segmentation increases. As a result, most trip-based models incorporate significant levels of aggregation, which compromises their sensitivities to different alternatives and limits their ability to provide detailed information on the impacts of these alternatives, reducing their usefulness as decision-support tools.

1.5.3
Activity-Based Model Features

1.5.3.1
Individual Travelers

Activity-based models provide a more intuitive, consistent, and behaviorally realistic representation of travel than trip-based models. Rather than representing each trip as independent, for each individual traveler chains of trips (tours) are modeled as part of generating overall daily activity patterns. By functioning at the level of the individual traveler, activity-based models are able to represent greater variation across the population than aggregate trip-based models.

The types of policies and investments that are of interest to decision makers change over time. A key advantage of activity-based models is that they can incorporate new explanatory variables and new sensitivities much more easily because they are typically implemented using a microsimulation framework, in which individual person and household choices are evaluated. Microsimulating individuals and households imposes fewer limitations on the levels of temporal and spatial resolution used in the model and allows for the use of detailed individual-level information. For example, a region may wish to consider a new pricing alternative in which users pay only once on entering an area and can then leave and return without paying again. An activity-based model can be modified to represent this type of policy, which would be impossible in a trip-based model. Figure 1.1 shows a tour composed of three trips.

1.5.3.2
Interrelated Decision Making

Activity-based models represent the interrelated aspects of activity and travel choices for all travel conducted by a person or household during a day, including purpose, location, timing, and travel modes, which results in a more detailed representation of how travelers may respond to investment and policy alternatives, as well as land use and socioeconomic changes.

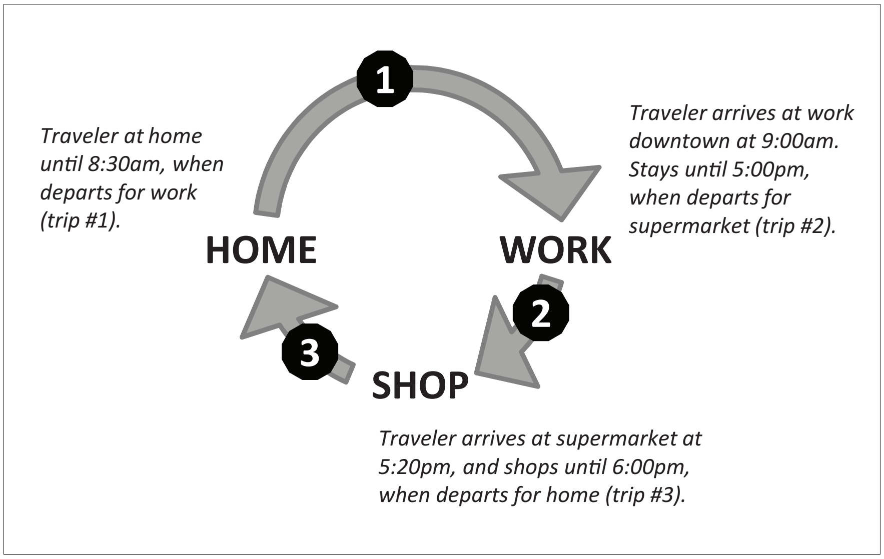

Figure 1.1. *A tour with three trips.*

One of the primary means through which consistency is achieved is through the representation of tours and trips. Activity-based models treat the tours and trips made by an individual as interrelated across the entire day. These relationships are manifest in a number of ways.

For example, activity-based models explicitly represent how individuals move from one geographic location to another during the day—the destination of one trip becomes the origin for the subsequent trip. This geographic consistency realistically bounds where, how, and when travelers can travel. Consistency in the representation of time of day also distinguishes activity-based models from trip-based models. In activity-based models, activities and travel are usually scheduled within the context of the time constraints of a single day. Participation in different activities is determined among a variety of potential purposes, depending on individual-level attributes, such as worker status, as well as network travel times and accessibility.

Figure 1.2 illustrates a scheduling example in which a mandatory work activity is scheduled first, a shopping activity is scheduled next, and finally, an eating out activity is scheduled in the remaining available time window between the other activities. In an activity-based model, as more activities are scheduled, the amount of time available to participate in additional activities become smaller. Arrival and departure times at destinations constrain when additional stops can be made, which also helps to ensure a coherent and consistent schedule for every traveler.

Activity-based models also use information about tours and trips to impose plausible constraints on the travel modes that are available to travelers. For example, it is highly unlikely that a traveler who has used transit to get to work is going to drive home alone, because he or she does not have a vehicle to use. The use of detailed traveler attributes when selecting destinations and the incorporation of realistic time–space constraints on destination choice also help to ensure consistency. Finally, the consideration of intra-household interactions, in which household members may allocate or coordinate activity participation in complex ways, results in greater internal consistency at both the person and household level.

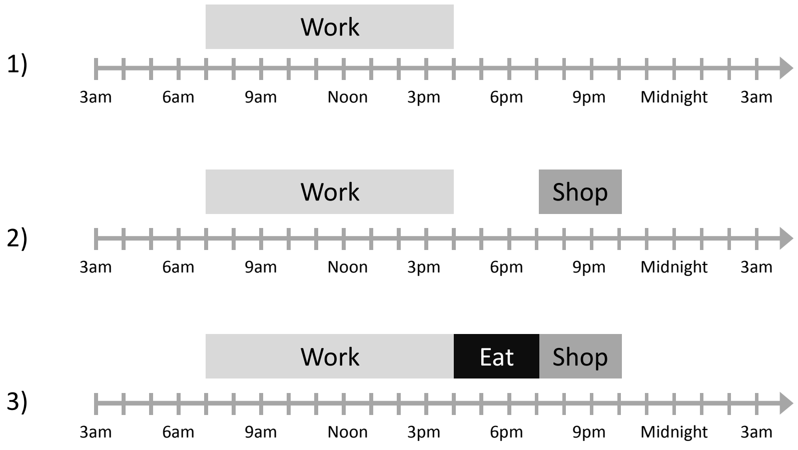

Figure 1.2. *Example of scheduling priorities.*

1.5.3.3

Detailed Information

Activity-based models incorporate significantly more detailed input information and produce significantly more detailed outputs than trip-based models. By operating at the level of individual persons and households, activity-based models can use a wider range of important explanatory variables to predict travel patterns than trip-based models. Attempting to incorporate more detailed household or person characteristics in trip-based models usually requires many additional files (trip matrices) to represent different market segments, substantially lengthening model run times and increasing memory and storage requirements. Instead, activity-based models use lists of households, persons, tours, and trips, which is much more efficient, and includes more information. Consistent representation of trips made jointly by household members, which often comprise a significant portion of shared-ride trips, is only possible using activity-based models. Activity-based models also include explicit and detailed models of time-of-day choices, such as the times spent participating in activities, the arrival times, and the departures times. The temporal information is especially critical given the travel demand and transportation system management policy and investment choices faced by decision makers. Table 1.3 lists household and person attributes for activity-based models.

Activity-based models also provide more detailed outputs, which allows analysts and decision makers to understand the impacts of alternatives on different communities. These

TABLE 1.3. ACTIVITY-BASED MODEL HOUSEHOLD AND PERSON ATTRIBUTES

Household Attributes	Person Attributes
• Number of persons • Housing tenure • Residential location • Number and age of family members • Household income • Number of vehicles owned • Number of workers • Number of students	• Relationship to householder • Gender • Age • Grade in school • Hours worked per week • Worker status • Student status • Transit pass ownership • Subsidized parking at work

detailed outputs also allow insights into how changes such as the vehicle miles traveled or emissions can be attributed to individual households. It is even possible for traveler benefits to be attributed to clusters of employment, which can be important for economic development analyses. Detailed output information also facilitates better interfaces with other analysis tools, such as traffic simulation models. However, different levels of detail in the model outputs are associated with different levels of confidence, which is an important consideration when applying the model.

1.5.3.4
Integrated Travel Demand Model System

Activity-based models, as well as trip-based models, are always embedded within an integrated model system in which there is an interaction between the activity-based or trip-based models, which predict the demand for travel, and network models, which predict how this demand affects the performance of the transportation network supply. Most activity-based models are embedded within a basic integrated model system that incorporates a limited number of essential components (Figure 1.3):

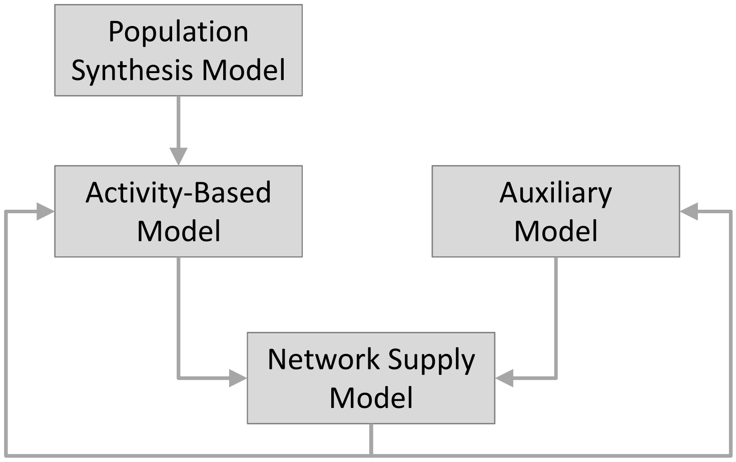

Figure 1.3. *Basic integrated model components.*

- Population synthesis models create detailed, synthetic representations of populations of individuals within households (agents) whose choices are simulated in activity-based models. This population is based on information produced by regional economic models, land use models, and demographic models.
- Activity-based travel demand models predict the long-term choices (such as work location and automobile ownership) and the daily activity patterns of a given synthetic population, including activity purposes, locations, timing, and modes of access. These estimates of travel demand can be used to help evaluate alternative transportation, land use, and other scenarios.
- Auxiliary models provide information about truck and commercial travel, as well as special purpose travel such as trips to and from airports or travel made by visitors. The travel demand represented in auxiliary models complements the personal travel generated by the activity-based model.
- Network supply models are tightly linked with activity-based demand models. The flows of travel by time of day and mode predicted by activity-based travel demand models and auxiliary models are assigned to roadway, transit, and other networks to generate estimates of volumes and travel times. Measures of impedance output from network supply models are usually used as input to activity-based models and other integrated model components.

1.5.4
Development Considerations

1.5.4.1
Data

The data required to develop and apply an activity-based model are not significantly different from the data required to develop a trip-based model. The primary data used to develop and apply both activity-based and trip-based models include household travel survey information, economic and demographic information about the spatial distribution of employment and households, and representations of transportation networks. Household travel surveys contain detailed information about whether, where, how, and when individuals and households travel. The same household surveys used to develop trip-based models can be used to develop activity-based models, although such surveys are subjected to much more scrutiny in developing an activity-based model because it is important that all the survey data be consistent internally across all the individuals in each household.

Data describing the spatial distribution of different types of households, persons, and employment by sector are required to develop and apply both activity-based and trip-based model systems and are largely consistent between the two types of models. If more detailed information is available, such as employment by detailed sector or households by detailed size category, this can be used more easily within the activity-based model framework. Activity-based models do require the development of one additional type of input, a "synthetic population" that represents a region's travelers and their detailed attributes. However, this input can be prepared using readily available data and tools.

Transportation network data requirements are very similar for activity-based and trip-based models. Most activity-based models used in practice are linked to traditional roadway and transit network components that are very similar to those used for trip-based models. However, because activity-based models include more detailed representations of time of day, they often include networks with more time-period–specific information.

1.5.4.2

Staff and Consultant Requirements

Activity-based models impose some different requirements related to staff knowledge and skills. Because they incorporate more detailed representations of travel choices, it is necessary that modeling staff have a good understanding of the activity-based modeling process and its statistical modeling methods. Often, the most effective means of developing this understanding is through on-the-job experience. Modeling staff also must have additional data management and statistical skills in order to be able to meaningfully summarize and understand the new detailed outputs produced by activity-based models. There is some additional burden associated with managing additional networks by time of day and with preparing synthetic population inputs. Most agencies have relied on consultants to develop, implement, and enhance activity-based models, but often, they rely on their own staff to perform model runs and analysis.

1.5.4.3

Costs and Schedule

The costs for developing activity-based models have significantly decreased to the point where recent activity-based model development efforts cost approximately the same as traditional trip-based model development efforts. The development of the first activity-based models was more costly as a result of the initial effort to establish methodologies and create implementation software. Similarly, if an agency wants to implement new or enhanced features or software, the costs can be higher; but, when existing methodologies and software are used, the costs are no longer as great. As with trip-based models, the calibration of activity-based models can make costs and schedules uncertain, because different model applications may require different levels of effort. Some additional costs may be associated with computer hardware, because activity-based model software is typically designed to employ distributed computing across multiple processors.

1.5.4.4
Model Run Times

Activity-based model system run times are dependent primarily on the size of the population of the region being simulated, the number of zones and time periods for which the network supply models are run, and the amount of computing resources available. For the activity-based component of the model system, there is essentially a linear relationship between the size of the population and run times—simulating a population twice as big will take approximately twice as long. The network model run times increase with the square of the number of zones, and linearly with the number of assignment time periods. The relationship with run times and computing resources is more nuanced. Activity-based modeling software is designed to be distributed across multiple computer processors to reduce run times. As more processors are available run times are reduced, although the performance gain associated with each additional processor diminishes due to computational overhead associated with managing and exchanging data. Finally, model run times are also influenced by the complexity of the model design, the number of alternatives included, and feedback and the level of convergence required. Both trip-based model and activity-based model run times vary greatly, and in both cases, assigning the demand to the network is the most time-consuming part of model runs.

1.5.4.5
Stakeholder Acceptance

The information produced by travel models is consumed by a variety of users for a broad range of purposes. Essential to the success of activity-based models is the acceptance by these stakeholders of the usefulness of the model outputs. Such acceptance is predicated on the clear communication of the purposes and structure of the model, in order to address the concern frequently expressed about both trip-based and activity-based models being black boxes. However, acceptance can be firmly established only by demonstrating the model's explanatory power and reasonable results when applied to actual alternative analyses, or through systematic backcasting exercises.

1.5.5
Integration with Other Models

While activity-based model systems represent a comprehensive approach to representing the activity and travel choices, they depend on relevant information that is often produced by other related models. For example, an activity-based model needs information about the location of future employment. Such information is sometimes produced by a separate land use model. A model system in which various different components interact and exchange information is often referred to as an integrated model. Integrated models provide the opportunity to represent various diverse, dynamic, and interrelated aspects transportation system performance and land use. Although activity-based models are always embedded within a basic integrated model system comprising travel demand and supply components as described earlier, they can also be integrated with other models to create an extended integrated model system (Figure 1.4) that may include the following:

- Regional economic models can provide overall estimates of regional employment or productivity by industrial sector based on the competitiveness of the region relative to other regions and can also provide information on overall changes in regional households and population. This information provides regional controls for activity-based model inputs.

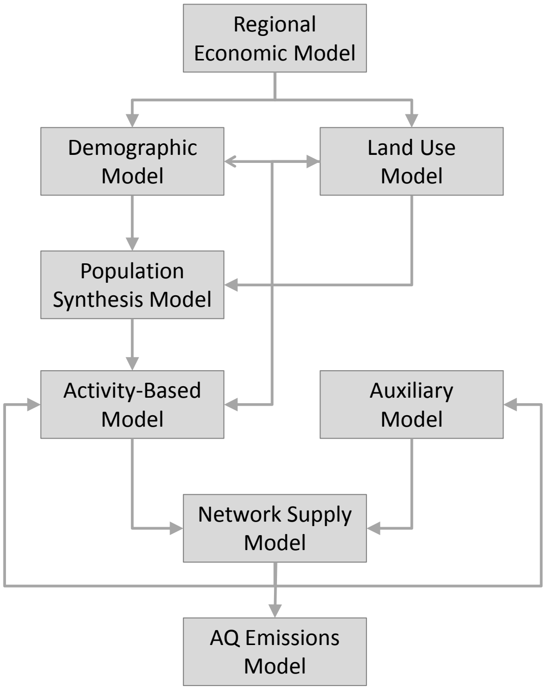

Figure 1.4. *Basic integrated model components.*

- Land use models typically provide more detailed information about subregional land use development and redevelopment, the economy, employment, and population. There is a broad spectrum of approaches to modeling land use and the land use–transportation interaction, and the outputs from these models may be aggregated, disaggregated, and transformed in order to provide direct inputs to an activity-based model.
- Demographic models show how the population is expected to change over time. Changes in demographics are manifest in different transportation and land use choices, and activity-based models incorporate many demographic explanatory variables.
- Air pollutant emissions models produce estimates of criteria pollutants and greenhouse gases based on network performance measures derived from network supply models and vehicle performance assumptions.

1.5.6
Application Stories

1.5.6.1
Congestion Pricing

Congestion pricing can encompass a wide variety of different pricing and toll schemes that may be intended to manage demand, improve travel time reliability, reduce congestion, and increase usage of alternative modes. Activity-based models provide more flexibility than trip-based models in their ability to represent different alternatives. Activity-based models have been used in both New York and San Francisco to evaluate congestion pricing options. In New York, an activity-based model was used to evaluate scenarios in which tolls were imposed for vehicles traveling to certain portions of Manhattan. In San Francisco, an activity-based model was used to evaluate area-based and cordon-based pricing scenarios. The activity-based models provided the ability to represent how different travelers respond differently to alternatives, and to provide a consistent representation of how the different alternatives impact the timing, destinations, modes, and even the generation of tours and trips. Because the models explicitly represent individual persons and households, the models could be used to evaluate a variety of alternative schemes, including discounts offered to different groups to address equity concerns.

1.5.6.2
Environment, Climate Change, and Air Quality

A critical concern in many regions is how urban form influences trip making, and the environmental impacts of alternative transportation and land use configurations. In order to have an analysis tool that is more sensitive to these transportation–land use interactions, the Sacramento Area Council of Governments (SACOG) developed an activity-based model system that uses very fine-grained geography of individual parcels and has applied the model to a variety of innovative analyses. For example, to analyze the impacts of a large-scale residential development that was designed to produce more pedestrian, transit, and other short-distance trips, the activity-based model was used to compare the travel behavior of tens of thousands of residents in two different scenarios: one in which these residents lived in the proposed development and an alternative in which these exact same residents lived in more typical suburban developments. The activity-based model demonstrated that the total vehicle miles traveled by these residents was significantly lower when they lived in the new development than when these same residents lived in more typical developments. In addition to using the activity-based model to perform innovative transportation and land use scenarios, SACOG has used their activity-based model as the basis for air quality conformity analyses, as have other regional planning agencies, such as the Puget Sound Regional Council in Seattle.

1.5.6.3

Regional Transportation Plans

Activity-based models have been used by MPOs to support the analysis of regional transportation plans. For example, the Metropolitan Transportation Commission, in the San Francisco Bay Area, recently and comprehensively applied their activity-based model to assess the impacts of individual projects as well as plan scenarios. Approximately 100 individual model runs were performed in order to develop projects-level performance measures. Outputs from the activity-based model were then used to support detailed analyses: a benefit–cost analysis as well as others. The benefit–cost analysis relied on detailed information produced by the activity-based model, such as the amount of transportation-related physical activity engaged in by each regional resident.

2

TECHNICAL ROAD MAP FOR DEVELOPING AN ACTIVITY-BASED MODEL SYSTEM

2.1

DEVELOPMENT PROCESS

Modeling managers must consider numerous factors when developing an activity-based model system. They must evaluate how model designs and specifications can address policies and projects being considered and make tradeoffs between model capabilities and development costs and schedule. In addition, they must confront data development challenges and address model implementation and maintenance requirements. The purpose of this chapter is to provide an overview of activity-based model development approaches that agencies have followed and to summarize the primary steps in the activity-based model development process, which include model design, data development, model implementation, and model application and maintenance.

2.1.1

Approaches

Regional and state transportation planning agencies have generally followed one of three model development trajectories: (1) upfront development, (2) incremental development, and (3) transfer and refinement. Each approach offers different advantages and disadvantages, and the identification of the best development path is highly dependent on each individual agency's analysis needs and available resources. In addition, model development often combines elements of these three different trajectories. For example, an agency may choose to transfer an existing model in order to leverage the results of other agencies and then develop substantial new features in order to achieve their own important objectives.

2.1.1.1

Upfront Development

This approach refers to an implementation process in which an agency develops an entirely new activity-based model system, largely independent of any prior trip-based or other travel demand model efforts by the agency. When developing a new activity-based model system upfront, an agency may gather new household survey data and other data describing travel behavior, design and estimate new component models such as destination choice or mode choice, develop new network integration processes and information such as skims (measures of network impedances) by detailed mode or detailed time of day, and calibrate and validate the model system. The result is a model system designed specifically to address the concerns and analytic needs of the particular region. Advantages of this approach are that the entire activity-based model system is designed and implemented as a single effort; the coherence of the overall model system design is enhanced and the development can include features important to the agency; and the overall amount of time required to have an operational, calibrated mode may be reduced. The primary disadvantage is that this approach requires significant upfront resources. Many of the first activity-based model efforts followed this development process.

2.1.1.2
Incremental Implementation

Rather than design, estimate, and implement an entirely new model system as part of a single effort, an incremental implementation process involves the gradual development of activity-based model system components, either in concert with or parallel to trip-based model maintenance and enhancement efforts. A common first incremental step is to implement a population synthesis component. A synthetic population is a key input to an activity-based model that can also be aggregated and used for input to a traditional trip-based model. Subsequently, a region might also implement an activity generator that uses the synthetic population and replaces a typical trip generation process. Advantages of this approach are that it allows agencies to make gradual investments in developing an activity-based model and provides an opportunity for agency staff to become familiar with disaggregate activity-based model inputs, outputs, and operation. It may also provide agencies with the opportunity to prioritize model investments that best address regional analysis needs. The primary disadvantage of this approach is that it may lengthen the schedule and increase the budget required for overall model development.

2.1.1.3
Transfer-and-Refine Implementation

Recently a number of agencies have pursued a transfer-and-refine implementation strategy. This strategy involves taking an existing activity-based model developed for another region and reconfiguring it to a new region. The primary tasks required to transfer an existing activity-based model are to develop new activity-based model inputs, such as developing new socioeconomic input files and updated network supply information and procedures, reconfigure the software to use these new inputs in conjunction with model parameters transferred from other regions, and recalibrate and revalidate the model system to the new region's observed data. Advantages of this approach are that the activity-based model can be implemented within 6 months, and there is no immediate need to re-estimate new model parameters. Also, the agency can get experience working with a fully functional activity-based model system and subsequently decide to refine it based on hands-on experience. Recent experiences and research suggest that this approach is both practical and statistically defensible (Bowman 2004, Picado 2013). A drawback of this approach is that many of the coefficients in the model components are not based on local data.

2.1.1.4
Stakeholder Acceptance

Developing an activity-based model requires the involvement of more than just agency technical staff and consultants. It must also involve the stakeholders who will be using the model to assist in decision making. The stakeholders include agency board members, executives, managers, planners, and other nontechnical staff, as well as outside constituencies. It is critical that the stakeholders have confidence in the tool, which can be most easily accomplished by providing transparency about model design and inputs and outputs and by demonstrating the usefulness of the tool for analyzing real projects and policies.

2.1.2
Design

Activity-based model design starts with an assessment of an agency's analysis needs in relation to the policies and projects that are expected to be considered by the agency. This assessment should consider not only the types of projects and policies to be evaluated using the model but also the specific performance measures to be produced by the model and a determination of the level of accuracy and precision that is required. Of course, practical considerations such as the model development costs and schedule are also key design determinants. The design process should involve the technical managers who will guide model development and the consumers of the model outputs, such as planning project managers.

2.1.2.1
Analysis Needs

Activity-based models can provide useful assessments of the effects of different transportation investment and policy alternatives, and the alternatives being considered help define an agency's analysis needs. Required policy and project sensitivities are a primary concern. For example, activity-based models can provide robust insights into projects and policies that involve willingness to pay, such as road pricing and parking costs. Similarly, activity-based models can provide the ability to analyze policies that involve coordination between individuals and time-sensitive scheduling constraints, such as telecommuting and compressed work schedules. Activity-based models are typically linked with static network assignment models and can produce the network-based performance measures that are used for project and plan development. But, activity-based models also produce a much broader set of measures than are possible using traditional aggregate approaches and can be used to support much more detailed and complex analyses, such as the effects on communities of concern.

2.1.2.2
Cost

Cost is a critical and practical model development consideration and is influenced by a number of factors. If an agency wishes to introduce new features not found in existing activity-based model implementations, in order to address an important analytic need, it will likely result in higher development costs. Implementing new features often necessitates conducting applied research and developing new software code, which can be expensive. Conversely, adopting an existing activity-based model structure and software can reduce development costs. However, even if an agency decides to adopt an existing activity-based model platform, it may be necessary or desirable to estimate new parameters based on local data, which can increase costs. In addition, new costs may arise from the need to collect and maintain data, such as household travel behavior survey data, parcel or business data, or transportation networks by detailed time of day. Potential costs associated with model application may also be considered. Finally, the costs for development may be significantly affected by the use of external consultants instead of, or in addition to, agency staff.

2.1.2.3
Schedule

Schedule is also an essential model development consideration that is influenced by many factors. If a new model system is required in order to fulfill immediate analytic needs, development schedules may be accelerated. Data availability influences model development schedules. Although some of the data from an agency's traditional trip-based model may be repurposed for use in an activity-based model, additional data such as household survey or traffic counts by detailed time-of-day may be required, and assembling this information takes time. Funding also influences schedules. Although activity-based model development costs have dropped significantly, agencies may not wish to or may not be able to fund large-scale model development efforts over short periods of time, which may lengthen the model development schedule. Anticipated model applications may also affect the schedule.

2.1.3
Data Development

A key stage in the activity-based model development process is assembling all of the data required to implement the model system. These data may include household survey data, land use information, demographic information, transportation network data, and other urban form indicators. Depending on the specific model implementation approach selected, not all data items may be required. Development of a data collection plan or strategy, in coordination with a model development plan, can be useful to ensure consistent data development and standards. Such a plan would inventory existing data sources and identify where additional data or better data are required and may also consider how the timing of data collection relates to the overall model development schedule.

2.1.3.1
Household Survey

If an agency pursues a transfer-and-refine process, household travel survey data collected to support trip-based model development can usually be used to support calibration of the activity-based model. Additional analysis of the survey data is required to chain the trips into tours and to classify the sequence of tours into relevant descriptors of a full-day activity and travel pattern, but after that the use of the expanded survey data to compare against and calibrate the relevant coefficients in the models is analogous to their use in calibrating a 4-step model. The survey data are used primarily to modify relevant alternative-specific constants and various impedance parameters in the models so that the results of applying the activity-based model system match the observed, expanded choice distributions from the survey to an acceptable degree, as a precursor to model validation on external data.

If an agency pursues an upfront development or incremental implementation process, the travel survey data requirements can be more stringent than for typical trip-based model work. Because activity-based models tend to consider a wider variety of socio-demographic variables and types of choice alternatives than in most trip-based models, the sample size requirements tend to be somewhat larger. A recent study of the transferability of activity-based model parameters (Bowman et al. 2013) concluded that a survey sample of at least 6,000 households may be adequate for a medium-to-large region. As the behavioral detail of the model increases, larger sample sizes are required. Smaller samples may support the development of calibration targets for transfer-and-refine implementation processes but may not support the estimation of new coefficients.

Another special case is if an agency requires the consideration of joint travel decisions and coordinated activity scheduling across household members. For such models, it is critical that survey data contain complete data across all household members, and that the survey methodology successfully captures instances when household members traveled together and performed activities together, including internally consistent data on trip arrival and departure times and locations.

Household surveys increasingly include information derived from the collection of GPS samples. In most cases, these GPS samples have been collected only for a subset of households, although in some cases GPS data have been collected for the entire household sample. GPS data can be used to understand underreporting of stops and tours, as well as the misreporting of activity locations and travel times.

2.1.3.2
Land Use

Land use data needed for activity-based models are similar to that needed for trip-based models, including the number of households, number of jobs by sector, and school enrollment by school level. This information is primarily used to influence activity generation and location choices. If an activity-based model is specified to use the same or similar basic travel analysis zone (TAZ) spatial units as a trip-based model, then there is little or no difference in the data required for an activity-based model as compared with a trip-based model. However, recent activity-based models have taken advantage of the flexibility of the methods to use basic spatial units that are smaller than standard network TAZs. For land use data, such models either use microzones, which are similar to U.S. Census Bureau blocks, or individual parcels. The use of parcels can entail some challenges, such as obtaining accurate and up-to-date parcel data for all jurisdictions in a region, addressing heterogeneity in how parcels are defined for different land uses (e.g., a large university may be a single parcel), and specifying forecast year land use at the parcel level. Census block–size microzones are an attractive compromise because they still offer a good deal of local spatial detail for defining land use, walk-access times to transit, distances for very short trips, and more, but they do not present the same challenges in terms of acquiring consistent data.

Basic population data at the block level are available from the U.S. Census Summary File One (STF1) data, and detailed employment data at the block level are available from U.S. Census Longitudinal Employer–Household Dynamics (LEHD) data. Such data can be used to distribute TAZ-level land use data down to the microzone level, so that the control totals within each TAZ still match the original data, but the more detailed spatial distribution best matches available information. Alternatively, if parcel data are available, that data can be aggregated up to the block or microzone level, and the Census data can be used for quality assurance and quality control comparisons on the results.

The primary goal of including finer geographic detail is to model travel behavior at a level of detail closest to what decision makers experience in order to avoid statistical aggregation bias in the models, which can be very large when measuring travel impedance for transit access and short trips, or attractiveness of potential destinations. Aggregating the model outputs rather than the inputs helps to avoid the ecological fallacy that one can model relationships at an abstracted level and trust that the results will be consistent with the underlying behavior of individual travelers.

2.1.3.3
Demographic

Activity-based models are implemented within a microsimulation framework. This microsimulation framework requires a record for each household and person rather than aggregate totals for each TAZ. These household and person records are referred to as a “synthetic population” that represents the sociodemographic characteristics of the residents of the modeled area. This demographic information is a key influence on travel choices. Software tools generate synthetic populations using information about distributions of key regional demographic attributes and detailed samples. The types of demographic controls used for generating synthetic populations typically include the following:

- Household size;
- Household composition and life cycle (e.g., age of householder by presence of own children);
- Number of workers per household;
- Household income category;
- Age and gender of each person; and
- Employment and student status of each person.

Additional variables such as housing type and owning or renting housing could be used, but it is important to remember that any controls used in the base year should also be possible to forecast in the future year, or at the minimum one should be able to make a reasonable assumption that the distribution will not change substantially from the base year.

Using this variety of controls produces a synthetic population that is representative of the actual population along all of these dimensions, and thus allows all of these variables to be used as explanatory variables in the model. With all these combinations of variables, the model may be able to consider literally thousands of different types of persons and households, rather than just a few different demographic segments as is typical in a trip-based model. This is another way that activity-based models can avoid potentially significant aggregation bias, and thus provide more likely predictions of choice behavior.

2.1.3.4

Network

In most cases activity-based models use the same types of network procedures and variables to represent automobile, transit, and nonmotorized travel routes that are used in trip-based models. These data include measures of travel times, costs, distances, and other network-related attributes that influence decision making, such as the number of transit transfers. This network information is typically generated at more spatially aggregate levels such as TAZs, even in activity-based models where finer spatial resolutions such as microzones are used for other model inputs, in order to avoid having to produce and store very, very large skim matrices. Activity-based models can incorporate additional network detail, such as more time periods or modes than trip-based models, and many activity-based models have been moving to more detailed network data as well, often using more than 3,000 TAZs to represent the region, and using 5 or more different time periods in the day (e.g., a.m. peak, midday, p.m. peak, evening, night/early morning) to represent different service levels for transit and different congestion levels for automobiles. With activity-based simulation models the amount of random-access memory (RAM) needed for software can increase with the number of TAZs and time-of-day periods, as does the time required by the network model components of the system. But, in contrast to trip-based models, the run time of the activity-based demand component of the model system does not depend on such considerations; its run time depends primarily on the size of the synthetic population.

In recent activity-based model implementations, some variations on the standard TAZ-based network approaches have been implemented. In order to provide more accurate representation of pedestrian, bicycle, and walk-to-transit travel impedances, a number of recent activity-based models have used a supplementary all-streets network to create shortest-path distances that consider every street in the region. The potential matrix size for such information can be huge, so the information is typically only used to provide distances for short distances of up to 2 miles or so. This radius will include the range of most actual walk and bike trips, as well as walks to and from transit stops, and even a large percentage of noncommute automobile trips as well. Beyond a distance of 2 miles or so, the

TAZ–TAZ skims are likely to be as accurate as, or more accurate than, all-streets network-based skims, especially since those skims also include the effects of traffic congestion.

Another recent variation, used in models in San Diego and other regions, is to use separate zone systems for the automobile and transit networks. The automobile network uses the existing TAZ system, while the transit network is based on transit stop–to–transit stop service levels, so each stop or cluster of stops (stop area) essentially forms a new type of zone to use in generating the transit network skims. This approach can improve accuracy in the service level information and the walk-access times to the transit stops.

2.1.3.5

Calibration and Validation

Calibration and validation involve comparing estimates of travel demand and related choices output by the model to observed real-world data and making changes to individual model components to improve model system performance. Calibration and validation data and observed target data vary based on the model design and the specifics of each region. For example, if transit ridership forecasting is a critical model capability, then transit ridership validation should be a primary focus. Agency and consultant staff should work together to identify critical calibration and validation measures and data sources for each model component as well for the overall model system. Calibration of the individual demand model components is primarily based on household travel survey data, which can provide necessary information describing observed activity patterns, destination choices, mode choices, and time-of-day choices.

For some model system components, such as automobile availability models or usual work location choice models, household survey data may be augmented with information derived from other sources such as the U.S. Census. In addition, required calibration and validation data also include information such as roadway counts and speeds by detailed time of day and vehicle class. Transit data are typically also required and may include on-board surveys as well as transit operators’ data such as transfer rates, ridership by submode, route, and major stop or station. Bicycle count data may also be necessary if the model includes a bicycle route choice model. It should be noted that different types and sources of calibration and validation data often conflict, despite the fact that these data are all “observed.” Significant cleaning or manipulation of data involving subjective judgment by agency or consultant staff may be required. Table 2.1 presents activity-based model data items along with their uses and sources.

2.1.3.6

Data Challenges

Model managers face many challenges when addressing activity-based model data needs. Key concerns include the identification of appropriate levels of spatial, temporal, and typological detail for model inputs and outputs, and the collection and maintenance of information at the selected resolutions. For example, extremely fine-grained spatial information at the parcel level can improve model sensitivity to short-distance trips, but such detailed data must be also be prepared for all future-year or alternative scenarios. Managers must consider issues such as data acquisition costs, data detail and reliability, and the level of effort required for ongoing model data updates and maintenance.

2.1.4

Implementation

2.1.4.1

Component Design

To determine whether the next model update should be to an activity-based model and to ensure that the activity-based model will be appropriately sensitive and able to generate the

TABLE 2.1. ACTIVITY-BASED MODEL DATA ITEMS, USES, AND SOURCES

Data Item	Use	Source
Household survey	• Model estimation • Calibration targets	• Local data collection of the National Household Travel Survey
Land use	• Synthetic population generation • Activity generation • Location choice	• U.S. Census • Business databases • Tax assessors data • Regional land use data • School departments
Demographic	• Synthetic population • All component models	• U.S. Census • Regional demographic forecasts
Network	• Transportation network geometries	• GIS databases • Transit agencies • Public works agencies
Calibration and validation	• Model calibration and validation	• Count databases • Highway performance monitoring • Transit agency reporting

information required by decision makers, it is necessary for an agency to carefully consider the critical questions and analysis needs over a time horizon of at least the coming 10 years. Agencies should consider whether there are policies or investments of interest to decision makers that are better evaluated using activity-based modeling approaches. For some policies, an activity-based model may be able to provide entirely new model sensitivities and capabilities, while for other policies, an activity-based model may simply provide enhanced model sensitivities and capabilities. These desired model sensitivities should be prioritized in order to allow decision makers to consider trade-offs between required capabilities and resource and schedule constraints.

2.1.4.2

Estimation

Estimating the component models for an activity-based model system involves using local data to identify the variables that are most important to activity and travel decision making and quantifying the relative importance of these variables in addition to processing survey data and attaching relevant data from network skim matrices and land use data. It also includes specifying the model utility functions and alternative availability constraints in a model estimation software package and then carrying out the estimation in an iterative process. This process requires expert judgment to determine what variables to include and sometimes involves constraining some coefficients to typical values in cases where the data for estimation are inadequate. The estimation task typically has been carried out by consultants rather than by the agency staff. Recently, some of the activity-based model software packages have been designed to make it easier to modify and re-estimate activity-based component models when starting from a known model specification (e.g., from another region) rather than starting from scratch.

Estimating new models depends on having robust travel behavior data that include a sufficient number of samples across key market segments and choices and involve the use of model estimation software. This software is used to describe the relative importance of variables factors affecting travel-related decision making. Model estimation is discussed in greater detail in this chapter and in Chapter 3.

2.1.4.3
Software Development

There currently are three or four software platforms that are used for the large majority of activity-based models implemented in the United States; most of these platforms are governed by open source licensing agreements. These platforms have been developed by the consultants who have created the original models, and then the models are adapted and improved over time as they are implemented for new regions. The software field for activity-based models may change substantially in the future, however, as the market for activity-based models matures.

2.1.4.4
Transferability

Given the extensive work involved in designing a new activity-based model system, estimating the component models, and creating the software to implement them, it can be expected that many activity-based model implementations in the future will start with models and software transferred from another region. Starting from this base, features can be added if necessary, and coefficients can be re-estimated and/or re-calibrated. Within this context, estimating model coefficients from robust local data is the preferred approach. However, there is evidence that it is better to transfer model coefficients from another similar region that have been estimated from a large data set, than to estimate local coefficients using a very small or poor quality local data set (Bowman et al. 2013).

2.1.4.5
Relationship of Convergence to Equilibration

Convergence to an equilibrated or stable solution is critical with both trip-based as well as activity-based model systems. The network performance indicators, such as travel times and costs that are output by the final model system assignment process, must be consistent with the times and costs used as input to the model system. In order to achieve this model system-level convergence, it is first necessary to establish network assignment model convergence. Most activity-based model systems are linked with static user equilibrium roadway network assignment models and transit assignment models. Activity-based model managers must ensure that the activity-based model system is configured to pursue convergence to an equilibrium or stable solution and that such a solution can be achieved within reasonable run times. The model system configuration also should consider issues such as the stochasticity of the activity-based model and how this effect can be reasonably managed.

2.1.4.6
Calibration and Validation

Calibration and validation of the entire activity-based model system is an iterative process in which changes are made to individual model components in order to ensure that the model matches observed data describing travel behavior and network performance reasonably well. Calibration also must include sensitivity testing to ensure that the model responds plausibly to changes in model inputs and that these changes are reasonably consistent with real-world outcomes. As with a trip-based model, the outputs of each individual component of an activity-based model are compared to observed external data, and overall network indicators, such as link volumes and speeds, are compared to observed traffic counts and speeds. The level of effort to calibrate an activity-based model system may not be significantly greater than to calibrate a trip-based model system because all the choice components in the activity-based model system are more closely linked.

2.1.4.7

Auxiliary Demand

Like trip-based models, activity-based models represent the trips made by residents of the modeled area when these residents are traveling entirely within the modeled area. Typically these trips make up about 80%–90% of the total demand. Auxiliary demand refers to trips that are not represented in the activity-based model system, such as commercial vehicle trips, truck trips, visitor trips, internal-external and external-external trips, and special generator trips. In most cases the auxiliary trip models used in conjunction with activity-based models are similar to those used in conjunction with trip-based models, although additional temporal or spatial detail may be included. In some cases more sophisticated auxiliary demand models have been implemented in conjunction with activity-based models, but such models are not required. Examples of more sophisticated auxiliary models include activity-based models for seasonal residents and/or overnight visitors, and tour-based commercial vehicle demand models.

2.1.5

Application and Maintenance

Model maintenance and application are necessary ongoing activities. New data—such as surveys, demographic assumptions, networks and other spatial data, and validation data—need to be incorporated and the model potentially adjusted as a consequence. In addition, as the model is increasingly applied to a variety of project and policy evaluations, refinements or enhancements to the model often are desired. Sometimes these can be transferred or adapted from other areas. Model application also reveals bugs in software code that must be fixed.

2.2

DESIGN

2.2.1

Policy and Investment Analysis Needs

To determine whether the next model update should be to an activity-based model and to ensure that, if selected, the activity-based model will be appropriately sensitive and able to generate the information required by decision makers, it is necessary for an agency to carefully consider its analysis needs. Agencies should consider whether there are policies or investments of interest to decision makers that are better evaluated using activity-based modeling approaches. For some policies, an activity-based model may be able to provide entirely new model sensitivities and capabilities, while for other policies, an activity-based model may simply provide enhanced model sensitivities and capabilities. These desired model sensitivities should be prioritized in order to allow decision makers to consider trade-offs between required capabilities and resource and schedule constraints. Examples of some of the potential sensitivities and capabilities that may be of interest are

- Long-range transportation plans. By including accessibility measures throughout, most activity-based models are better able to capture effects such as induced demand. By functioning at a fully disaggregate level, activity-based models can support comprehensive equity analyses. Incorporating more detailed representations of individual choice contexts renders activity-based models more appropriately sensitive to a wider variety of policy and investment strategies.
- Conformity and air quality analyses. Most activity-based models are linked to traditional static network assignment models, which provide the primary inputs to many air quality and emissions models. However,

activity-based models typically are used to provide more detailed information, such as network assignment model results by detailed time of day, and can also provide estimates of start and stop emissions by time of day. Because of their disaggregate nature these models can provide measures such as emissions by household, and, due to their flexible structure, activity-based models can easily accommodate new models, such as automobile ownership, that include information on vehicle type choice.

- Pricing. Activity-based models have significantly more robust capabilities with respect to representing pricing strategies and effects than trip-based models. These enhanced sensitivities result from factors such as the activity-based models' greater sociodemographic, purpose, and time-period detail. In addition, activity-based models can explicitly represent parking pricing and subsidies.
- Reliability. Reliability is a key focus of federal transportation policy highlighted in the Moving Ahead for Progress in the 21st Century Act (MAP-21). Recent second Strategic Highway Research Project (SHRP 2) research projects have provided evidence about the trade-offs that travelers make between cost, usual travel time, and travel time reliability. These research efforts also have identified and investigated innovative methods for incorporating travel time reliability into both trip-based and activity-based travel demand models, as well as into network assignment models. The detailed scheduling capabilities of activity-based models can potentially exploit network assignment model-based reliability measures, though additional investigation into methods for quantifying this information on an O-D basis is required because of the nonadditive nature of travel time reliability.
- Travel demand management and transportation systems management. Activity-based models can better represent the effects of effective travel demand management strategies, such as flexible work schedules, because they represent the entire set of activities that individuals and households participate in during the day. In addition, these models include time-of-day choice models, which are absent from the vast majority of trip-based models, and can be sensitive to peak-spreading effects.
- Transit. By using tours (a series of linked trips that begins and ends at a single home or work location) as a fundamental organizing structure, activity-based models have more realistic sensitivities to transit investments and policies. For example, transit options on the return "half tour" influence the choice of transit on the outbound half tour, or tolls may be only in one direction or may vary by time of day and direction. Activity-based models also provide the ability to test a wider range of fare policies, including person-level influences such as transit pass-holding or targeted discounts. Activity-based models also typically provide better sensitivity to the influence of urban form, accessibility, and demographics on auto ownership choices.
- Land use. Activity-based models typically include more travel purposes than trip-based models, providing more sensitivity to detailed land use information. In addition, they can better capture the effects of transit-oriented investments because of the ability to more easily incorporate short-distance travel factors that influence transit choice.
- Active transportation. As with transit, activity-based models more easily incorporate short-distance travel factors that influence active transportation modes and are

better able to represent true modal availability and constraints.

- Equity. Because they work at the disaggregate levels of individuals and households, activity-based models provide more opportunities to report effects by any sociodemographic characteristic included in the synthetic population file.

2.2.2

Design Considerations

When designing a new activity-based model or choosing an existing activity-based model to transfer, there are several different considerations, including the following:

- The level of detail to include in terms of spatial resolution, number of different time periods, number and type of market segments, number and type of modes to consider, and number and type of different activity purposes.
- The range of different types of model components to include in the system.
- Internal component linkages, including how outcomes of higher-level models influence the choices available in the lower-level models, and how the accessibility variables, representing the total accessibility across lower-level alternatives, affect the higher-level choice decisions.
- External linkages with other model components, such as network assignment models and models of auxiliary markets such as freight, special generators, and external trips.

Each of these considerations is described as follows.

2.2.2.1

Resolution and Detail

There are several different types of resolution to be considered in an activity-based model design. When these resolutions are being considered, there are two important aspects that distinguish activity-based models from trip-based models.

First, in contrast to the zone-based looping structure of most trip-based models, adding more zones, more time periods, more demographic segments, and/or more trip purposes does not greatly increase the run time of activity-based model components. Adding detail along all of those dimensions has not been practical in the past because the run time and data storage requirements in trip-based models increase with the square of the number of zones, times the number of population segments, times the number of trip purposes, and times the number of time periods. In an activity-based model, however, the run time depends primarily on the number of different households and persons simulated. The amount of detail used in the various dimensions may add to memory requirements but will not substantially influence run times. This fundamental difference is what has made it possible to include more detail in activity-based models.

Second, additional detail is incorporated into the model system to provide more accurate aggregate forecasts, not to report the detailed forecast for a particular household, or parcel, Census block, or 15-minute period of the day. With an activity-based model, one simulates behavior in more detail and then aggregates the model outputs, rather than aggregating the inputs from the outset. This feature has the statistical advantage of avoiding likely aggregation bias in the forecasts. The feature also allows the model to represent a wider range of aspects of travel behavior, and thus the model can be used to study a wider range of policies and scenarios.

2.2.2.1.1

Representation of Space and Accessibility

Activity-based models can use the same size TAZs as those used in a typical aggregate zone-based model. However, it has become more common to include more detail to represent key spatial data such as employment and school enrollment, distance to transit stops, urban design, and local street infrastructure. In some activity-based models, individual parcels or points are the basic spatial unit. This approach requires robust parcel data for the modeled area as well as a means of forecasting future-year land use at the parcel level. An intermediate approach that is becoming more common is to use spatial units that are roughly the size of the Census blocks. A typical model might include 30,000–150,000 microzones, an order of magnitude more than the typical number of TAZs but also an order of magnitude less than a typical number of parcels in a region. These microzones are often based on Census blocks in order to exploit data available at this geographic level.

Using blocks or parcels as the basic spatial unit does not require using automobile and transit network skims at that level of detail because such skim matrices would be impractically large. Instead, each block or parcel is associated with a network TAZ and uses TAZ-level skims. For most trips longer than a mile or two, this level of network path detail is adequate. For shorter trips, these TAZ skims can be augmented with short-distance impedance measures that use finer level street network detail, such as the block-to-block shortest-path distance along an all-streets network between any pair of Census blocks. This flexibility in the structure of activity-based models makes it possible to incorporate multiple levels of spatial resolution of skims.

2.2.2.1.2

Representation of Time

Most activity-based models contain model components that simulate scheduling of trips and activities consistently across the day in response to congestion levels and other factors. Therefore, it is advantageous to distinguish multiple time periods, particularly during peak periods. As with spatial detail, the temporal detail does not need to be a perfect match for the number of different time periods used in the accompanying network assignment model.

The earliest activity-based models only used four or five time periods across the day, both in their scheduling models and in network assignment. Recently, most new activity-based model systems have used time periods as small as 15, 30, or 60 minutes for scheduling models within the activity-based system. The temporally detailed information is aggregated up to only 5 periods or so for the network assignment model. This aggregation has been done mostly for purposes of minimizing network assignment run times. Ideally, more detailed information on network congestion during peak and shoulder time periods can be fed back into the activity-based model. Thus, recently implemented activity-based model systems tend to use more detailed time periods for assignment, including as many as 10 to 15 time periods, with separate assignments and skims for 30-minute or 60-minute time periods during the a.m. and p.m. peaks. This provides a closer match to the length of time periods used inside the activity-based model scheduling components.

As time goes by, both activity-based models and network assignment models are moving toward a more continuous representation of time across the day, using periods as short as 5 or 10 minutes for scheduling models within the activity-based components and integrating with dynamic network assignment models [colloquially referred to as DTA, or dynamic traffic (or network) assignment, models, although they may consider transit in addition to vehicular traffic] on the supply side to simulate and feedback measures of traffic congestion at that same level of detail. However, such detailed temporal resolution may not be necessary or appropriate for all regions. The SHRP 2 C10 projects provided a proof of concept for integrating demand-and-supply models with high levels of temporal (and spatial) detail, although significant methodological and practical issues associated with these advanced models remain.

2.2.2.1.3
Market Segmentation

Demographic Segmentation. Market segments are used in trip-based models to reflect the influences of attributes on different populations. In contrast to trip-based models, most activity-based models do not necessarily need to predefine a set of market segments. Each household and/or person is simulated individually, and any characteristics that are known about that household and/or person can be used in the models. Variables typically used to define market segments are household size, number of household members in different age categories, number of employed adults, number of students, household income, person age, person gender, person employment status, and student status. These are standard variables available in household travel surveys and in the synthetic population that is used as an input to the activity-based model. When one considers the number of different combinations of these household and person variables that can exist across the population, the number of demographic segments used in the activity-based model can be virtually unlimited. Of course, for reporting purposes, results are aggregated for specific districts, income groups, and other segments. Note that it is also possible to use other demographic variables such as race/ethnicity, housing type and/or ownership status, and length of residence in the neighborhood. Using race/ethnicity has often been avoided because of the difficulty of separating those effects from income effects and predicting future land use residential patterns of different race/ethnic groups. Other variables such as housing type and own/rent status may become more commonly used in the future in cases where the activity-based model is integrated with a land use model that predicts such outcomes.

Activity Purpose Segmentation. Early activity-based models tended to include only three or four distinct activity purposes, such as work, school, other, maintenance, and discretionary. Recently, as many as 7–10 activity purposes have been included in activity-based models. “Escort” activities, also referred to as “chauffeuring” or “serving passenger,” tend to have different characteristics than other activities, particularly in terms of mode choice, since these activities tend to involve automobile shared-ride tours. Meal activities can usefully be separated from other types of maintenance activities, because they tend to take place during certain periods of the day at locations where food service employment is located. Shopping is another type of maintenance activity that can be tied to specific attraction variables, such as retail employment, and tends to happen during store opening hours. Medical visits are another activity purpose that can be tied to a specific attraction variable (medical employment). On the discretionary side, it can be useful to separate social visits as a separate activity purpose, as they often occur at residential locations and outside of working hours. Outdoor recreation can be another useful activity category, as it can be tied to open space/parks/sport fields, as attraction variables. In general, if the land use data have sufficient detail that will allow prediction of where specific types of activities are likely to take place, then the data can also be useful to distinguish those types of activities in the activity-based model components. The model then can better predict which types of people tend to visit certain types of locations during certain periods of the day.

Mode Segmentation. In general, the set of modes used in an activity-based model is similar to the set that would be used in a trip-based model. A minimal number of modes to include in an activity-based model would be automobile, transit, and nonmotorized. With the increased interest in walking and biking, these two nonmotorized models are considered as separate modes in most recent activity-based models. If park-and-ride is a relevant choice in a region, it can be separated from walk-access transit as a separate mode alternative. Some models treat different transit submodes (e.g., bus, light rail, heavy rail, ferry) as separate modes in mode choice, while other models leave it to the transit network path building software to determine the best overall transit path and its attributes.

Different activity-based models use different patterns to segment the auto submodes. In some model designs, only the automobile occupancy is important [e.g., different mode choices for single-occupancy vehicle (SOV), high-occupancy vehicle (HOV, HOV 2, or HOV 3+)], without predicting exactly which person is the driver and who are the passengers in the HOV tours and trips. In other model designs, the driver–passenger distinction is predicted explicitly. All designs tend to include an explicit choice between different occupancy levels, however, which is important for obtaining the correct number of vehicle-trips for assignment purposes. In addition, some model designs also treat the choice between a tolled path and a nontolled path as essentially two different types of automobile alternatives in mode choice, while in other models, that choice is done completely in the automobile network path building process.

In general, the specific set of modes used is probably the least consistent across the various activity-based models that have been designed and used in practice, partly because different regions have different types of modes available currently and different emphases in adding certain modes in the future. One design issue to consider is the ease in adding new types of modes into the choice set for future-year scenarios, rather than being restricted by the model design to a fixed set of modes in all scenarios.

2.2.2.2

Subcomponents

Table 2.2 provides an overview of the types of model components that have been included in advanced model systems as they have evolved from simple tour-based models (in the late 1980s and early 1990s) to the most advanced activity-based models today. In order to provide concise information, Table 2.2 does not consider every detail of every model used in practice, so there may be exceptions to this typology. This table is meant to cover the major variations in model designs, as an aid to discussing the various components in more detail.

The earliest tour-based models were similar to trip-based models, but generated tours instead of trips, and typically used regression models and logit models for all components, including generation and distribution (destination choice). Complexities such as time-of-day choice and intermediate stop-making on tours were typically dealt with using simple factoring approaches, rather than detailed choice models. Because the structure of such models is similar to trip-based model structures, they could be applied in a traditional aggregate zone-based framework, without simulating individual households. More advanced tour-based models replaced the simple factoring with explicit time-of-day choice models and explicit models of the generation and location of intermediate stops on tours. This structure, which essentially adds a third spatial dimension (stop location depends on both the tour origin and destination locations), made traditional aggregate zone-based application infeasible, so these models moved to the microsimulation approach, or some combination of aggregate and microsimulation approaches. The shift

TABLE 2.2. COMPONENTS INCLUDED IN VARIOUS TYPES OF TOUR-BASED AND ACTIVITY-BASED MODELS

Simple Tour-Based	Advanced Tour-Based	Day-Pattern-Based	Day Pattern with Longer-Term Choices	Day Pattern with Longer-Term and Mobility Choices	With Explicit Intra-Household Interactions
Population segmentation	Population synthesis	Population synthesis	Population synthesis Usual work (and school) locations	Population synthesis Usual work (and school) locations	Population synthesis Usual work (and school) locations
Automobile ownership	Automobile ownership	Automobile ownership	Automobile ownership	Automobile ownership Transit pass and parking pass ownership	Automobile ownership Transit pass and parking pass ownership Joint household day pattern and joint (half) tour generation
Tour generation	Tour generation	Day pattern (tours and some aspects of intermediate stops)	Day pattern (tours and some aspects of intermediate stops)	Day pattern (tours and some aspects of intermediate stops)	Remaining individual tours and some aspects of intermediate stops
Tour-level models—mode and destination choices	Tour-level models—mode, destination, and time-of-day choices	Tour-level models—mode, destination, and time-of-day choices	Tour-level models—mode, destination, and time-of-day choices	Tour-level models—mode, destination, and time-of-day choices	Tour-level models—mode, destination, and time-of-day choices
Simple postfactoring	Intermediate stop generation Intermediate stop location	Intermediate stop generation Intermediate stop location	Intermediate stop generation Intermediate stop location Trip-level mode and departure time choices	Intermediate stop generation Intermediate stop location Trip-level mode and departure time choices	Intermediate stop generation Intermediate stop location Trip-level mode and departure time choices
Usually aggregate application	Aggregate and microsimulation applications	Person-based microsimulation applications	Person-based microsimulation applications	Person-based microsimulation applications	Household and person-based microsimulation applications

to a microsimulation approach required the introduction of population synthesis in order to provide records for individual households and persons in a prototypical, representative population.

The first practical use in the United States of what we now recognize as activity-based models came with the introduction of the day-pattern approach (Bowman 1995). The day-pattern approach assumes that tours for different activity purposes are not generated independently of each other, but are generated jointly to take account of substitution and complementarity effects of different types of tours and activities across a single day. In some model designs, some aspects of intermediate stops on tours are predicted at this day-level as well, although the exact numbers of stops and allocation to tours are always predicted at the lower levels of the model system. Because there are so many different possible day-long patterns of tours and stops, all models of this type have been applied using a microsimulation approach at the person-day level, using single stochastic (Monte Carlo) choices for each model component. Although the person-day is used as the basic unit of simulation, effects of other household members are typically incorporated through using variables on household characteristics and/or simulating the household members in a specific order and making some household members' choices conditional on the choices of previously simulated members.

An advance to the day-pattern approach that was put into practice around the year 2000 was to include longer-term location choices such as workers' usual work locations and students' usual school locations at the upper level, instead of leaving these choices to be predicted at the tour level only. This provides more control for matching work and student commute flows to control data, and allows those choices to influence other aspects of the model system (e.g., people may be more likely to own a car and/or to telecommute from home on some days if their usual work location is a long distance from their residence). Recently, some activity-based model systems have included other longer or medium-term mobility choice models such as the decision to own a transit pass or whether or not free parking is provided at the workplace.

The most advanced activity-based models explicitly link joint travel and activities across different household members. This feature, termed "explicit intra-household interactions," has evolved to include complex interactions such as parents taking children to school. The inclusion of such features requires a more complex microsimulation framework and software to account for the joint scheduling and locations of different persons' activities across the simulated day.

2.2.2.2.1

Population Synthesis

Population synthesis is a procedure to create a set of household and person records that match relevant demographic control totals for a recent base year or for a forecast year. For a base year, the control totals are typically from the U.S. Census and/or American Community Survey (ACS), and the individual household and person records are drawn from public use microdata sample (PUMS) files, such as from the Census and/or ACS. Early population synthesizers were fairly simple and tended to use only household-level marginal controls such as distributions on household size, household workers, income, and/or age of head of household. More recent procedures and software provide users with more flexibility in using a wider range of person-level and household-level controls, as well as more sophisticated methods of drawing samples into the population to match controls more closely. The availability of sociodemographic forecasts for a region is one aspect that should be considered when selecting which control variables to use in population synthesis.

An alternative approach to synthesizing a population separately for each forecast year is to synthesize the base-year population and then use a population evolution model to evolve that population over time to represent phenomena such as aging, births and deaths, marriage and divorce, and immigration and emigration. At the time of writing, these types of evolution models have not yet been used in practice along with activity-based models.

Because the population is synthesized at the TAZ or Census block group level because of the availability of marginal control data at this geography, it may also be necessary to use methods to allocate synthetic households to more detailed spatial units used in the model system such as microzones or parcels. In practice, this allocation has often been done randomly, although modeling approaches have been used to associate households with spatial units based on the households' characteristics, such as size and income, and the locations' attributes, such as type of available housing and distance from transit.

2.2.2.2.2

Long-Term Models

All tour-based and activity-based models have included a model component to predict household auto availability, as this is one of the most important variables in subsequent models such as tour generation and mode choice. As mentioned, more recent activity-based model systems also predict the usual work location for workers and often predict the usual school location for students. Those locations tend to be key aspects of how workers and students plan their days spatially and temporally. Also, specifically in the case of work locations, the user may wish to doubly constrain the choice to make sure that the number of workers predicted to have jobs in specific zones or microzones closely matches the number of jobs that are located there. In activity-based models, this type of constraint is typically implemented using an iterative shadow pricing procedure, where the attractiveness (utility) of specific work locations is iteratively revised until the match between predicted workplaces and available jobs in each spatial area is considered acceptable.

In most U.S. model systems, work and school locations are predicted before automobile ownership on the assumption that one can more easily buy or sell an automobile to fit the commuting needs than one can find a different job to match the car ownership level. In reality, these two choices are interdependent and have sometimes been modeled that way. It should be noted that all choices modeled in an activity-based system are interdependent to some degree, but it would not be possible to estimate a model along all dimensions simultaneously. One of the aspects that differentiate model designs, even within the same family of designs, is which model components are modeled and applied jointly versus which model components are modeled and applied sequentially.

An additional consideration regarding longer-term models, such as usual work location and usual school location, is that some land use forecasting models also predict these choices, so it may not be necessary to include them as part of the activity-based model system. In that case, the usual work and school location is just passed to the activity-based model as a variable on the synthetic population file, the same as residence location, income, and so forth. A possible advantage of including workplace location as part of a land use simulation model might be that the residence location and workplace location can be predicted simultaneously, or in a naturally occurring temporal sequence through the course of the land use simulation, since in many cases people will choose their residence location based on where their workplace is located, rather than vice versa. This is particularly relevant for multiworker households. Finally, consideration should be given to the policy or project contexts for which it is appropriate to run long-term choice models.

2.2.2.2.3
Mobility Models (Medium Term)

A recent trend in activity-based model design is to explicitly model mobility modifiers, such as the ownership of a transit pass or the availability of free parking at the workplace. These variables can significantly influence the relative attractiveness of competing modes in the subsequent lower-level models such as mode choice. A key consideration is how these modeled outcomes are used in the lower-level models of the system, and how the relative attractiveness of the modes available to usual destinations is used to influence the upper-level choices as described in the "Accessibility Measures" section (see Section 2.2.2.3) that follows. A person is likely to own a transit pass only if there is reasonably attractive transit service to that person's workplace or other usual destinations. This aspect needs to be included in order for a transit pass ownership model to predict reasonable behavior.

2.2.2.2.4
Daily Models (Short Term)

In addition to the long-term and medium-term choices, activity-based models also consider short-term or day-level choices. Activity-based models consider these short-term choices at three main sublevels:

- The full-day level;
- The tour level; and
- The trip level.

The Full-Day Level. The representation of day-level choices is the aspect of activity-based models that first distinguished them from earlier tour-based and trip-based models. Modeling an entire day makes it possible to fully integrate time-of-day models and temporal constraints into the model system, and the modeling of a day pattern at the day level is an important way of incorporating the trade-offs that people make when faced with the limits of a 24-hour day. Not surprisingly, it is at the full-day level that the existing activity-based models implemented in practice vary the most. There are a number of different design considerations as to how the day-level is modeled, and different combinations of these aspects are used in practice. These include the following:

1. Are the numbers of tours made during the simulated day for the various purposes modeled independently of each other or modeled jointly (allowing for substitution between tours for different purposes)?
2. Are the mandatory (work and school) tours generated before generating the tours for the other (nonmandatory) purposes, or are these tours all generated jointly in a single model?
3. If work and school tours are generated first, are they also scheduled before generating any nonmandatory tours, so that the time left over in the day can influence the likelihood of making individual tours?
4. Are all activity episodes generated first and then allocated to tours or, at the other extreme, are only tours generated first, with any additional activities at intermediate stops generated later at the tour level? Several models used in practice are somewhere between these two extremes, where certain information about intermediate stop activities is generated at the day level at the same time as tour generation, but individual stop activities are generated and allocated to tours at the tour level, conditional on the day-level predictions.

In reality, some intermediate stops are planned in advance, and some are made on the spur of the moment for convenience sake, so there is no completely correct way to structure such models.

5. For workers, is the decision to work at home during the day (telecommuting), or to have a nonwork day, modeled explicitly?
6. Are the types of day patterns (go to work or school, go to other types of destinations, stay home all day) coordinated jointly across different household members? If so, is this coordination done in a sequential model fashion or in a single joint model across all household members, and how do travel conditions affect these choices?
7. Are household maintenance tours (e.g., shopping, errands, dropping off and picking up passengers) generated at the household level? Are individual maintenance tours generated for individuals?
8. Are completely joint tours (where different household members travel to all activity locations together for the entire tour) modeled explicitly as joint travel decisions, or are all tour generation decisions modeled separately for each household member?
9. Are partially joint tours for work and school purposes (where one family member chauffeurs or accompanies another one to work or school) modeled explicitly or as separate decisions for different household members?
10. Are partially joint tours for other purposes (where one family member chauffeurs a child to a sporting event or to play at a friend's house) modeled explicitly or as separate decisions for different household members?
11. Is joint travel between members of different households (where two workers from different addresses carpool to work together) modeled explicitly as a joint decision?
12. Are full social networks, including non-family members, taken into account when generating and scheduling tours for a day?

Aspects 6–10 are what are commonly referred to as "explicit intra-household interactions," and have been incorporated in the designs of some of the most recent activity-based models. These explicit intra-household interactions can be quite complex to model, particularly the partially joint tours in Aspects 9 and 10, because the simulated travelers travel together for part of the tour but can then do different things for the remainder of the tour, so there are many possible permutations of such tours and many ways to model those permutations. To date, partially joint tours have been included in practical models for work and school activities (Aspect 9), but not yet for other activities (Aspect 10), where the possibilities are even more numerous.

Aspects 11 and 12 address modeling joint travel decisions between members of different households. Although such modeling has been done as part of university research, it has yet to be incorporated into practical activity-based models, in part because the methods for identifying travel partners across the region would be very complex.

Overall, among these aspects there is a trade-off between model complexity and behavioral accuracy of the results. On the one hand, models that do not represent explicit intra-household interactions may be too sensitive to some travel policies because these models do not fully portray the constraints on travel choices imposed by household members having to synchronize their schedules and vehicles to travel together. On the other hand, models that pose such joint behavior as inflexible constraints may over-constrain the model predictions in the long term, as household members can adjust their joint travel patterns if conditions change enough. This issue brings up the importance of including travel accessibility effects at all levels of the model system, as the convenience of traveling together and the options for traveling by alternative modes can influence whether or not household members choose to travel together. As this is one of the newer and continually developing aspects of activity-based model design, these issues are likely to be the subject of future research.

The Tour Level. Given the day-level outcomes, the tour level is where many of the key behavioral outcomes in activity-based model systems occur. Once tour decisions are made, models at the trip level add important details, but the trip-level models are constrained by the outcomes at the tour level, so they are not as influential as the tour-level models.

In most cases, three main decisions are modeled at the tour level:

1. Destination choice;
2. Mode choice; and
3. Time-of-day choice.

Destination choice involves choice of parcel (or point), microzone (block), or TAZ, depending on the level of spatial resolution used in the model. When the spatial resolution is more detailed than TAZ, destination-choice models use sampling of alternatives, identifying only a subsample of spatial units as choice alternatives rather than the full set. Sampling is done for reasons of computational efficiency and, since we are modeling choices for many thousands or even millions of tours per day in a region, each possible choice alternative will still be included in the choice sets for many tours in the course of a simulation. Typically, importance sampling is used (Ben-Akiva and Lerman 1985) where the destination sampling probabilities are based on a simpler function with a form analogous to a gravity model, so that the more attractive alternatives are more likely to get into the choice set and the sampling is more statistically efficient. In general terms, logit destination-choice models are very similar to, but more flexible than, a singly-constrained gravity model. To also add controls at the destination end for a doubly constrained model, shadow pricing methods are often used, but typically only for work or school destinations.

Tour-level mode choice models are very similar to their trip-level counterparts, but they consider both halves of the round trip tour. Because people tend to use the same mode for an entire tour in more than 90% of cases, it is logical to model this as a single, tour-level decision. Subsequent trip-level models are used to represent the infrequent cases of multimodal tours. Alternatives such as park-and-ride are also modeled at the tour level, because people have to return to the same park-and-ride lot to retrieve their cars on the way home. The typical modes included in activity-based models are as follows:

- Car drive alone (sometimes distinguished by toll status);
- Car shared ride 2 (sometimes distinguished between driver and passenger and by toll status);
- Car shared ride 3+ (sometimes distinguished between driver and passenger and by toll status);
- Transit-walk access;
- Transit-drive access (sometimes distinguished between park-and-ride and kiss-and-ride);
- Nonmotorized (usually distinguished between walk and bike); and
- School bus (only for school tours in areas where such service is provided).

Tour mode choice models typically use nested logit modeling either using a predetermined nesting structure from previous stated preference research or letting the estimation data decide which nesting structure performs best. The nesting structure may vary depending on activity purpose, available modes, or other local characteristics.

Tour time-of-day models are also typically done for the round trip. In some cases, these models predict the time the person leaves home to begin the tour and simultaneously the time the person arrives back at home. In other model designs, the model predicts the time arriving at the primary tour destination and the time departing from the tour destination again. The number of different time periods used in the tour time-of-day models can be as low as 4 or 5 (e.g., a.m. peak, midday, p.m. peak, evening, night), or as many as 24 (one-hour periods) or 48 (half-hour periods).

An important design option at the tour level is the hierarchy to use for the three types of models: destination choice, mode choice, and time of day. Nearly all activity-based models used in the United States have included destination choice above mode choice, but for some activity purposes alternative sequences may make sense. There is no clear consensus on where in this hierarchy the tour time-of-day models should be placed. Both research and practice have indicated that the more detailed the time periods used in the time-of-day models, the more likely that travelers are to shift time periods, and thus the lower down in the choice hierarchy that the time-of-day models should be.

An alternative to estimating complex, multidimensional, nested models is to assume a nesting structure and estimate and apply the models as sequential nested models. This may mean estimating a mode/time-of-day logsum across all possible mode and time-of-day combinations for use in the destination-choice model. The disadvantage of calculating all the accessibility logsum variables across all times of day is that this calculation can greatly increase the run time of the model, particularly if there are many different time periods used.

These design considerations affect the vertical integrity of the models—the idea that although each choice in the hierarchy is conditional on the choices simulated above it, each choice alternative also receives information about the expected utility across all of the remaining choice alternatives at all levels below it, if it were to be chosen. As more different types of choices and choice levels are incorporated in the design, it becomes more difficult, yet no less important, to maintain the ideal vertical integrity of a fully branched tree of nested models from top to bottom.

The Trip Level. Below the tour level, the trip-level component models tend to include the following:

- Work-based subtour generation;
- Intermediate stop generation;
- Intermediate stop location;
- Trip mode; and
- Trip departure time.

As mentioned previously, in some model designs detail has already been simulated at the full-day level about what types of stops and/or how many stops must be simulated on the tours that occur during the day. This information is used to condition the choices simulated in the intermediate stop generation model. In other designs, there are no such prior constraints from the day-level predictions.

The intermediate stop location model can be one of the most complex models in an activity-based system because it is anchored by two different locations—the current location (the destination of the previously simulated trip or tour) and the location where the particular half tour is ultimately heading, as shown in Figure 2.1. The latter is either the tour origin or the tour destination, depending on whether the model design simulates each half tour in-

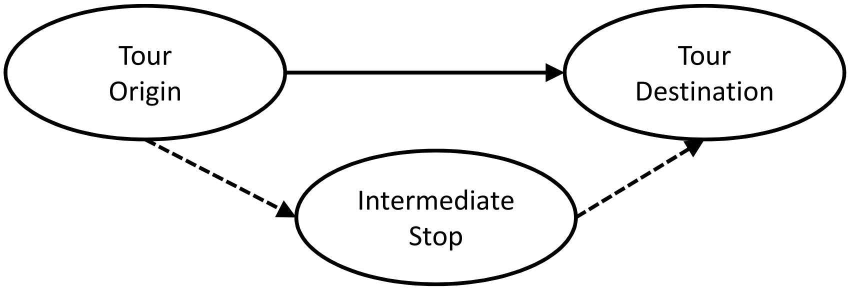

Figure 2.1. *Intermediate stop locations.*

ward toward the tour destination, or outward toward the tour origin, which is the home location for home-based tours.

Just as at the tour level, the relative ordering of the trip mode and departure time models can vary from one model design to the other. In this case, however, it is not as critical because the trip-level models do not have as much influence on the model results as the tour-level models, since they simply provide more detail based on the tour-level choices. For model systems where the tour time-of-day model already models the main tour arrival and departure times at the most detailed level, often 30 or 60 minutes, the trip-level departure time model only needs to be used to model the departure time from any intermediate stops, typically at that same level of temporal detail. In some recent model systems, however, even more detailed time periods have been used at the trip level, with periods as detailed as 5 or 10 minutes.

There are two reasons for moving toward a design with more detailed time periods, as small as 5 or 10 minutes. The first is that the output is more compatible with DTA methods that use similar time slices, if one is planning to move from static assignment to DTA in the near future. Second, some of the most complex logic in the activity-based model software is that of scheduling activities and travel in available time windows for each simulated person in the simulated day. The more accurate the trip departure and arrival times and the activity start and end times can be simulated in the system, the more accurately the time-window accounting can be simulated. Such precision may not be necessary for most model applications, and model users should be cognizant of the difference between the precision of these times and predictive accuracy.

2.2.2.3
Accessibility Measures

Accessibility measures are critical to ensuring reasonable policy sensitivity at the various levels of the model design to changes in infrastructure or land use, or both. In general, four types of accessibility variables are included in the models:

1. Direct measures of travel times, distances, and costs from modeled network paths;
2. Detailed logsums calculated across alternatives in models that include direct measures;
3. Aggregate (approximate) logsums calculated across alternatives in models that include direct measures; and
4. Buffer measures representing the activity opportunities and urban design surrounding each parcel or microzone (e.g., Census block).

The direct measures are used in all mode, destination, and time-of-day choice models wherever possible. Often, however, the model hierarchy makes it impossible to use a direct measure because it depends on a yet-unmodeled outcome. This would be the case, for example, for travel time in a destination-choice model that is higher in the hierarchy than mode and/or time-of-day choice, since in order to measure travel time directly it is necessary to know the mode and time of day. In such cases, detailed logsums can be calculated from the lower-level choice models and used instead of direct measures in the upper level model. A typical example in practical activity-based models is the use of tour mode choice model logsums in higher-level models such as tour time-of-day choice, tour destination choice, and workplace location choice.

There are cases when it is not practical to apply fully detailed versions of the logsums that are calculated on the fly during the simulation every time a logsum is needed. The number of logsum measures required and the time to generate, store, and access these measures may simply be infeasible. More generalized logsums that reflect overall perceived accessibility may be more useful. To address this issue, a common approach is to precalculate more aggregate accessibility logsums to be used in models in which using the more impractical ones would not be computationally or conceptually feasible. For example, some model systems use aggregate accessibility logsums calculated from each origin TAZ or microzone to all possible destinations via all possible modes. Aggregate logsums are typically calculated for each combination of up to four or five critical dimensions, including the following:

1. Origin TAZ or microzone;
2. Tour purpose;
3. Household income group, or value-of-time (VOT) group;
4. Household automobile sufficiency (automobiles owned compared with driving-age adults); and
5. Household residence distance from transit service.

Aggregate measures are used most often in the day-level models and some of the longer-term models, where the model is not yet considering a tour to a specific destination, but is considering, for example, how many tours to make for a given purpose from the home location during the day.

Finally, buffered measures represent the accessibility to very nearby destinations, as could be visited by walk, bike, or very short car trips. The typical measures that are buffered include the number of nearby

- Households;
- Jobs of various types (as proxies for activity locations);
- School enrollment places of various school types; and
- Transit stops.

Clearly, these measures are most relevant when the spatial units themselves are much smaller than the radius of the buffer area. Thus, using buffer-based measures is really only useful when the spatial unit of the model is parcels or, at the largest, Census blocks. One way to make the buffer measures more accurate and relevant is to use on-street, shortest-path distance to measure the distance to the edge of the buffer, rather than using straight line (as the crow flies) or Euclidean distances. Additionally, use of distance-decay functions can mitigate the "cliff effects" that are sometimes associated with the use of simple buffer measures.

2.2.3

Other Model Component Design Considerations

The preceding sections have described the issues that need to be considered when designing the core components that form the activity-based model system and configuring the interactions and exchanges of information among these components. However, the overall activity-based model system design must also consider the interactions with other tools that, in conjunction with the core activity-based model, make up the entire model system. These additional tools include the synthetic population model, the network assignment model, and potentially other tools such as a land use model.

2.2.3.1

Synthetic Population Characteristics

The synthetic population is key input to the activity-based model, as it provides information about the fundamental decision-making units in the model system: households and persons. There are two fundamental aspects that must be considered to ensure that the synthetic population is compatible with the activity-based model. First, it is essential that the synthetic population include any attributes that may be included in the specifications of any of the model components that compose the activity-based model, or implement a submodel that provides these attributes. For example, if income variables are used, the synthetic population must include relevant information on income that can be used in the model. If new models are to be estimated using local household survey data or other information, the included variables in the survey can be compared to those available in the synthetic population. If models are to be transferred, the specifications of these existing models should be reviewed to ensure consistency. Second, it is also important that the design of the synthetic population reflect the policy analysis needs of the region. For example, if it is anticipated that a region wishes to perform analyses of communities of concern based on ethnicity, race, income, or age, it is necessary to ensure that these attributes will be included in the synthetic population.

2.2.3.2

Network Assignment Model Design Considerations

Activity-based models are travel demand models that are influenced by the performance of transportation network—travel times, distances, costs, and other attributes by different travel modes and different times of day. Network assignment models, which assign travel demand to individual transportation network links and transit routes, produce estimates of transportation network performance. Thus, an activity-based model system is typically formed by two main components: the activity-based demand component and the network assignment model component.

The network assignment model produces network performance indicators, such as travel times by time of day and mode, which are input to the activity-based model. In turn, the activity-based model provides estimates of travel demand from origins to destinations by time of day and mode that are input to the network assignment model. Most activity-based models have been linked with static network assignment models, although a limited number of models also have been linked with more advanced DTA models.

2.2.3.2.1

Policy Analysis Needs and Consistency with Other Model Components

Just as it is necessary for agencies to carefully consider their analysis needs before initiating an activity-based travel demand model development effort, agencies must similarly consider how such needs may affect the design of the network assignment model. The policy analysis needs of the models are intrinsically related to the issue of maintaining consistency with other model system components. The spatial, temporal, and typological resolution of the activity-based model must inform and align with these same dimensions in the network assignment model. For example, if the activity-based model design incorporates the ability to represent policy changes such as network pricing by time of day, then ideally network information such as times and costs at a temporal resolution consistent with this pricing scenario can be fed back from the network assignment model to the activity-based model. If time-of-day information is used when predicting demand, or if truck volumes on roadways are of particular concern, then the network assignment model should be configured to exploit this time-of-day information and should assign the truck classes that are output by the auxiliary truck model component.

Spatial Resolution. Activity-based models can more easily incorporate more detailed spatial resolution than traditional trip-based models because they are not constrained by the limitations imposed by the use of matrices for generating estimates of travel demand. As a result, many activity-based models incorporate enhancements to use smaller spatial units, such as microzones or parcels, or improved methods for representing short-distance travel impedances. Including more accurate short-distance travel can be particularly important for accurately predicting pedestrian, bicycle, and transit travel modes.

The network assignment model design should be consistent with the spatial resolution of the activity-based model. When using traditional static network assignment models to develop measures of automobile impedances, also known as "skimming," or to assign automobile trips, this typically means aggregating more spatially detailed outputs to the level of TAZs and using less detailed planning-level network. Transit network skimming and assignment is also typically performed using a spatial resolution of TAZs, although some regions are now using alternative transit spatial schemes such as transit access points. Detailed all-streets networks are being used in some regions to develop pedestrian and bicycle network impedances, although very few actually assign these nonmotorized trips to these spatially detailed networks.

Temporal Resolution. One of the distinguishing aspects of activity-based models is that they include an explicit representation of time of day. Many trip-based models generate estimates of daily trips and incorporate peak and off-peak assignment models by using fixed time-of-day factors. In contrast, activity-based models explicitly predict tour and trip arrival times, departure times, and activity durations. The temporal resolution of these more detailed times of day can vary from as broad as 3 hours or more, to as detailed as 15 minutes or less. The network assignment model design should be consistent with the temporal resolution of the activity-based model. If the activity-based model produces more temporally aggregate demand, such as multihour periods, then the network resolution must reflect the activity-based model resolution. However, if the activity-based demand model produces more temporally detailed demand, then users may have tremendous flexibility in the network assignment model design to incorporate this detail. This detail can provide better estimates of network performance by time of day and potentially provide more sensitivity to phenomena such as peak spreading. Ideally, the temporal resolution of the activity-based demand and network assignment model would be exactly aligned. This alignment is usually not possible in practice, because most activity-based demand models are linked with static network assignment models, which are incapable of generating reasonable measures of link volumes and network performance indicators for small time periods less than 1 hour in duration.

Typological (Including Auxiliary) Resolution. The overall demand for travel can be considered to comprise the sum of a set of smaller market segments. For example, one could consider a distinction between the transit travel demand market segment and auto travel demand market segment. It is highly desirable that the market segmentation in the network assignment model maintain consistency with the market segmentation in the activity-based demand model. If the activity-based model includes transit submode choices, such as bus and light rail, then ideally the network assignment model will include a parallel segmentation. Parallel segmentation makes it possible to produce submode-specific network performance indicators that are used as input to the activity-based model as well as to assign the travel demand forecast by the activity-based model to mode-specific transportation networks. An important feature of activity-based models is that they incorporate significantly more detail by functioning at the disaggregate level of individual persons and households. This disaggregation allows for the flexible definition of market segments from activity-based model outputs.

2.2.3.2.2
Types of Network Assignment Models

Activity-based models, like trip-based models, can be linked with either static network assignment or DTA models. Static network assignment models have been used widely in practice for decades, and their properties are well understood. However, static network assignment models are limited in their ability to capture changes in network performance by detailed time of day and to represent many network operational attributes. DTA models have only begun to be used more widely in practice and can provide detailed temporal information used as input to activity-based models, but they have a number of properties that complicate their broad use in practice, such as long run times, and an inherent stochasiticity. All activity-based models implemented in the United States have been linked with static network assignment models, although only a few activity-based models have been linked with DTA models.

Static. Static network assignment models are the most widely used roadway network assignment models. They are used typically with the input travel demand generated for longer time periods, such as multihour peak periods or entire days. As a result, they can generate only estimates of average network travel times and link volumes representing longer time periods for input into the activity-based travel model. While the behaviors of static network assignment models are well known and they have relatively fast run times, they are limited by their insensitivity to many operational attributes and by their inconsistency with traffic flow theory (Chiu et al. 2011). Most transit network assignment models are also static, although they vary in their level of complexity. Most activity-based models are linked with simple shortest generalized path transit assignment models, although some transit assignment models used include the ability to distribute flows across multiple competing routes and even to reflect the effects of transit crowding.

Dynamic. In contrast to static network assignment models, DTA models capture the changes in network performance by detailed time of day and can be used to generate time varying measures of this performance for input to an activity-based model. This temporal resolution can be flexibly defined, and recent implementations have tested resolutions as fine as 10 minutes. The network performance indicators derived from DTA models such as congested travel times arise from the dynamic interaction of individual vehicles or packets of vehicles being simulated or calculated using extremely fine-grained temporal resolution, such as seconds or fractions of seconds. DTA models are sensitive to operational attributes and are founded on traffic flow theory, but their wide adoption has been hindered by long run times and by their inherent stochasticity (Chiu et al. 2011, p. 4).

2.2.3.2.3
Modes

The modes defined in the network assignment model should be consistent with those employed in the mode choice component of the activity-based model system. Activity-based models have the flexibility to incorporate additional modes and relevant modal attributes but generally include the same modes as advanced trip-based models.

Roadway. Most network assignment models linked with activity-based models include the traditional vehicle modes by occupancy class. In some cases, the network assignment model has also included assignment classes by value of time. The roadway network assignment model design also must consider any truck assignment classes generated by a commercial or truck auxiliary model component.

Transit. There are two basic options for representing transit submodes: explicitly modeling submodes in the activity-based model using submodal skims produced by the transit network model or allowing the transit network model to select the submodes, and passing composite transit mode skims back to the activity-based model. If the first option is chosen, the network assignment model design must reflect any transit submodal detail included in the activity-based model mode choice component. Activity-based models usually include some additional submodal detail such as distinguishing local buses, premium buses, light rail, and commuter rail. Recent activity-based models have included enhancements that eliminate the need to generate separate transit choices by access mode (i.e., walk-access transit alternatives and drive-access alternatives), which simplifies the transit network assignment modeling process.

Active. Activity-based mode choice models are increasingly sensitive to active transportation models such as bicycling and walking. These sensitivities are predicated on having network assignment modeling processes that can produce enhanced active transportation network impedance measures. In the limited number of model systems that have incorporated enhanced active transportation sensitivities, the active transportation network assignment modeling tools used are distinct from the roadway and transit network assignment modeling tools.

2.2.3.2.4
Network Performance Measures

The roadway, transit, and active transportation network assignment models provide two primary types of information: network impedance measures and network flows. The network impedance measures are indicators of travel times, costs, distances, transfers, and boardings to and from different places. The network flows are indicators of total volumes on roadway, transit, and active transportation network links by mode and time of day. The information generated by the network assignment models to support activity-based models is generally consistent with the information generated to support traditional trip-based models, although there may be some additional segmentation or details generated.

2.2.3.3
Land Use Model Design Considerations

Although land use models have existed for years, in many ways land use modeling is still an emerging practice, and the underlying theories, policy sensitivities, and software capabilities vary widely by land use model. Some models may represent the actions of disaggregate households, individuals, firms, and developers; may incorporate more complex interactions within a regional economy; or may address long-term demographic changes. Transportation system performance indicators derived from activity-based or traditional travel demand models are key inputs to many land use models, and the locations of households and employment produced by a land use model are key inputs to activity-based and traditional travel demand models. The design of the land use model should consider the policy analysis requirements of an agency, the measures that can be produced as output from the activity-based model for input to the land use model, and the information required as input to the activity-based model that is produced by the land use model.

2.2.3.3.1

Policy Analysis Needs

The motivation for linking a travel demand model with a land use model is a recognition of the complex interactions between transportation system performance, land use, and regional economics (Johnston and McCoy 2006). An agency may desire to understand and evaluate the influences of transportation network performance and accessibility on land use development patterns as well as to understand how these land use development patterns, in turn, influence transportation system performance (Fehr & Peers 2007). Agencies have developed linked land use and travel demand models in order to represent the effects of land use planning and zoning constraints, to generate better long-range estimates for input to air quality and emissions models, to evaluate transit-oriented development scenarios, to provide new regional indicators such as housing affordability, and to address many other policy questions. Because of the tremendous variety of land use model structures, policy sensitivities, data requirements, and output capabilities, agencies must carefully consider which policy or analysis questions are of greatest interest or concern as well as what data are required for both model development and application.

2.2.3.3.2

Consistency with Other Model System Components

The earlier discussion of linkages between activity-based models and network assignment models proposed that the policy analysis capabilities of the overall model system are intrinsically related to the issue of maintaining consistency among model system components. The spatial and typological resolution of the land use model must inform and align with these same dimensions in the activity-based travel demand model. For example, if the activity-based demand model design uses information about the locations of housing and employment at the spatial resolution of TAZs, then ideally the land use model can produce housing and employment information at this same spatial resolution. Typologically, if the activity-based model requires as input information on employment by detailed industrial sector, then ideally the land use model should produce information using the same level of detail. However, the flow of information is not simply from the land use model into the activity-based model. Information on network performance output by the activity-based model and the network assignment model is also key input to a land use model. The land use model design must consider this information flow as well.

2.2.4

Model Integration Considerations

All activity-based model systems comprise a series of subcomponent models that exchange information in a systematic way to simulate an outcome. In addition to the issues of policy sensitivity and information consistency, agencies developing integrated models must also specifically consider how these different model components are configured to interact to achieve an overall solution. Some components may be interacted to equilibrate to a convergent solution or at least a stable solution, while other components may be interacted in a more path-dependent manner. This design must consider the interactions among subcomponents of the activity-based model system (such as the destination-choice models and mode choice models), the interactions between the activity-based model and the network assignment model, and the interactions between the linked activity/network assignment model and the land use model. Implementing an integrated model system involves configuring individual model components as well as configuring an overall model system flow.

2.2.4.1
Activity-Based Model Components Linkages

Activity-based models include a number of subcomponent models that interact and which are intended to provide behavioral realism by addressing numerous choice dimensions such as activity generation, destination choice, mode choice, and time-of-day choice. These subcomponent models are linked and executed in a manner that is intended to realistically represent the interaction of the various important dimensions of choice that individuals and households face in carrying out their daily activities and travel, as discussed in an earlier section (Bowman 1998). Typically a set of multinomial logit and nested logit choice models is estimated and implemented (Bowman 1998). The activity-based model components do not equilibrate explicitly, although measures of accessibility from lower models such as mode choice are fed back up to higher-level models such as automobile ownership. Most activity-based models are implemented using Monte Carlo simulation, which means that they are subject to some degree of simulation variation. In some regions, multiple activity-based model simulations are executed and averaged before being used as input to the network assignment model.

2.2.4.2
Activity-Based Model–Network Assignment Model Linkage

There is essentially a two-way exchange of information between the activity-based model and the network assignment model. In this exchange, the activity-based model provides estimates of travel demand that are used as input to the network assignment model. In turn, the network assignment model uses this travel demand information to generate estimates of network performance that are then used as input to the activity-based model. In order to facilitate this exchange of information between the activity-based model and the network assignment model, it is essential that there be some basic typological, spatial, and temporal consistency between the two models and their inputs and outputs. In addition to this data consistency, it is also essential that the model system incorporate a systematic means of iteratively executing the model system components in order to achieve a convergent, or at least a stable solution. These iterative feedback strategies vary in their complexity. Some employ averaging procedures in which network impedances, demand trip tables, or link volumes are averaged and delays recomputed. Rarely will naïve strategies, in which there is a direct exchange of information, result in a model system that achieves a stable or converged solution efficiently.

2.2.4.3
Activity-Based/Network Assignment Model–Land Use Model Linkage

If a regional agency has a land use model that it wishes to link with the integrated activity-based/network assignment model system, there is typically a two-way exchange of information between these model system components. The land use model often provides information on location of housing units and employment (typically with some detail by industrial sector), although in some cases land use model outputs may need to be translated into the basic units that are used as input to the activity-based models. The land use model may also be used to provide some estimates of long-term choices such as work locations. The integrated activity-based/network assignment model provides estimates of network impedances (travel times, costs, accessibility measures) that influence the location of housing and employment location choices predicted by the land use model. The predictions about locations are then used as input to the integrated activity-based/network assignment model. Unlike activity-based model/network assignment model linkage, which is configured to achieve either a convergent or stable solution, most integrated travel demand/land use models are path-dependent. There is no assumption of a convergent solution across time.

2.2.5
Performance Metrics

Activity-based model systems produce a broader range of performance metrics than traditional trip-based models. Activity-based models can provide more explanatory power to decision makers because they consider the interrelated nature of the activities and travel that individuals participate in, as well as how individuals within a household may coordinate their activities. These metrics can be more intuitive than those generated by a trip-based model, which can help facilitate communication with decision makers. Two main types of activity-based model system performance metrics can be considered: (1) metrics derived directly from the activity-based model component and (2) metrics derived from the network assignment model that is linked to the activity-based model component.

2.2.5.1
Activity-Based Model

A distinguishing feature of virtually all activity-based models is that the primary outputs from the model are estimates of travel demand in the form of disaggregate lists of individual tours and trips rather than aggregate trip tables. The list of tours and trips output from the activity-based model is essentially a travel diary that is similar to that provided by a detailed household travel survey, with full spatial and temporal consistency within each person's daily travel for all persons in the population. This disaggregate approach to representing travel choices provides the ability to track important measures, such as daily vehicle miles traveled (VMT) by household (Resource Systems Group 2012b), and to perform detailed and targeted equity analyses (Castiglione et al. 2006). Activity-based models can produce all the types of performance measures that are typically generated by trip-based model systems, such as mode shares, trip length frequency distributions, and trips. But activity-based models also have the ability to report a broader range of performance metrics. For example, activity-based models can produce detailed information about tour and trip making, capturing the trade-offs between making multiple tours or linking together activities into fewer tours but with more trips. Tour and trip rates can be calculated from activity-based model outputs rather than be used as fixed inputs to a trip-based generation model. As a result, an activity-based model can indicate how tour and trips rates may vary as a result of different levels of accessibility. Because activity-based models explicitly represent time-of-day choices, often using a temporal resolution of half-hours or even finer, measures of trip making by detailed time of day and activity durations can be easily generated.

2.2.5.2

Network Assignment Model

When linked with an activity-based model, static network assignment models can produce all the metrics that are typically produced when such network assignment models are linked with traditional trip-based models, such as link volumes and congested link travel times. Because activity-based models include explicit time-of-day choice models, the static network assignment models that are linked with activity-based travel models often include more time periods than those linked with trip-based models. In addition, because the disaggregate structure of the activity-based model system can more easily support additional market segmentation such as toll and value-of-time classes, static network assignment models linked to activity-based models may have additional assignment classes. The types of performance metrics that can be derived from a DTA model are considerably more extensive than the types that can be derived from a static assignment model. Their more detailed metrics may include system delays and volumes at fine-grained temporal intervals, queues, and other more detailed operational statistics.

2.2.5.3

Reporting and Visualization

As previously described, the disaggregate nature of the activity-based model facilitates more detailed reporting, such as the ability to support detailed analyses of effects on communities of concern. The primary output formats of activity-based model components are notably different from the output formats from traditional trip-based models. Whereas trip-based models employ matrices indexed by origin and destination zones as the primary format for travel demand data, activity-based models use lists of trips and tours. Use of tour and trip lists is more efficient than using matrices, because matrices frequently have large numbers of O-D pair cells that are either empty or have small fractional values of trips. In contrast, all the tour and trip lists generated by the activity-based model represent discrete tours and trips, with no inefficient storage devoted to representing no-demand or fractional-demand zone pairs. Tour and trip lists, as well as other disaggregate inputs and outputs from an activity-based model system, can easily be used to perform relational queries and provide flexible summaries that can easily be visualized using standard statistical and geographic information software.

2.2.5.4

Uncertainty Analysis

Many activity-based models employ Monte Carlo simulation in order to realize discrete outcomes from the probabilities predicted by the model components. Use of Monte Carlo simulation represents a fundamental shift in model implementation, from more deterministic approaches to forecasting demand, which employs fixed trip generation rates and applies mode shares to aggregate estimates of demand (Rasouli et al. 2012). When using Monte Carlo simulation, the same probability distributions may result in different outcomes based on the random numbers used to select choices. Therefore, an important consideration when applying activity-based models that employ Monte Carlo simulation is identifying the number of runs necessary to have confidence in the model outputs. Generally, more runs are required when seeking stability for rarer choices, such as information for smaller geographic areas or travel modes that compose a small market share. Empirical investigations of activity-based models have shown that all activity-based models were generally stable and that only a relatively small number of runs are typically required to address simulation error (Castiglione et al. 2003). In practice, only a few existing activity-based model systems explicitly address simulation variation.

2.3

DATA DEVELOPMENT

Activity-based model system development, like trip-based model development, requires assembling a diverse set of data. These data reflect travel behavior, regional demographics, land use, network configuration, and network performance, and many of the required data items must be available for all base-year, future-year, or alternative scenarios.

2.3.1

Activity-Based Model

The data required for development of the activity-based model system come from exogenous and endogenous sources. Exogenous information sources include items such as a household travel survey, base and future-year land use, and demographic and economic assumptions. Endogenous information sources include synthetic populations and network performance indicators generated by ancillary tools.

2.3.1.1

Survey

Depending on the specific development path pursued by an agency, household travel survey data collected to support trip-based model development can usually be used to support the estimation and calibration of the activity-based models. Additional analysis of the survey data is required to chain the trips into tours and to classify the sequence of tours into relevant descriptors of a full-day activity and travel pattern. Household survey data requirements are greater if new activity-based model components are to be estimated from the survey data, as is the case with upfront development or incremental implementation activity-based model development. Activity-based models incorporate a wider variety of sociodemographic variables and types of choice alternatives than trip-based models and, as a result, the sample size requirements tend to be larger (Bowman et al. 2013). A recent study of the transferability of activity-based model parameters (Bowman et al. 2013) concluded that a survey sample of at least 6,000 households may be adequate for a medium-to-large region. If an existing activity-based model is to be transferred and refined, the household survey data requirements may be less because the data will primarily be used to derive calibration targets. Another consideration is whether the activity-based model will consider joint travel across multiple members within a household. If so, it is essential that survey data contain complete data across all household members and that the survey successfully captures instances when household members traveled together and performed activities together.

2.3.1.2

Employment and Land Use

Land use data needed for activity-based models are similar to data needed for trip-based models, including the number of households, number of jobs by sector, and school enrollment by school level. If an activity-based model is specified to use the same or similar basic TAZ spatial units as a trip-based model, then there is little or no difference in the data required for an activity-based model as compared to a trip-based model. However, recent activity-based models have begun to use basic spatial units that are smaller than standard network TAZs, such as microzones and parcels. The use of parcels can entail some challenges, such as the ability to obtain accurate and up-to-date parcel data for all jurisdictions in a region, heterogeneity in how parcels are defined for different land uses, and challenges in specifying forecast year land use at the parcel level. The primary goal of including finer geographic detail is to model travel behavior at a level of detail closest to what decision makers experience, in order to avoid statistical aggregation bias in the models.

2.3.1.3

Synthetic Populations and Demographic

A key input to most activity-based models is a synthetic population that is used as the basis for forecasting the behavior of the households and persons in the modeled area. The specific data required to generate a synthetic population are influenced by the design of the synthetic population, which is itself reflective of the specification of the activity-based model system components. Although there are a variety of population synthesis approaches and tools and the data requirements of these tools vary, in general there are two primary data inputs to most synthetic population generation tools (Bowman et al. 2013).The first primary input is control data. These control data represent the attributes that are being explicitly accounted for in the generation of the synthetic population. The more attributes that are explicitly controlled for in the synthetic population design, the greater the data requirements in both the base year and for any alternative or horizon year. In addition, the control data information must be provided at relatively detailed geographic levels, and information at multiple geographic levels are often combined. These data are typically derived from Census data and from external demographic forecasts. These demographic forecasts may be based on growth factor models, land use models, or other methods. The second primary input is sample data. After the control data have been used to identify a multidimensional distribution of households and population at a fine-grained spatial level, it is necessary to then sample households and persons to create a list of households and persons that matches these distributions for input to the activity-based model system. In the United States, Census PUMS data are often used as the source for this sample, although it is also possible to use a regional household survey as the basis for the disaggregate sample (Resource Systems Group 2012d).

2.3.1.4

Network Performance Indicators

Network performance indicators, often called network skims, are a fundamental input to the activity-based model. Information about travel times, costs, and other metrics by time of day and market segment are used in both the estimation of activity-based model parameters, as well as in the application of the final activity-based model system. Network skims are endogenous to the overall activity-based model system because they are produced by the network assignment model component that is linked to the activity-based model component. The network skims should be carefully constructed to provide unbiased information required by the activity-based model component. For example, if the activity-based model component includes transit submode alternatives in the tour or trip mode choice components, then detailed information on transit network performance by submode should be generated by the network assignment model component. However, it is not always practical to ensure complete consistency between the network performance indicators and the activity-based model component structure. For example, the activity-based model component may use half-hours as the fundamental temporal unit, but it is typically not realistic for a static network assignment model to generate performance indicators at this resolution. Note that the network assignment procedures used in the model system are consistent with the network skimming procedures.

Accessibility indicators are also frequently included in activity-based model component specifications and must also be endogenously generated by the overall activity-based model system. These accessibility indicators represent the combined effects of land use and transportation system performance. Simple accessibility indicators include buffer measures, such as the number of jobs within a fixed travel time, while more complex accessibility indicators can include combination mode-choice and destination-choice logsums.

2.3.1.5

Calibration and Validation

Calibration refers to the process of adjusting model parameters to better match some base case observed conditions, while model validation involves the application of the calibrated model and the comparison of the results to observed data that have not been used in the model estimation or calibration process. Each component of the activity-based model system is individually evaluated relative to observed data source. Automobile ownership model results are usually compared to household survey data or to Census data. Activity generation and time-of-day model results are initially evaluated relative to targets derived from the household survey, although these targets are sometimes adjusted to be consistent with observed traffic and transit counts by time of day. Work location choice models may be compared to either Census journey-to-work data or to household survey data, while the destination-choice models for all other activity purposes are compared to household survey information. Mode choice results are evaluated relative to calibration targets derived from the household survey but may also be adjusted in order to ensure consistency with observed traffic and transit counts. The network assignment model component and overall model system calibration and validation area primarily evaluated by comparing the estimated traffic and transit volumes to observed count data. Speeds may also be evaluated, although static assignment models often produce unreliable speed estimates. Comparisons to regional VMT statistics derived from highway monitoring systems as well as other measures, such as transfer rates derived from transit on-board surveys, are also often used.

2.3.1.6

Base Year Versus Forecast Year

In order for activity-based models to generate estimates of future travel demand, future-year inputs to the model are required. Most critically, these inputs include future land use, demographic, and economic assumptions, as well as future network configuration assumptions. The availability of future input assumptions should be a key consideration when designing the model system specifications. For example, if detailed estimates of employment by industrial sector are unavailable for forecast years, then it may be advisable to employ a simpler destination-choice specification that reflects only the available data.

2.3.2

Network Assignment Model

The data required for development of the network assignment model are determined by the overall model system design and are primarily derived from existing exogenous data sources. Information about market segmentation such as modal detail as well as temporal detail significantly influences the type of information required to build the network assignment model. There are many robust sources for information for building network assignment model inputs, although extensive checking and cleaning of the network are often required to ensure the integrity of the network.

2.4

IMPLEMENTATION

2.4.1

Estimation

Estimating the component models for an activity-based model system involves using local data to identify the variables that are most important to activity and travel decision making and quantifying the relative importance of these variables. In addition to processing survey data and attaching relevant data from network skim matrices and land use data, which are required whether or not the implementation involves model estimation, it includes specifying the model utility functions and alternative availability constraints in a model estimation software package, and then carrying out the estimation in an iterative process. This process requires expert judgment to determine what variables to include and sometimes involves constraining some coefficients to typical values in cases where the data for estimation are inadequate. The most typical example of this is in the travel time and cost coefficients of mode choice models, where the data for estimation do not give reasonable results in terms of imputed time and cost trade-offs (value of time). The need to constrain time and cost coefficients often arises because there are very few non-automobile observations in the data, so there is very little observed time and cost trading between modes. In such cases, one may use coefficients from previously revealed preference and stated preference models or from project documents such as the SHRP 2 C04 report (Parsons Brinckerhoff et al. 2013).

The estimation task has typically been carried out by consultants rather than by the regional planning agency staff. Recently, some of the activity-based model software packages have been designed to make it easier to modify and re-estimate activity-based component models when starting from a known model specification (e.g., from another region) rather than when starting from scratch. So, rather than simply transferring another model and calibrating a few specific variables to observed data (a process discussed in Section 2.4.3), it may be possible for local agency staff to re-estimate all parameters of the model system based on local survey data, provided that the data are sufficient in quality and sample size. That process would also typically benefit from some guidance from outside consultants, unless the agency has the required expertise in-house.

2.4.1.1

Data Requirements and Preparation

The data required to estimate the model components are, for the most part, the same as required to apply the model in the base year, including

- A land use database with all variables that will be used in model, at the level of spatial detail desired for the ultimate model (TAZ, microzone, or parcel);
- TAZ-to-TAZ network skim matrices for all travel time and cost variables, for all modes and time periods that will be used in the model;
- Additional data for distance along an all-streets network for short trips, if that is included in the model design; and
- Data from a household travel diary (or wearable GPS-based) survey, containing all trips and activities for all household members for at least one full day.

The last data component, the survey, is the only one that is not used in model application, but it should contain data on all of the important household and person characteristics that will be included in the synthetic population to which the models will eventually be applied. The survey data, when expanded to represent the full population, are also typically used in the later model calibration stage.

The data preparation stage typically requires processing the survey data to create files at all the different levels at which the model will be applied:

- The household and person levels (to model longer-term and mobility choices);
- The day level (to model tour and trip generation patterns at the full-day level);
- The tour level (to model tour-level choices); and
- The trip level.

Many survey data sets already are structured into household-level, person-level, and trip-level records, so two of the main steps in the data processing are tour formation and day-pattern formation. Tour formation is the process of combining home-based and work-based trip chains into tours and writing records with the relevant tour attributes. Day-pattern formation is the process of combining information on all the tours made by persons and households across the day, to be classified into types of full-day activity patterns, depending on the model design.

There are no standard procedures for tour formation or day-pattern formation, as they match the model design, although the hierarchies used across travel modes (to determine the main mode of a tour) and activity purposes (to determine the primary destination of a tour and/or the primary tour of the day) tend to be quite similar across different model designs. The most complex logic tends to arise in model systems that explicitly model joint tours and joint half-tours across household members, as this adds another layer of logic that must be included in the data processing, and the logic can be very complex in survey datasets where the travel records of household members who actually travel together do not match up very well, leaving the analyst to do a fair amount of guesswork regarding whether household members actually performed certain trips and activities together or not.

2.4.1.2
Model Design and Testing

The specification of the component models of an activity-based model system is, along with the overall model system structure, of fundamental importance in determining how the model system performs in forecasting. A model component's specification includes its structure (e.g., alternatives and nesting), as well as the variables and coefficients included in each alternative's utility functions. If a model specification lacks aspects of how conditions affect behavior, or if it specifies them incorrectly, then the model will not behave correctly when those conditions change; rather, it will either not respond at all or it will respond with bias. The ability to correctly specify a model is limited by the quantity and quality of the data, as well as by the modeler's understanding of the behavior being modeled and model development expertise. On the one hand, it is easy to overspecify a model through a process known as data mining, which tries to find all possible statistically significant effects and ends up including effects that represent idiosyncrasies in an imperfect sample. On the other hand, it is easy to underspecify a model by excluding all coefficients that fail a certain significance test, thereby excluding an important variable—one that should be there but is insignificant merely because of a small data sample—and causing the resulting model to be biased. In practice, there are many possible ways to specify a model, and no two modelers do it the same way. It is important that the modelers responsible for specifying and estimating models have a solid understanding of model development theory and well-developed skills in model development practice.

2.4.2
Software Development

There are currently three or four software platforms that are used for the large majority of activity-based models implemented in the United States. These have been developed by the consultants who have created the original models and then adapted and improved over time as they are implemented for new regions. The software field for activity-based models may change substantially in the future, however, as the market for activity-based models matures.

2.4.2.1

Components

Not surprisingly, the components of the software system tend to mirror the components of the model system itself. Typically, a software platform uses objected oriented code (e.g., in C#, Java, or Python) to create general model classes that can then be customized to accommodate each separate model component.

2.4.2.2

Process Flow

The most complex part of the software design tends not to be in the programming of each separate model component but in how the information is passed from each model to the next, and from the user to the model and back to the user again. This is typically done in the context of an iterative feedback loop with network assignment software, so that the final levels of travel demand and congestion will be consistent between the activity-based model outcomes and the network assignment model outcomes, at least for the highway assignment.

When considering software implementations, the main factors that a potential user may be most concerned with are

- Model documentation and clarity: How easy is it to understand how the various models are coded and how the data flow through the model?
- Front-end data input: How easy is it to specify and create the specific types of data that go into the model and to detect errors in the data before they influence the model results?
- Code efficiency: What are the memory and hardware requirements for using the software, and how fast will the model run on various types of hardware?
- Back-end data output: Are there ways of analyzing and visualizing the data that are produced from the model system (other than via the network assignment model software package that the system is integrated with)?
- Configurability: How difficult is it to turn certain features in the model on or off, or to change certain aspects of the model such as the number of modes used, the number and definition of time periods used, and so forth?
- Re-estimation and calibration: Does the software platform contain features that automate some of the work necessary to re-estimate models on new survey data, or to calibrate the model to match external data?

2.4.3

Transferability

Given the extensive work involved in designing a new activity-based model system, estimating the component models, and creating the software to implement the models, it can be expected that most activity-based models implemented in the future will be models transferred from another region, starting with the model design, software platform, and model coefficients from that previous model and then re-estimating and/or re-calibrating some of the coefficients. In general, one expects more behaviorally detailed models to be more transferable across regions than very simple models, because many of the variables that are different across regions—different sociodemographics, different land use patterns, different mode availability, and more—have been incorporated more fully into explicitly modeled effects rather than left as part of the error components that are captured in alternative-specific constants and the overall scale of the coefficients.

A recent Federal Highway Administration (FHWA) study on model transferability (Bowman et al. 2013) recommends full re-estimation may only be beneficial in cases where there are new survey data available with a very substantial sample size. Otherwise, it is likely to be more accurate to use the coefficients from a model system estimated on a large survey in a comparable region elsewhere, and use the local survey data to simply recalibrate certain key model coefficients such as alternative specific constants.

2.4.4
Synthetic Population

Earlier sections have identified a synthetic population as a key input to most activity-based models. This synthetic population is used as the basis for forecasting the behavior of the households and persons in the modeled area. The synthetic population process uses both aggregate information about the distributions of households and persons along key demographic dimensions, as well as detailed disaggregate household and person records, in order to create a full enumeration of regional households and persons. In order to implement a synthetic population process, it is necessary to establish a population synthesis design that outlines the demographic attributes that will be controlled for, to gather the information required to implement the population synthesis, and to validate that the process is producing reasonable results.

2.4.4.1
Design and Controls

The specific data required to generate a synthetic population are influenced by the design of the synthetic population, which is itself reflective of the specification of the activity-based model system components. The first input is marginal "control data," and the second input is "sample data."

2.4.4.1.1
Marginals

The control data represent the attributes that are being explicitly accounted for in the generation of the synthetic population. The more attributes that are explicitly controlled for in the synthetic population design, the greater the data requirements in both the base year and for any alternative or horizon year. In addition, the control data information must be provided at relatively detailed geographic levels, and information at multiple geographic levels are often combined. The types of marginal controls used for generating synthetic populations, and for which base-year data and future-year data should be generated, often include attributes such as household size, household income, and household workers. A more detailed list can be found in the earlier synthetic population discussion.

Data sources for marginal controls may come from a variety of sources. Ideally, this information is derived from a demographic forecasting model or method that can provide base-year and future-year distributions for all of the marginal controls. However, it is more common that agencies may have information on only a limited number of these marginal controls. In these cases, base-year distributions may be assumed to remain fixed, although such an assumption will influence the distribution of other marginal controls.

2.4.4.1.2
Samples

The second data input is sample data. After the control data have been used to define a multidimensional distribution of households and population at a fine-grained spatial level, it is necessary to then sample households and persons to create a list of households and persons that matches these distributions for input to the activity-based model system. The samples used to generate the synthetic population must have the detailed information corresponding to the marginal controls.

Data sources for samples are typically more limited than sources for marginal controls, because these samples ideally contain detailed information. The samples may include both controlled for and uncontrolled for attributes. In the United States, Census PUMS data are often used as the source for this sample, although it is also possible to use a regional household survey as the basis for the disaggregate sample.

2.4.5
Feedback, Convergence, Equilibration

Linked demand-and-supply model systems such as activity-based model systems typically include processes of iterative feedback. These feedback processes are implemented in the network assignment model and between the network assignment model and the activity-based model components. Iterative feedback is used to ensure that the models are achieving convergence to an equilibrium, or at least a stable condition. Convergence is important within the context of activity-based model systems because it provides confidence in the integrity of the model system and helps ensure that the model will be a useful analytic tool.

2.4.5.1
Network Assignment Model Convergence

In the context of an activity-based model system, an essential precondition for pursuing overall model system convergence is establishing network assignment convergence. In static network assignment models, convergence to a user equilibrium condition is typically pursued. User equilibrium is described as a condition when travelers cannot reduce their travel costs by unilaterally changing their route. There are well-established procedures for pursuing convergence to a user equilibrium condition. As convergence is approached, estimated link volumes and impedances stabilize, as do the aggregate network impedance skims that are produced by the network assignment model component and input to the activity-based model component. Although less stringent convergence may be acceptable in early model system iterations, later model system iterations should incorporate stricter network convergence criteria.

2.4.5.2
Linked Activity-Based Network Assignment Model System Convergence

When convergence is achieved, the network performance measures that are used as input to key activity-based model components are consistent with the network performance measures output by the network assignment model when the activity-based demand is assigned. This consistency is important for establishing that the activity-based model system will be a useful tool for analysis. The stability of model outputs is essential to support planning and engineering analyses, and changes to demand or supply should lead to reasonable changes in model outputs.

2.4.6
Integration with Auxiliary Model Components

Activity-based models typically provide estimates of weekday travel demand made by regional residents when traveling within the region, but this demand makes up only a portion of the total travel demand that uses regional transportation networks. In addition to the internal demand generated by the activity-based model system, the overall model system also must incorporate auxiliary demand, such as trips in which one or both trip ends is outside the regional (often referred to as external trips), truck and other commercial demand trips, trips made by nonresidents or visitors traveling within the region, and trips associated with special purposes or events. Often, this auxiliary demand is represented in a region’s existing trip-based model system but must be refined or enhanced to facilitate integration with the more detailed demand generated by the activity-based model. Note that estimates of auxiliary demand are combined with the demand estimates generated by the core activity-based model components prior to the network assignment stage in the overall model system.

2.4.6.1

Internal-External and External-External Travel

Internal-external and external-external demand represents travel in which one or both of the trip ends is outside the modeled area. In activity-based model systems, this travel demand is often generated from two sources. Most of this demand is generated by separate internal-external models. These models provide estimates of flows to and from critical external stations that are located at the boundaries of the modeled area. These estimates may be derived from data such as existing traffic counts or from estimates of base-year and future-year traffic volumes at these gateways. The level of typological segmentation can vary, with some internal-external models providing detailed estimates of flows by vehicle occupancy class and truck type and others providing aggregate estimates of total vehicle flows. In either case, these segments must be aligned with the classes used in the network assignment model. Also, it should be noted that in some activity-based model systems at least a portion of the internal-external demand can be generated by the activity-based model, which may predict which regional residents are commuting outside the modeled area or which regional jobs may be filled by people commuting in from outside the modeled area.

2.4.6.2

Freight and Commercial Vehicles

Modeling freight and commercial vehicle travel demand is an important component of the overall model system, as these vehicles can represent between 10% and 20% of the volumes on regional roadway networks. Precise estimates are difficult to obtain because vehicles being used for commercial purposes are not always identifiable. Some regional model systems include components that distinguish between freight and nonfreight (commercial) vehicle movements, while others use a set of more generic truck classes, often segmented by size. More advanced practice includes the development of tour-based models, as well as the linkages between freight demand and regional land use models. When integrating estimates of freight and commercial vehicle travel demand, agencies should pay particular attention to the temporal aspect of this demand, as the timing of this demand is often different from the diurnal pattern observed with passenger travel demand.

2.4.6.3

Special Purpose Models

In addition to internal-external travel demand and freight and commercial travel demand, consideration should be given to other unique travel markets that may affect overall travel demand and network performance. Many regions have developed airport models, which predict travel demand associated with nonregional resident visitors arriving at the airport and accessing regional destinations, as well as regional residents traveling to the airport to depart for nonregional destinations. Some regions that have significant numbers of tourists have implemented visitor models that estimate the travel demand of visitors to the region, using information on hotel room locations and key regional visitor destinations. Other special purpose models have included border crossing models and models that generate demand associated with special events such as sports competitions. In general, the demand from these special purpose models can be easily integrated in the activity-based model system, provided that attention is paid to ensure temporal, typological, and spatial consistency. The regional household survey typically does not include sufficient information about these special purpose markets, so additional data collections are often required.

2.4.7
Calibration and Validation

Calibration refers to the process of adjusting model parameters in order to better match some base case observed conditions. Model validation involves the application of the calibrated model and the comparison of the results to observed data that have not been used in the model estimation or calibration process. Adjustments to other model assumptions and inputs are also often made during the calibration and validation process (Cambridge Systematics 2010). It has been argued that it is necessary to be able to match base conditions before using a model for any future-year application (Cambridge Systematics 2010).

Calibration and validation of activity-based models bears some similarities to the calibration and validation of traditional trip-based model systems in that the individual model subcomponents are individually calibrated, and then the overall model system is validated. Activity-based model calibration and validation efforts are different from trip-based model efforts primarily because there are more component models to evaluate and adjust. However, the overall level of calibration and validation effort for activity-based models is usually not significantly different from trip-based models, because fewer adjustments to any individual model component are typically required.

The calibration and validation process should be systematic. A model calibration and validation plan should ideally be established early in the model development process, and required data identified and collected. Each component of the activity-based model, as well as the network assignment model, is then evaluated and adjusted as necessary, ultimately leading to the validation of the overall integrated model system. For each model system component, key metrics are identified, and comparisons between model estimates and observed data are made, which inform the adjustment of model parameters. The strategies used to systematically adjust model parameters vary by model component. Some components such as automobile availability models may be calibrated by simply adjusting alternative specific constants based on the ratio between observed and estimated values, while other components such as tour destination-choice models may require more complex calibration strategies in order to ensure that tour length frequency distributions are reasonable. Calibration and validation of an activity-based model system is an iterative process due to the activity-based model components being interrelated. Adjustments to upstream model components affect downstream model components and, ultimately, the network performance measures. These network performance measures, in turn, affect the upstream model components, necessitating the re-evaluation and adjustment of all model component calibrations until no significant changes occur. Finally, the calibration and validation process should be documented, identifying adjustments made to model parameters and assumptions and summarizing final results (Cambridge Systematics 2010).

2.4.7.1
Activity-Based Model

Model calibration and validation efforts usually begin after the entire model system has been implemented, including any estimation or transfer of model coefficients, development of any auxiliary model components, and completion of any software code or scripts required to implement model components or to facilitate the linkage with the network assignment models or to control the overall model system flow.

2.4.7.1.1
Components

The results of each individual component of the activity-based model system are compared to observed data in order to ensure that all components are producing reasonable results.

Automobile ownership model results are usually compared to household survey data or U.S. Census data. Activity generation and time-of-day model results are initially evaluated relative to targets derived from the household survey, although these targets are sometimes adjusted to be consistent with observed traffic and transit counts by time of day. It is not uncommon for household surveys to underreport nonmandatory activities or to miss short trips, which often occur during off-peak travel times. Work location choice models may be compared to either Census journey-to-work data or to household survey data, while the destination-choice models for all other activity purposes are compared to household survey information. Mode choice results are evaluated relative to calibration targets derived from the household survey, but may also be adjusted in order to ensure consistency with observed traffic and transit counts.

2.4.7.1.2
Model System

The overall model system is primarily evaluated by comparing the estimated traffic and transit volumes to observed vehicle count data. Speeds also may be evaluated, although static network assignment models, which are the primary type of network assignment model linked to activity-based models, often produce unreliable speed estimates. Comparisons to regional VMT statistics also are often used.

2.4.7.2
Network Assignment Model

The calibration and validation of the network assignment model component are performed in conjunction with the calibration of the activity-based model component because of the linked nature of these two primary model system components. However, considerable additional effort is typically expended in the final network assignment model calibration and validation to ensure that the network assignment model results look reasonable not only at aggregate regional levels, but also at the level of detailed individual links, and that differences in volumes between scenarios are also reasonable. Link volumes by time of day are one of the main metrics produced by the model system of interest to analysts and decision makers.

2.4.7.2.1
Static Network Assignment

Two types of modifications are usually performed as part of the calibration and validation of static network assignment models: (1) adjustments to the volume delay functions that control the relationship between forecast volumes and speeds and (2) adjustments to network assumptions. These adjustments are analogous to those that would be made if the static network assignment model were linked to a trip-based model. Volume delay functions are often stratified by facility type (e.g., freeways, major arterials, minor arterials, and collectors), and the volume delay function parameters are adjusted until a reasonable distribution of flows by facility type is achieved. Network assumptions, such as hourly per lane capacities, freeflow speeds, network loading points, and transit transfer penalties, also are adjusted as necessary to achieve reasonable estimates of traffic and transit volumes. As with trip-based models, making fine-grained adjustments to network assumptions in an activity-based model system can be time-consuming.

2.4.7.2.2
Dynamic Network Assignment

Although dynamic network assignment models, often referred to as DTA models, have begun to be more widely used in practice in the past decade, there are very few examples of the integration of dynamic network assignment models with activity-based models. The overall process for calibration and validation of a dynamic network assignment model is in many ways similar to the process for static network assignment model, involving the adjustment of model parameters and input assumptions. However, calibration of a dynamic network assignment model is significantly more involved because of the additional details included in the model, such as explicit inclusion of traffic flow models and the vastly more detailed network input assumptions that affect results such as lane configurations and signal timings. The inherent stochasticity of dynamic network assignment models, which may represent network performance more realistically, also can lengthen model calibration and validation efforts.

2.4.7.3
Sensitivity Testing

Sensitivity testing should be considered an intrinsic part of the model calibration and validation process. Matching observed base conditions is necessary, but not sufficient, to ensure that the model will provide reasonable results when used to evaluate a future-year or alternative scenario. It is possible that adjustments made to match observed base conditions may, in fact, distort and compromise the sensitivity of the model. Sensitivity testing should not only confirm the model's sensitivity to changes in policy and investment inputs but also confirm that these changes are reasonably consistent with real-world outcomes.

2.4.8
Application

Model application refers to the use of the model to simulate alternative scenarios and to produce meaningful performance metrics in a timely manner that can inform decision making. Model application requires software that has been developed to implement the model design and the availability of computing resources or hardware that can efficiently run the model software. Model application also involves extracting performance metrics from the model system and evaluating whether these measures are reasonable.

2.4.8.1
Hardware and Software

Hardware and software issues need to be considered simultaneously in model design, implementation, and application. The model design has hardware implications, such as the amount of memory that is required to ensure that data required for model application can be accessed quickly or the number of processors that are required in order to ensure that model run times are reasonable. Distributed processing is a key issue. The software and hardware should be implemented in such a way as to use multiple processing cores on a single server or to provide the ability to exploit processors across a cluster of multiple machines.

Few of the general purpose, commercial travel demand forecasting model packages that are widely used by agencies are able to efficiently implement core activity-based model components and, as a result, much of the software that implements activity-based models are custom products created by activity-based model system developers. In many cases, this software is governed by open source licenses, which, in theory, allows others to acquire, modify, and run the software. Until now, no one other than the original software developers has managed activity-based model code (Resource Systems Group 2012a). However, some agencies have recently initiated collaborative, activity-based model software development efforts.

Although it is general purpose software, commercial travel demand modeling software has not been widely used to implement the core activity-based model components. This type of software is usually used in the overall model system typically to provide roadway and transit network assignment capabilities and to perform associated matrix manipulations. The core activity-based model components and the commercial travel demand modeling software should ideally be implemented to allow for the efficient exchange of network skim information from the commercial package to the activity-based model and exchange of demand information from the activity-based model to the commercial package.

2.4.8.1.1

Configuration Options

Activity-based model systems should provide the ability to configure individual model components as well as the overall model system. This ability to configure allows for the most efficient use of available computing resources and ensures that the model sensitivities can be fully exploited. Most activity-based model system components require some degree of configuration. For example, it may not be necessary to run a full sample of all households and people in the synthetic population in order to analyze every type of alternative scenario, or on all iterations within the equilibrating model system, so the ability to flexibly configure the sample rate is important.

Activity-based model components exchange information with network assignment models in a systematic way to create an overall model system that produces equilibrated solutions. Users may want to configure this overall model system equilibration process in order to achieve different levels of equilibration or stability or to ensure reasonable overall model system run times. It can also be useful to be able to configure or specify inputs associated with different alternative scenarios.

2.4.8.1.2

Flexibility and Extensibility

Flexibility is a desirable quality in the software design. This flexibility can encompass many aspects of the model and software design. At the most basic level, model component software should allow users to update model assumptions that may need to be revised without fundamentally altering the underlying functionality of the model components or making changes to the underlying software code base, such as key coefficients and calibration constants. An intermediate level of flexibility may provide model users with the ability to redefine more fundamental aspects of the model system design, also without making changes to the underlying software code base. For example, some activity-based model system software has been designed to allow users to redefine the alternatives that are included in a model, or to revise the manner in which network skims are used. Advanced flexibility in software involves designing an overall model software architecture that allows the software code base to be easily extended to include new types of models or data structures.

2.4.8.1.3

Run Times

Model run time is an important issue. Activity-based model software has matured significantly in the past 15 years, and the availability of inexpensive distributed and multithreaded computing resources has reduced activity-based model run times significantly. However, model run times may still vary depending on the specific design aspects of the model components, the size of the population being simulated, and the extent of computing resources available. In addition, overall model system run times may be significantly affected by the run times associated with the network supply component. Run times for the network assignment model components linked with activity-based models may be longer because of the inclusion of additional temporal, modal, or typological detail in the network assignment and skimming procedures.

Long model system run times can limit the ability of agencies to evaluate multiple alternatives and to resolve any inconsistencies or errors that are discovered in the course of performing model runs. Long model system run times also may result in longer model development, calibration and validation times, as model development requires the iterative running and re-running of the model components and the overall model system. Model run times are typically reduced by providing additional computing resources and through software engineering and optimization. Consideration should be given not only to the model run times but also to the entire time required for the analysis process. A model that runs quickly may not be helpful if it takes significant amounts of time and effort to extract meaningful statistics.

2.4.8.1.4
Software Transferability

Cost, schedule, and data limitations are often cited as factors in developing activity-based modeling systems (Picado 2013, Resource Systems Group et al. 2014). Transferring activity-based model software from one region to another can be an effective means of addressing these concerns. There are numerous examples of activity-based model software being successfully transferred from one region to another. This transferability has taken different forms. In some cases, the software and coefficients have been transferred from one region and adapted for another. This can involve making minor adjustments to the activity-based model software and undertaking coefficient recalibration and revalidation effort (Resource Systems Group et al. 2014) to reflect local conditions. In other instances, more substantive changes have been made to the model specifications and software code in order to provide enhanced model capabilities and to be more sensitive to critical local concerns (Picado 2013).

2.4.8.2
Data Extraction, Analysis, and Interpretation

Activity-based model systems produce far more detailed and voluminous outputs than a traditional trip-based model. Although these detailed outputs facilitate more targeted analyses, they also require more skills to identify and extract relevant measures. Simple spreadsheet-based methods used for trip-based model analyses are insufficient for analyzing the information-rich outputs of activity-based models. Many agencies store model output in relational databases or highly compressed and efficient data structures and then use a variety of off-the-shelf tools such as GIS software, as well as custom analysis tools, to summarize and interpret model outputs. It should be noted that agency staff may spend significant amounts of time analyzing model outputs because activity-based models can support many dimensions of analysis.

Some agencies have implemented more complex systems to view and analyze activity-based model outputs; these systems are made up of a database component and a visualization and query interface. These interfaces may provide the opportunity to view either predefined analyses or perform custom queries. Data visualizations may include traditional tables, charts, and maps, as well as other unique representations that exploit the detailed activity-based model outputs (Atlanta Regional Commission 2010). One powerful data visualization technique is to simultaneously illustrate multiple dimensions of model outputs. Agencies may also consider means of facilitating model analysis and disseminating model outputs through the use of Internet-based reporting and visualization tools. At a minimum, agencies should develop standard outputs that allow agency staff to quickly determine if model results appear reasonable before performing any more detailed analysis.

2.4.8.3
Simulation Variation

Many activity-based models employ Monte Carlo simulation in order to realize discrete outcomes from the probabilities predicted by the model components. When using Monte Carlo simulation, the same probability distributions may result in different outcomes based on the random numbers used to simulate choices. In application, one important issue is controlling for how the random number seeds and sequences are used to choose outcomes. A second important issue is exploiting this feature to provide more robust performance indicators. A third important issue is how these performance indicators are transmitted and explained to decision makers.

The ability to control the random seeds and sequences in model application is useful because it provides confidence that the model implementation runs consistently and that it produces the same outputs, given the same inputs. Once the random numbers are controlled, users are able to exploit this model feature to run the model system more efficiently and to produce better performance measures. Activity-based models should be run multiple times in order to account for simulation variation (also referred to as simulation error). The disaggregate outputs can be used to produce distributions and confidence intervals for core activity-based model measures, in addition to average values that can be used as inputs to traditional static assignment models. If regional-scale DTA models are adopted, use of disaggregate outputs to produce multiple network simulations may be desirable. Empirical testing of the number of runs required to produce results with confidence is also desirable, although only a limited number of regions have implemented this in practice. The number of runs is dependent on the spatial, temporal, or typological detail that is of interest. Analysis of smaller spatial, temporal, or typological segments requires more runs.

Traditional trip-based models do not produce distributions of outcomes given fixed inputs. Decision makers are most familiar with the single-point forecasts generated by these models. Thus, the communication and interpretation of activity-based models that include ranges of potential outcomes present new opportunities and challenges. Distributions or ranges of outcomes provide the advantage of illustrating the existence of uncertainty around different outcomes, but if not properly presented, may be misinterpreted by decision makers. However, it should be noted that these distributions of outcomes, while informative, are also contingent on the assumption that decision-making processes and elasticities remain fixed over time, that future land use and transportation inputs are known with certainty, and a number of other dynamic factors are unchanged over time. All of these assumptions may be unreasonable.

2.4.8.4

Reasonableness Checks

Reasonableness checks are an important practical consideration. Travel patterns, whether for a single scenario or when comparing across scenarios, should be plausible. Reasonableness checks for activity-based models may include an analysis of activity durations by purpose, the amount of time spent in out-of-home activities, and the share of people who choose to make no travel, either overall or for a particular purpose (Resource Systems Group 2012b). Additional checks may include an analysis of tours by activity purpose, stop generation rates, and possibly, joint activity generation (Cambridge Systematics 2010). The tour-based nature of activity-based models necessitates the review of tour-level statistics, such as tour mode choice and tour destination-choice, and the inclusion of explicit time-of-day models requires the review of temporal measures. Although these measures are considered in the calibration and validation process, subjecting the model system to a set of sensitivity tests and evaluating these metrics can ensure confidence that the model responds appropriately to investment and policy alternatives.

In addition to the reasonableness checks that are unique to activity-based models, there are additional checks that are similar to those performed for trip-based models, such as evaluations of trip length frequency distributions, trip flows by geography, and trip mode choices. In addition, because, at present, activity-based models are typically linked to static network assignment models, many of the reasonable checks appropriate to trip-based static network assignment models are equally applicable to static network assignment models linked to activity-based models. These checks may include assessments of regional traffic volume errors, regional VMT, transit boardings and transfer rates, screenline and cordon volumes, and many other measures (Cambridge Systematics 2010).

2.4.8.5
Logging and Archiving

To ensure the defensibility of model system results, it is essential that the assumptions used to generate alternative scenario results be, at a minimum, logged, documented, and traceable. Version control of networks, inputs, control files, parameters, and software executables is mandatory. The model results for every alternative scenario evaluated using a model system are the result of a specific set of inputs to the model system, the versions of the model system component software, scripts, configurations, and potentially even the computing resources on which the model run was performed. Alternative scenario results should generally be archived to allow for a more detailed review of these assumptions, if necessary. Archiving runs requires that agencies establish protocols for which alternative scenario model runs should be stored, how long these runs should be maintained, and what media should be used to store these runs. Model applications often result in the proliferation of model runs as alternative scenarios are tested and refined, and activity-based model inputs and outputs can require significant amounts of data storage capacity. Ideally, model results could be duplicated by third parties running the model system at a later date or on different computing resources, although practically this can be challenging because of the dynamic evolution of hardware and software external to the model system, such as hardware operating systems.

2.5
ADMINISTRATION AND MAINTENANCE

2.5.1
Inputs

Activity-based models require a rich set of input information, including detailed information and input assumptions about regional sociodemographics, employment, multimodal transportation networks, urban form, and other key influences on travel behavior. These input assumptions are developed for both the base year used for model calibration and validation, as well as for all required forecast years. Both the base-year assumptions and future-year assumptions are dynamic. Over time, it is necessary to update base-year model assumptions to ensure that they reflect the most up-to-date information about existing conditions. It is also necessary to update future-year model assumptions to reflect changing expectations of these inputs.

2.5.2
Computing Platform

An important challenge to agencies developing activity-based models is how to maximize the opportunities provided by recent hardware and software improvements, such as distributed and multithreaded software and the availability of large numbers of computing processors, while minimizing the expenses and risks associated with purchasing and maintaining these resources in-house. Broadly speaking, there are two main approaches that agencies may consider. They are acquiring and maintaining local computing resources, or using remote computing resources. At present, the majority of agencies are using local resources, although it seems very likely that in the near future many agencies will start to employ remote computing resources.

Local computing resources are typically in-house servers or workstations. Use of local resources provides agencies with complete control over software and hardware and may avoid many concerns about data control and data transfer issues. However, maintaining local computing resources requires agencies to make up-front as well as ongoing investments in computing hardware and maintenance. Remote computing resources are often either externally managed servers, or "cloud computing" resources. If the activity-based model software has been designed to efficiently use large numbers of processors, then either of these may offer compelling performance improvements. In addition, both remote computing options can reduce the burden on agencies to make ongoing investments in hardware and maintenance, although any savings would be balanced against costs for the use of these remote resources. One potential drawback of these servers is that they may offer less control if additional commercially licensed software is required for model system application.

2.5.3

Licensing

The core components of many activity-based model systems in the United States are implemented using custom software. Typically, this software is not commercially licensed but rather is governed by open source agreements, and long-term software maintenance and enhancement is often funded on an as-needed basis through on-call or project-specific consultant contracts.

These core activity-based components are used in conjunction with network assignment model components to make up the overall equilibrating model system. In all activity-based models systems currently used by agencies in the United States, the network assignment model component employs static assignment methods implemented using commercially licensed travel demand forecasting software. In addition, these licensed travel demand forecasting software packages are also typically used to perform network-related data processing, such as manipulating matrices of travel demand input to the static assignment procedures or generating matrices of network performance skims for input to the activity-based components. These licensed software packages may also provide other capabilities, such as distributed computing capabilities or optional DTA capabilities. Although some advanced DTA software is available on an open source basis, agencies should expect that licensing of some commercial travel demand forecasting software will be a necessary to complement the activity-based model components.

2.5.4

Schedule

Inevitably, as advanced model systems have become more widely adopted, the amount of time required for model development has shortened. This shortening of model development time is likely the result of the increasing maturity of the software used to implement these models, the broader use of transferred models, the improved knowledge and sophistication of both agency staff and consultants, and the ability to acquire and manipulate data and perform model runs more quickly. This trend can be observed across all types of advanced models, including activity-based model systems, DTA models, and land use models.

However, there are still aspects of model development that are largely insensitive to these changes. For example, the amount of time required to collect new household survey data in order to estimate region-specific models can still be significant, although automated data processing and analysis has reduced these schedules as well. Agencies must carefully consider the schedule trade-offs between developing new capabilities or region-specific models, project or analysis schedule constraints, and agency staff and resource availability.

New activity-based models have been implemented in as little as 6 to 9 months when the model structure, software, and coefficients have been transferred from one region to another (Resource Systems Group et al. 2014). The main tasks in these types of simple model transfer efforts are developing the input data from existing sources, and calibrating and validating the model to regional conditions. More involved activity-based model development efforts can often take longer, however, especially if new capabilities are being developed or if additional data collection is involved. For example, the development of a new activity-based model system with enhanced capabilities for a large region may easily take 4 years and, in some cases, has taken much longer (Resource Systems Group 2012a).

2.5.5
Personnel

No two agencies are exactly alike in terms of their institutional responsibilities, modeling resources, or staff knowledge and availability. As a result, the type and level of involvement of agency staff, and the reliance on external consultants required to develop, apply, and maintain an activity-based model varies significantly. However, the active involvement of agency staff in all aspects of model development improves the ability of agency staff to apply and understand the model and to communicate model results effectively to decision makers. Staff involvement may also reduce the dependence of an agency on consultant help. Agencies using activity-based models have as few as 2 people devoted to modeling to as many as 10 supporting model data, development, and application.

2.5.5.1
Staff Skills and Training

Specific technical skills useful for activity-based modeling include discrete choice modeling, knowledge of the activity-based modeling principles and process, statistical analysis, and database or data management. Ideally, agency staff also has software development and scripting experience (Resource Systems Group 2012a). In addition, depending on the specific features of the model, it may be useful for staff to have other skills as well. For example, if a detailed spatial resolution is used in the model, such as microzones or parcels, familiarity with GIS is essential. Similarly, if the modeling system includes a DTA model component, then knowledge of traffic engineering principles is critical. In general, common sense and critical thinking, as well as a willingness to work through the complexities of software development are essential skills for activity-based modelers.

In addition to all these technical skills, it is essential that agency staff have robust communication skills and knowledge of the overall planning context in which travel forecasting is performed. This knowledge is especially important when complex tools, such as activity-based models, are being used, because the practical advantages of such tools need to be conveyed in a logical and compelling way.

2.5.5.2
Development

Agencies have often, but not always, relied on consultants to lead model development and enhancement efforts; this reliance on consultants has allowed advanced models to be implemented more quickly than would have been possible if relying solely on agency staff. However, staff participation and training during model development are very important because this investment in staff builds familiarity with the model system, improves the ability of staff to communicate effectively about the model, and facilitates immediate testing and application by agency staff.

2.5.5.3

Application and Maintenance

In contrast to activity-based model system development, agency staff have typically played a much more significant role in activity-based model system-level applications. Active involvement in model applications provides agency staff with the opportunity to understand model capabilities and sensitivities, increases familiarity with model inputs and outputs, and helps agency staff identify potential model improvements. Agency staff have also played a leadership role in overall activity-based model system-level maintenance, especially with respect to updating model input assumptions. Institutional knowledge about model system data has been identified as a challenge (North Central Texas Council of Governments 2013). Consultants have also played a significant role in model maintenance, particularly with respect to software code and scripting.

2.5.5.4

In-House Versus Consultant Expertise

As stated previously, agencies have often used consultants to provide activity-based model development expertise that they may not have in-house or to supplement the capabilities of agency staff. Consultant services provide agencies with the ability to effectively spend limited model development resources on critical model development tasks for limited periods of time. However, reliance on consultant expertise has some risks. Some agencies have reported that the use of consultants to develop advanced models can result in situations in which the agency staff are not able to effectively understand and apply the new tools; these situations may be problematic (North Central Texas Council of Governments 2013). It is essential that documentation of all model development and implementation efforts be prioritized.

2.5.6

Funding

Agencies have pursued a variety of different strategies for funding activity-based model system development. Broadly speaking, most agencies have pursued strategies that can be characterized along two primary dimensions: program-based versus project-based and incremental versus comprehensive strategies. Program-based strategies involve funding activity-based model system development and enhancement as a core element of agencies' work programs, while project-based strategies involve funding model development and enhancement using project-specific resources. For practical reasons, agencies often use a mix of these strategies to fund model efforts. Incremental strategies involve the gradual development of an activity-based model system by funding a set of discrete successive tasks over a longer period of time. Comprehensive strategies involve developing an initial complete model more quickly as part of a single effort. Activity-based model systems have been successfully implemented using a variety of different funding strategies. Decisions about how to fund activity-based model efforts should be primarily informed by agencies' requirements and constraints.

In recent model development efforts, agencies have spent as little as $250,000 for the transfer of an activity-based model in a small region over a relatively short schedule, to as much as $1.2 million for a large region over a 4-year time period, excluding household survey data collection. Other large regions have spent comparable amounts for model development, but spread this expenditure over longer time periods (Resource Systems Group 2012c).

3

ACTIVITY-BASED MODEL CONCEPTS AND ALGORITHMS (FOR MODELERS)

3.1

FOUNDATIONS

3.1.1

Demand Models and Supply Models

Activity-based models are travel demand models. Travel demand models may estimate the demand for travel by regional residents, the demand for travel for commercial purposes, or the demand for travel for special purposes or destinations such as special events or airports. This demand is typically characterized by information about origins, destinations, timing, and modes of travel.

Supply models predict the performance of the transportation system, given a set of input travel demand. These performance indicators include measures such as O-D travel times and costs by time of day and mode, and estimated link volumes. The time, costs, and other network impedance estimates produced by the supply model are then fed back as input to the demand model.

Activity-based models forecast the demand for travel for regional residents: the purpose and number of activities to participate in, the amount and type of travel required to fulfill these activities, the destinations of these activities, the mode of travel used to access activity locations, and the timing of this travel. This demand is primarily influenced by household and individual characteristics and by the performance of the transportation system as reflected in travel times, costs, and accessibilities. The household and individual characteristics are input to the activity-based model based on exogenous sources of base-year and future-year demographic information. The network performance inputs to the activity-based model are produced by a network supply model, which is typically executed sequentially and iteratively with the activity-based model.

3.1.2

Aggregate Versus Disaggregate

One of the distinguishing features of activity-based models is that they are typically implemented using a disaggregate microsimulation framework, in which the choices are predicted at various decision-making levels, such as households, persons, tours, and trips. In a traditional trip-based model, aggregate estimates of demand are predicted first. Then each subsequent step in the model system further disaggregates the overall aggregate estimates of demand. For example, the total number of trip productions and attractions by purpose are first predicted during the trip generation step for each TAZ. These total trip productions and attractions are then disaggregated to O-D pairs in the trip distribution step. Within each O-D pair, the number of trips is then further disaggregated to estimate the number or trips by mode during the trip mode choice step. Once all these disaggregation steps have been performed, the demand can be input to the network assignment model.

In contrast, in an activity-based model system, disaggregate estimates of demand are predicted first, and then these estimates are aggregated by geography, time of day, and market segment for input in the network assignment model. Producing disaggregate estimates of demand helps reduce bias in the estimates of demand and provide greater flexibility to analyze the impacts of policies and investments. However, the use of this disaggregate data must be informed by the analysis context. Although the activity-based model produces precise disaggregate estimates of demand at detailed spatial and temporal resolutions for many market segments, the accuracy of these estimates at fine levels of disaggregation should be carefully considered in application.

3.1.3

Discrete Choice Models

Activity-based models simulate the activity-travel decisions of households and individuals that collectively result in the activity patterns researchers observe. These activity patterns are composed of many smaller, often-related decisions, such as what time to depart home for work in the morning, what mode to take, whether to make an extra stop for groceries on the way home, and where to make that stop. Other longer-term decisions also have a bearing on activity and travel, such as the choices of where to work, where to live, how many cars to own, and whether or not to participate in an employer's transit pass program.

Most travel demand modelers are already familiar with mode choice models. In Figure 3.1 the left diagram depicts the choice from among 5 different mode choice options. Choice models, however, are also used to model other types of choices, such as the choice of destination and time of day depicted by the center and right-most diagrams, respectively. Choices made in space and time, respectively, are in reality continuous dimensions, which modelers parse into discrete units for analytical and computational convenience. Some of the early activity-based models employed regression models and hazard-based duration models to predict activity durations or ending times, given a starting point; however, in practice discrete choice formulations such as the ones shown in Figure 3.1 have proved to be easier to calibrate and integrate with other model structures and to incorporate sensitivity to travel conditions that vary by time of day.

For destination choices, the fundamental unit of analysis might be a zone, or it could be smaller units, such as a gridcell, microzone, or

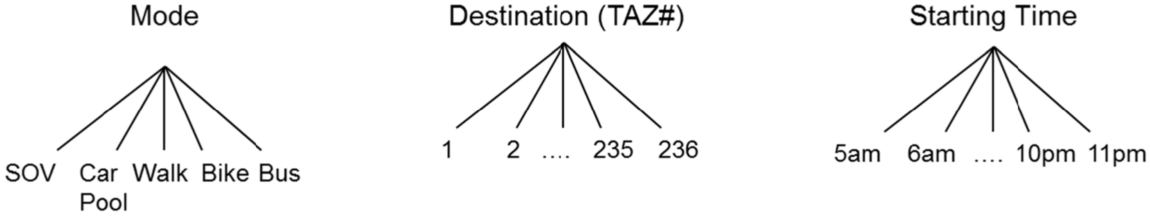

Figure 3.1. *Choice structures applied to activity-travel dimensions of mode, space, and time.*

even parcel. Likewise, modelers parse time into intervals and choose a starting time interval for an activity. In practice, activity-based modeling systems in use to date have used 60-, 30-, and even 15-minute decision intervals. The ways in which space and time are transformed into discrete intervals has important implications for how these data are processed in surveys, for the creation of networks loading points, for assignment time intervals, and for the maintenance of geo-databases.

3.1.3.1
Choice Horizons

Activity-based models consider different time horizons in addition to different units of analysis. Figure 3.2 illustrates a few of the common long-term choice models that appear in activity-based modeling systems. These include the choices of workplace location (defined, for example, as a TAZ), the number of household automobiles to own, and whether an individual would purchase a transit pass. While workplace location and transit pass are individual choices, the number of automobiles to own is an example of a household-level choice. In real life, these three decisions might be somewhat interdependent. For example, the number of cars owned might depend on where individual household members work. In the case of some part-time workers, however, the direction of causality might be reversed. In addition, whether someone bought a transit pass might also depend on workplace and the availability of automobiles. The sequence in which these decisions are represented in activity-based modeling systems is part of the model design. In addition, there have been models developed in a research setting that attempt to integrate these decisions into a more complex, single multidimensional choice.

The set of choices shown in Figure 3.3 are simplified depictions of models aimed at daily tour pattern generation and certain stop details. The left diagram represents a model that predicts the number of shopping tours in a daily pattern, given the existence of at least 1. This is an example of using a choice mode approach to predict the frequency of occurrences of something like tours, where the number is likely to be small (e.g., 0, 1, 2, 3+).

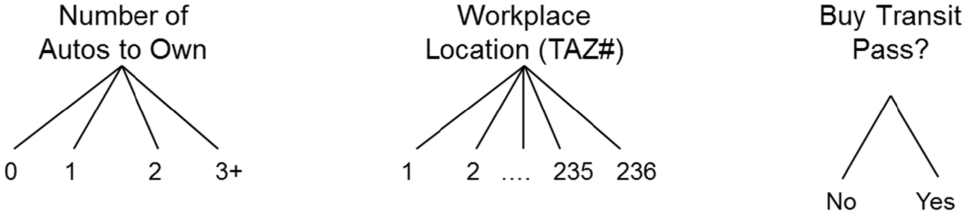

Figure 3.2. *Examples of long-term and mobility choices.*

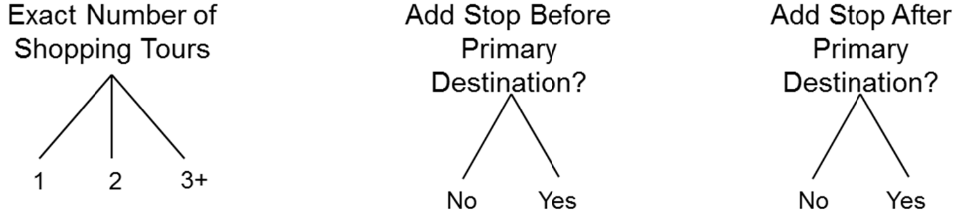

Figure 3.3. *Example choice structures for daily activity and stop generation models.*

The center and right diagrams in Figure 3.3 illustrate binary choices of whether to add an intermediate stop before or after the primary destination stop. Binary choice structures are efficient for predicting a "yes-no" type of response. This type of "add stop" model might be applied multiple times. For example, it may be applied once to predict an initial insertion of a first intermediate stop and then re-evaluated to predict whether there is room in the schedule for additional stops. There are other ways to represent this decision process, including linked and ordered choices; however, in practice, activity-based modelers have found that some of the simplest model structures work the best over a wide range of input cases.

3.1.3.2

Joint and Conditional Choices

Because many choices are interdependent, activity-based modeling system designs try to capture these interdependencies to the extent practical. Most modelers recognize that what have been described as separate choices, such as mode and destination, are really bundled choices, for example, choosing between combinations of mode and destination. Figure 3.4 represents the joint choice of tour primary destination and mode in a hierarchical manner. While it is possible to enumerate every combination of destination and mode, all on the same level, that does not necessarily lead to more accuracy and is less practical in terms of model estimation and application. It is worth noting that this example shows the choice of destination first, and conditional on destination, the choice of mode. In some model systems, particularly in Europe, this ordering is reversed; however, the way it is shown here is more familiar to most U.S. modelers. The important takeaway is that the choice of destination conditions the choice of mode, and that the composite travel times and costs of the modes available to travel to each destination alternative affect the choice of the destination.

Another example of a joint or conditional choice would be the choice of tour starting and ending times, as shown in Figure 3.5. Here there is an obvious logical constraint being enforced in which the tour ending time intervals must be later than the tour starting time intervals. Implicit in this choice of starting and ending times is the tour duration. The choice hierarchy may seem incontrovertible due to temporal ordering of starting times before ending times; however, the utility of ending time and duration may influence the tour starting time.

Yet another example of a conditional choice would be the choice of trip mode, conditional on tour mode. This would seem to be a rather obvious hierarchical relationship in which the mode chosen for the whole tour dictates what is available for individual trips on the tour. As

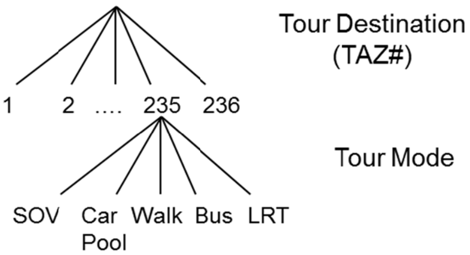

Figure 3.4. *Tour destination conditioning tour mode choice.*

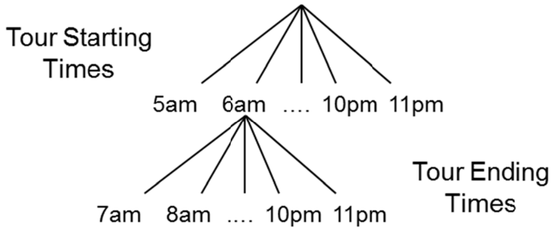

Figure 3.5. *Tour starting time conditioning tour ending time choice.*

shown in Figure 3.6, a person chooses to walk for the tour mode, leaving SOV and bike unavailable for the subsequent trip mode choices. In an activity-based modeling system, however, there may be one or several other choice decisions that take place in between tour and trip mode choice. For example, after choosing the tour mode, there may be the choices of tour start and end times, the decision of whether and how many intermediate stops to insert, and the choices of destinations for those stops. As a consequence, while the choice of trip mode is certainly conditional on tour mode, it is also conditional on a handful of other choices that take place upstream. It is part of the model design, and a challenge in its implementation, to maintain these conditional relationships consistently throughout the model system.

3.1.3.3
Utility Maximization

Although there are a number of ways that one could go about attempting to model these choices, the travel demand modeling profession has come to accept the theoretical premise that these choices are not simply random. Rather, they are part of a deliberate process in which an individual trades off the worth of one alternative course of action versus another and chooses the alternative that is most likely to maximize his or her welfare. Accordingly, discrete choice models based on the principal of random utility maximization (RUM) have become the primary method for modeling activity and travel choices. While there are a number of competing theories of decision making that might work better than RUM for certain decision contexts—such as elimination by aspects, regret minimization, and prospect theory—RUM has proved to be robust over a wide range of decision contexts.

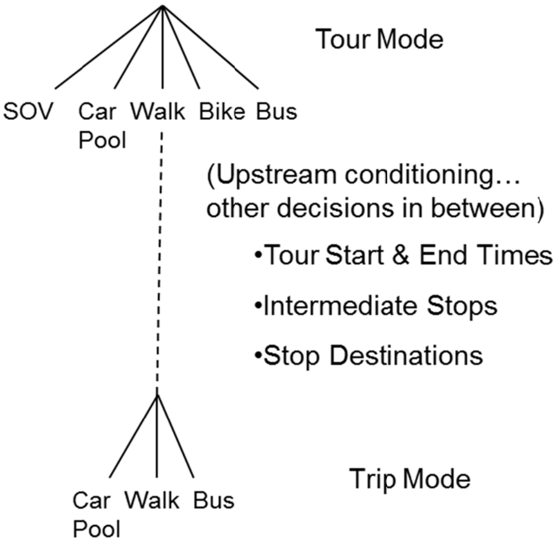

Figure 3.6. *Tour mode choice conditioning trip mode choice, with intervening models.*

The assumption is that people choose the alternative that provides them with the highest utility among available alternatives. RUM has been found to be robust over a wide range of decision making and choice contexts. While it carries with it certain assumptions, it is applied probabilistically in model formulations, which allows modelers to account for measurement error and random heterogeneity in the population. Some of RUM's less realistic assumptions include that the decision maker has full knowledge of the attributes of each alternative and pays equal attention to all available alternatives.

3.1.3.4
Random Utility Theory

Because most travel demand modeling professionals are at least familiar with mode choice models, this section highlights certain important aspects of discrete choice models that are central to their use in activity-based travel modeling and important terminology. Of particular concern are the roles of choice sets and composite utility (or logsums) and how models are applied in a simulation environment.

We assume that the decision maker selects the alternative that is perceived to offer the maximum utility from a set of alternatives that are mutually exclusive, which we call the choice set. The observer does not know the true utilities; however, they may be inferred from the choices made. Sources of error include missing variables, unobserved taste variation (preferences), measurement error (actual versus perceived travel time), and using the incorrect functional form (e.g., linear, nonlinear, hierarchical). We treat these errors as random and additive, such that $U_i = V_i + \varepsilon_i$.

Total utility, U_i, is composed of a systematic portion, V_i, which we account for through the variables in our models, and a random component symbolized by the error term, ε_i. Using a mode choice example to illustrate how a utility function is formulated, we can write

$$\begin{aligned}\text{Utility}_{\text{Transit}} = {} & a * \text{in-vehicle time} \\ & + b * \text{fare} \\ & + c * (\text{access time} + \text{egress time}) \\ & + d * \text{wait time} \\ & + \text{mode-specific constant}\end{aligned}$$

Utility equals the weighted sum of the attributes of the alternative. The weights in the model are known as model parameters, shown here as *a*, *b*, *c*, and *d*. These parameters can be estimated from survey data, borrowed from another model, or asserted based on experience. The parameters convert the modal attributes in various units, such as minutes and cents, to a general value called a "util" (because they measure utility). This has important implications for how the weights can be compared to one another. There is an additional term called a mode-specific (or alternative-specific) constant, which represents the value (in utils) of all of the attributes of the alternative that are not explicitly listed in the utility equation. In the case of transit, this could include difficult-to-measure factors such as transit reliability, transit safety, and the influence of weather on the choice of transit.

3.1.3.5
Utility Expressions and Choice Probabilities

The probability of choosing an alternative *i* from a set of choice alternatives *C* may be expressed probabilistically as

$$\begin{aligned}P(i : C) &= \text{Prob}(U_i \geq U_j, \forall j \subset C) \\ &= \text{Prob}(V_i + \varepsilon_i \geq V_j + \varepsilon_j, \forall j \subset C)\end{aligned}$$

General assumptions for the distribution of the error term, following a Gumbel distribution, lead to the multinomial logit model:

$$P(i : C) = \frac{\exp(V_i)}{\sum_{\forall j} \exp(V_j)}$$

This is the model that is used so often to represent mode choices. It carries with it the important simplifying assumption that error terms are independently and identically distributed (IID). The IID property is important, because it assumes that a change in the utility (e.g., level of service or cost) of one alternative will have an equal proportional effect on the probabilities of choosing all of the other alternatives, all else being equal. This assumption may not necessarily hold in all choice contexts.

3.1.3.6
Nested Models and Composite Utilities (Logsums)

One reason for relaxing the IID assumption is to account for correlation between alternatives that may share unobserved similarities. For example, travelers may view two types of transit alternatives, such as bus and light rail, as being more similar (i.e., closer substitutes) than other model alternatives. Thus, a change in the level of service of bus should have a greater effect on light rail than it would on, for example, automobile alternatives. A common alternative form for this is the nested logit model. As previously discussed, activity-based modeling systems make extensive use of such hierarchical or nested choices for more than just mode choice.

Consider the example of the hierarchical choice of tour ending time, conditional on tour starting time, as shown in Figure 3.7.

We can represent the conditional probability of a choice that appears in a lower-level nest on the choice made in the upper-level nest in the following formulas. The probability of mode i is conditional on nest n:

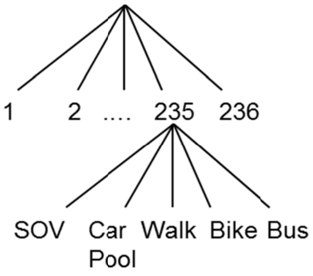

Figure 3.7. *Use of logsum of the lower-nest mode choice alternatives in the upper nest.*

$$P(i) = P(i \mid n) * P(n)$$

$$P(i) = \frac{\exp\left(V_{i|n}/\theta_n\right)}{\sum_{j\in n}\exp\left(V_{j|n}/\theta_n\right)} * \frac{\exp\left[V_n + \theta_n \ln\left(\sum_{j\in n}\exp\left(V_{j|n}/\theta_n\right)\right)\right]}{\sum_{\forall m}\left[\exp\left[V_m + \theta_m \ln\left(\sum_{j\in m}\exp\left(V_{j|m}/\theta_m\right)\right)\right]\right]}$$

where θ_m is a dispersion parameter specific to each nest and reflects the correlation between alternatives in the same nest. To be consistent with utility maximization parameters, these parameters must have values greater than zero and less than or equal to one. Logsum terms represent composite utility of lower-level nested alternatives.

The left term in the equation represents the conditional choice of mode, and the right term represents the unconditional choice of destination zone. In the equation such a logsum variable is the term

$$\ln\left(\sum_{j\in n}\exp\left(V_{j|n}/\theta_n\right)\right)$$

This is the natural log of the denominator of the lower-level nest and represents the composite utility of the nested alternative (modes). Note that the denominator for the lower-level choice (mode) appears in the utility expression of the upper-level choice of destination zone. Because we take the natural log of this sum, this term is commonly referred to as the "logsum." In choice theory, the logsum represents the maximum expected utility that may be derived from the lower-level choice, which in this case is mode. In the choice of a destination, the logsum term represents the mode-weighted accessibility for travel to each zone alternative. The equation also includes another portion of the utility of the zone alternatives V_m that represents other attributes of the zone, such as attraction variables. Thus, it is common in activity-based models to use composite accessibilities, such as mode choice logsums, to account for travel times and costs by all available modes when choosing a destination. The assumption is that the destination is chosen first; however, this conditional ordering could be reversed.

3.1.3.7

The Importance of Choice Sets

The choice set is the group of alternatives considered to be available to the chooser in a given choice context. The role of choice set formation and restrictions are important in activity-based modeling systems. This is particularly true for nested choices and conditional choice relationships. In conditional choice contexts, the upstream model choice will in many cases condition the availability of alternatives downstream. For example, the choice of tour mode conditions the availability of certain trip modes. Generally speaking, if a person does not choose to drive for the tour mode, then we would not expect driving to be available for any trip on the tour. Similarly, we might expect that bicycle would be available only to persons who left home with a bicycle; however, in household surveys it is common to find exceptions to these assumptions as people sometimes leave cars and bikes behind, used rental or company vehicles, or have access to car-sharing or bike-sharing services.

In addition, the presence or absence of an alternative in a lower-level choice may greatly affect the composite utility of the upper level choice. In a policy context, if one were to model the addition of a new transit service to the region that would greatly improve travel time by certain zones, then this addition of a new alternative to serve those zone pairs would make those destinations more attractive. This change in accessibility would be reflected in the mode choice logsums that would be used by an upstream destination-choice model and possibly even long-term workplace and automobile ownership choice models.

3.1.3.8
Other Considerations

The multinomial and nested logit models described are by far the most common model forms used in practice in activity-based modeling system. They owe their ubiquity to being relatively easy to comprehend and to implement over a wide range of choice contexts. Use of different model forms is, of course, possible. Most variations focus on different methods for handling the error terms in the models to better account for heterogeneity across users and correlation across choice alternatives. Some choice model variations specify different forms of the dependent variable that may be more applicable in certain modeling contexts, such as ordered choices and combinations of discrete and continuous choices. Still other models deviate from the RUM paradigm in an attempt to capture different decision-making theories, such as risk aversion. Computational complexity, run time, and the ability to explain results to end users are the chief challenges of adopting the more advanced model forms in practice. Interested readers may want to consult recent research in the area of discrete choice and related econometric models. Excellent basic references on discrete choice models include the works of Ben-Akiva and Lerman (1985); Hensher, Rose, and Greene (2005); Koppelman and Bhat (2006); and Train (2009).

3.1.4
Activity Pattern Structure

An activity-based travel model differs from a trip-based model by modeling decisions to participate in activities. The central focus of the models is whether, when, and where to participate in activities and for how long. Travel is a derived demand resulting from the need for people to engage in activities outside the home. Trips are a means of traveling between activity locations and decisions related to trip scheduling, such as mode and departure time, are made to accommodate desired arrival and departure times from activity sites. In some activity-travel modeling systems, these decisions are coordinated between members of the same household. Activity-based travel models also are characterized by their disaggregate representation of individuals and households, which typically using simulation methods. This enables modelers to track these individuals and to effectively use their demographic characteristics in analysis.

3.1.4.1

Activities Versus Trips

Activity modeling does bear some resemblance to trip-based modeling in terms of generating activities, distributing them to locations and time periods, and choosing travel modes for them. Some activity purposes, such as work and school, have similar labels in the trip-based world; however, we actually model the trips within an activity-based modeling system as separate entities that allow persons to travel between activity locations.

Activities have a duration, which we model, that has intrinsic value to the participant. People derive satisfaction from participating in activities, and we assume that the amounts of time that we observe people participating in activities reflect the utility the participants derive from it. Therefore, when we model the schedule of activities and travel, we take into account the expected amounts of time that individuals will spend in each activity; how they prioritize their time between work or school, and shopping and recreational activities; and how much time they are willing to devote to travel.

Modeling activities also means allowing for the possibility of in-home substitutions and trade-offs, such as telecommuting from home, at-home leisure, eating, and other activities. This is important for modeling future scenarios in which gasoline prices are higher or predicting the impacts of online commerce and social media. One response that people may choose in reaction to high travel costs is to undertake activities at home. In addition, in-home activities of other household members are important. For example, many parents of young children time their work departure times and forego some discretionary activities out of the home so they can be at home for their children. Some of the most advanced activity-based modeling systems try to capture this dynamic.

3.1.4.2

Tours and Half-Tours

A key aspect of activity-based travel models is that travel is organized around tours. A tour is a series of trips beginning and ending at home or work anchor location. By modeling decisions on a tour basis, there is enforced consistency between the outbound and return portions of the tour, so that a mode chosen to go to work conditions the mode available for the return home.

Common to tour-based activity modeling is the identification of a primary destination on each tour and the insertion of intermediate stops either before or after the primary destination. In addition, there may be subtours within a tour. Figure 3.8 shows a home-based tour in which work is the primary activity/destination.

3.1.4.3

Primary Stops on Tours

How to determine which stop in the tour is the primary destination is one key design decision. While it is possible in recent tour-based household surveys to ask the primary purpose of the tour, this has not always been the case and is certainly not true in all surveys, particularly older ones. Using a hierarchical typology based on activity purposes is one method, which works well for work, school, and college purposes, but for other purposes primacy is less clear. Other tie-breaking rules include the first stop on the tour, the stop farthest from the home anchor point, and the stop with the longest duration. These have important implications for the construction of tour schedules,

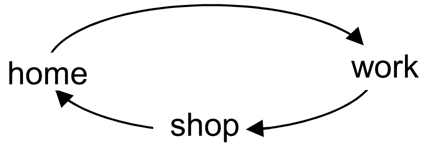

Figure 3.8. *Home-based tour.*

since time-window availability criteria for the insertion of intermediate stops would be influenced by both activity duration and travel time to the primary destination.

3.1.4.4
Intermediate Stops on Tours

There can be zero or more intermediate stops on the tour, which are stops made between the anchor location and the primary destination. Some activity-based modeling systems refer to sequence of one or more stops between the anchor location and the primary destination as the first half of the tour, or outbound half, and the sequence of one or more stops between the primary destination and the anchor location as the second half of the tour, or return half. In Figure 3.8, there is one intermediate stop on the return half of the tour; the stop is between work and home. There are no stops on the outbound half, which is between home and work. Whether to model stops on tours using this half-tour schema, or a more sequential method, is a design decision.

3.1.4.5
Work-Based Tours (or Subtours)

As shown in Figure 3.9, the sequence of trips between work and lunch is referred to as a work-based tour (or subtour). In this case, the anchor location for the tour is the workplace, and the primary destination is lunch, and there are no intermediate stops on this subtour. In trip-based practice, both of these trips would have been cast as nonhome-based work trips. Although it is possible to allow nonwork locations to be anchors for subtours, nonwork subtours are observed less frequently in survey and are difficult to identify accurately; therefore, this has generally not been done in practice. Because of the frequency of work-based subtours, however, these are typically generated as part of a daily activity pattern.

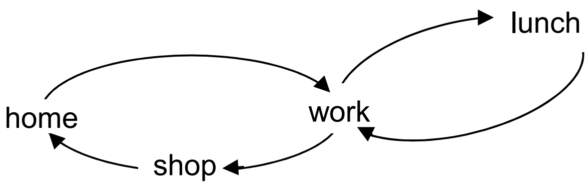

Figure 3.9. *Home-based tour with a work-based subtour.*

3.1.5
Activity Types

In general, disaggregation of travel purposes by activity types makes activity-based models more sensitive to variations in travel behavior than trip-based models and allows them to be more accurate when matching person types with activity locations and times of day. While the labeling of activity types will vary from place to place, the following list of activity types is generally found in most activity-based modeling schemes:

- At home;
- Work at home;
- Work (at workplace);
- School (K–12);
- University/college;
- Personal business/medical;
- Shopping;
- Eat meal;
- Social/recreational; and
- Escort passenger.

Two schemes for classifying these activities are important to model specification because they contextualize decision making. One scheme is based on the relative fixity in place and time of an activity, and the other scheme is related to whether activities and travel involve coordination with other household members.

3.1.5.1

Mandatory, Maintenance, Discretionary, and At-Home Activities

Activities are sometimes grouped into four general categories according to priority in the daily activity pattern schedule. The categories are mandatory, maintenance, discretionary, and at-home.

Mandatory activities consist of work and school. They are the least flexible in terms of generation and scheduling and are the basic building blocks of activity schedules for workers and students. Some model systems differentiate between work-at-home (telecommuting) and work-out-of-home activities. Some models also categorize school activities by grade level.

Maintenance activities include escort, shopping, and other maintenance (e.g., doctor's visits). Some modeling systems model certain purposes explicitly, while others combine them into more general categories, like "other." This is a design decision that should depend on local modeling needs. For example, in areas with a large contingent of senior citizens, explicit modeling of a medical activity purpose may be desirable. Many of these maintenance activities are performed on behalf of the household, such as picking up or dropping off household members or going grocery shopping. In model systems that represent joint travel explicitly, the escort purpose may be replaced by more detailed descriptions.

Discretionary activities include eating out, visiting, and other recreational activities. They are the most flexible in terms of generation and scheduling and are often substituted for in-home activities, particularly for households with poor accessibilities to recreational opportunities. In some activity-based modeling systems, maintenance activities are grouped under the discretionary activities in recognition of the fact that they often have similar scheduling flexibility and are often found on the same tour.

Most activity-based models used in practice classify at-home activities into working at home and other at-home activities. The reasons for this lack of further stratification are partially due to lack of survey information on in-home activities. In addition, however, where in-home activity data have been collected analysts have found it difficult and perhaps unnecessary to effectively distinguish between nonwork at-home activities.

In addition, some modeling systems also differentiate activities on work-based subtours from those belonging to the main home-based tour. One reason for this is because subtours tend to be more constrained in terms of time; therefore, activities on work-based subtours are likely to have significantly shorter average durations and travel distances.

3.1.5.2

Independent, Joint, and Escort Trips

The definitions of independent, joint, and escort trips depend on the level of involvement between individuals, as can be determined from available household diary data. In older trip-based surveys, determining whether two household members participated in an activity together or shared a ride could be difficult, because older survey methods did not stress consistency across individuals when reporting events. In more recent activity-based surveys, survey firms have been more vigilant and systematic in ensuring consistency, making it somewhat easier to identify joint activities and travel, albeit not without some challenges in identifying information.

As depicted in Figure 3.10, a fully joint tour is one in which two or more household members travel together to some out-of-home location at which they participate in an activity together. In this case the activity is a leisure activity, but generally any nonmandatory out-of-home activity type would qualify. Usually two or more household members who commute to

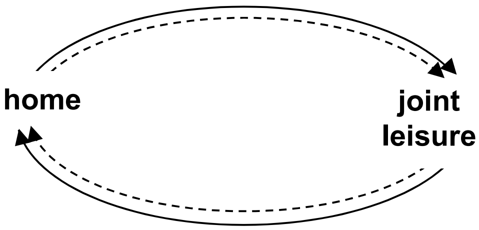

Figure 3.10. *Fully joint tour between two household members.*

work or school together are considered to be not engaged in a joint activity, the assumption being that they are engaging in independent work or school activities, even if in close proximity. In such cases, there is joint travel on the tour, but this is simply represented as a shared-ride mode choice for both persons, not as an instance of joint activity participation. If, however, they were to stop on the way home from work for a meal, the meal event would indeed represent joint activity participation, making this a partially joint tour.

Figure 3.11 represents two variations on a partially joint tour. In the left diagram, two household members travel together to run an errand, a joint activity, after which one goes to work while the other goes shopping, and they both return home separately. In the right diagram, one household member goes to work at the beginning of a tour; the second household member meets the first at a store to go shopping together; they then continue on to dinner, and travel home together. In practice, fully joint tours are more common than partially joint tours.

Figure 3.12 represents joint travel but not joint activity participation. In this example, an adult drops off a child at school on her way to work, and picks up the child from school

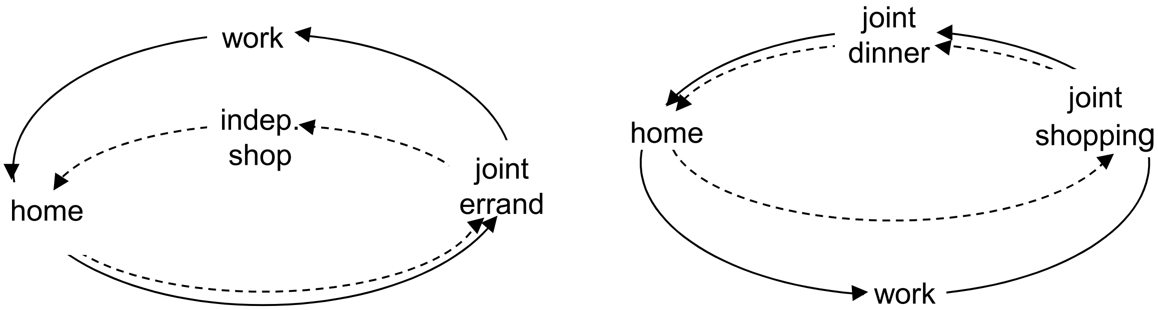

Figure 3.11. *Two variations on a partially joint tour.*

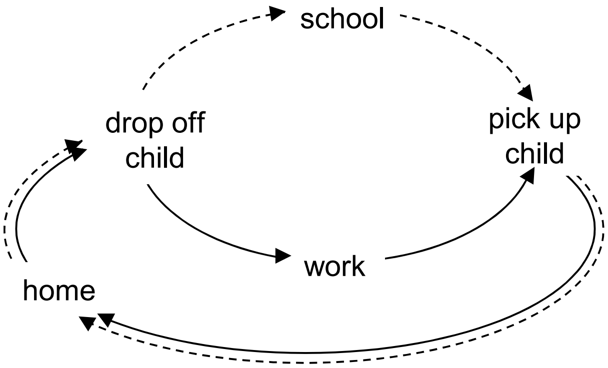

Figure 3.12. *An escort tour.*

on her way home from work. The school and work activities are considered to be independent activities; however, the drop off and pick up events are generally referred to as escort activities for the driver. For the person being escorted (the child in this case), it is simply an independent school activity with a shared-ride mode.

In practice, some activity-based modeling systems explicitly distinguish between activities performed with other household members, while others use a looser correlation specification. For example, it is possible to generate escort trips for an individual adult in the household, and the propensity to undertake escort trips will be correlated with household structure, particularly the presence and ages of children. This would be an example of a correlated model. An explicitly coordinated activity-based model system would generate some escort trips as outcomes of a joint decision model in which children (or other household members) were directly matched with other household members as part of tour mode choice process.

3.1.6

Daily Activity Patterns

There are many different ways in which choice elements can be represented and integrated into an activity-based modeling system. Differences in activity-based model design are expressed in how certain choices are represented structurally, as well as in their sequencing. Figure 3.13 depicts the representation of the choice of an overarching day pattern for an individual using two different schemes for representing daily activity patterns.

The first model (Model A) represents day patterns as combination of tour types. Given a large number of combinations of different type tours, there could be thousands of individually defined alternatives. Although practically this type of day-pattern model would eliminate those that are observed rarely and group certain alternatives. The exact number of tours of each type would be chosen in a subsequent series of models.

The second model (Model B) defines day-pattern alternatives differently by characterizing the day patterns as being either mandatory or nonmandatory, with a secondary choice of whether to include joint activities with other household members. As used here, a mandatory pattern is defined as a pattern involving work, school, or college activities, but may include other, discretionary activities, such as eating out, shopping, and social/recreational. A nonmandatory day pattern would include only discretionary activities. Joint activities with

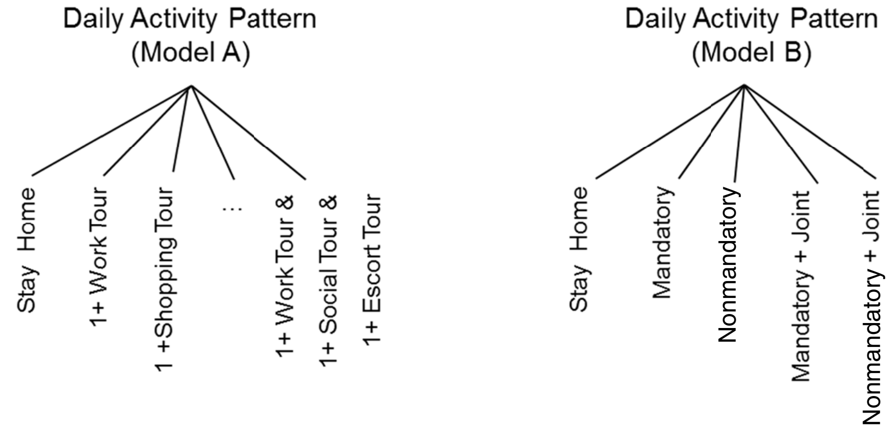

Figure 3.13. *Two different ways of representing daily activity pattern choices.*

other household members are an extra dimension that could be added to either a mandatory or nonmandatory day pattern. The exact number of mandatory, nonmandatory activities and tours, as well as joint activity participation would be determined in downstream models.

3.1.7
Implementation Framework

There are many different ways in which developers of activity-based models have structured the sequencing and information flow between model components. Figure 3.14 is a generalized representation of the major model steps that are common in activity-based models used in practice.

As the model system progresses, travelers make decisions: whether to travel, where to go, how many stops to make, what mode to choose, and so on. Earlier decisions influence and constrain the decisions made later. For example, the number of vehicles owned, modeled in the automobile ownership (mobility) model, influences the number of tours and the mode used on each tour. The mode used for the tour then influences the location of stops on the tour, and so on. This conditioning effect is referred to as "downward vertical integrity."

Activity-based models also use information from models that are lower in the model chain to inform the choices made by decision makers in upper-level models. This information typically takes the form of accessibility variables, which are formed from the composite utility of a lower-level choice. For example, a mode choice logsum, which reflects accessibility by all modes of transport, can be used to inform the choice of destination for the tour or stop. This representation of the composite utility represents the maximum expected utility that the decision maker can expect to receive from a lower-level choice, before making that choice. This flow of composite utilities back up the

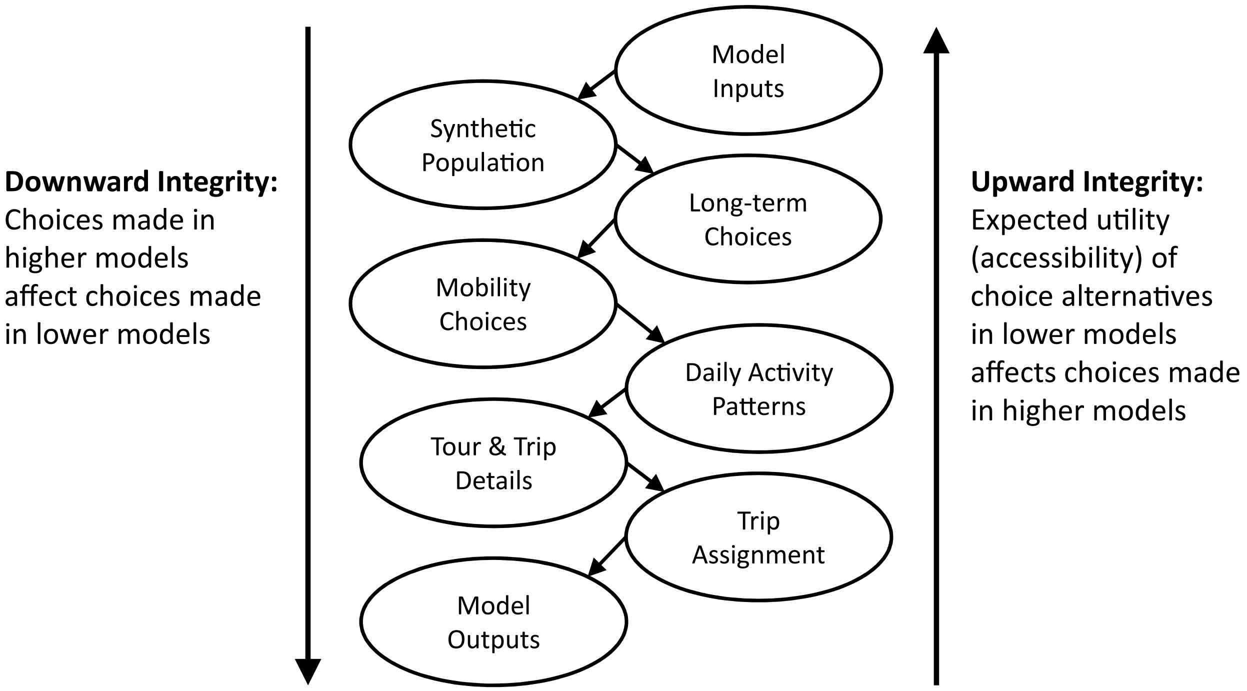

Figure 3.14. *Major steps and information flow in an activity-based modeling system.*

model stream is referred to as "upward vertical integrity." Together the downward and upward vertical integrity built into activity-based model system designs help to ensure a high degree of internal consistency among space, time, and mode dimensions and to recognize their interdependence.

3.1.8

Disaggregation

One of the chief strengths of disaggregate modeling methods is elimination of aggregation bias that may threaten the validity of forecasted responses to transportation system and policy changes. Activity-based models do this by simulating activity-travel patterns of individual travelers and their interactions with other household members, which has led activity-based modeling practice to use microsimulation techniques, typically Monte Carlo methods. As an outcome, this creates forecasts in which each trip is represented as a whole number (integer), a stark departure from conventional trip-based modeling practice. Four-step models generate interval values for trips and then allocate fractions of trips to TAZs, modes, and time periods. This difference between whole trips and fractions has important implications for both computational efficiency and forecast variance.

3.1.8.1

Logit Models and Aggregation Bias

Figure 3.15 illustrates the issue of aggregation bias using logit models. The horizontal axis represents the cost of a choice for two different decision makers, Person A and Person B. The vertical axis represents the resulting logit-calculated choice probabilities. The probabilities for each individual, as predicted by the model, are quite different, and their average (circled) is halfway in between. If we were to aggregate these two individuals and take their average cost, then we would obtain a different probability, following the lighter-gray dashed lines. The probability of this average cost is different from the average probability we obtain when we calculate each person's probability.

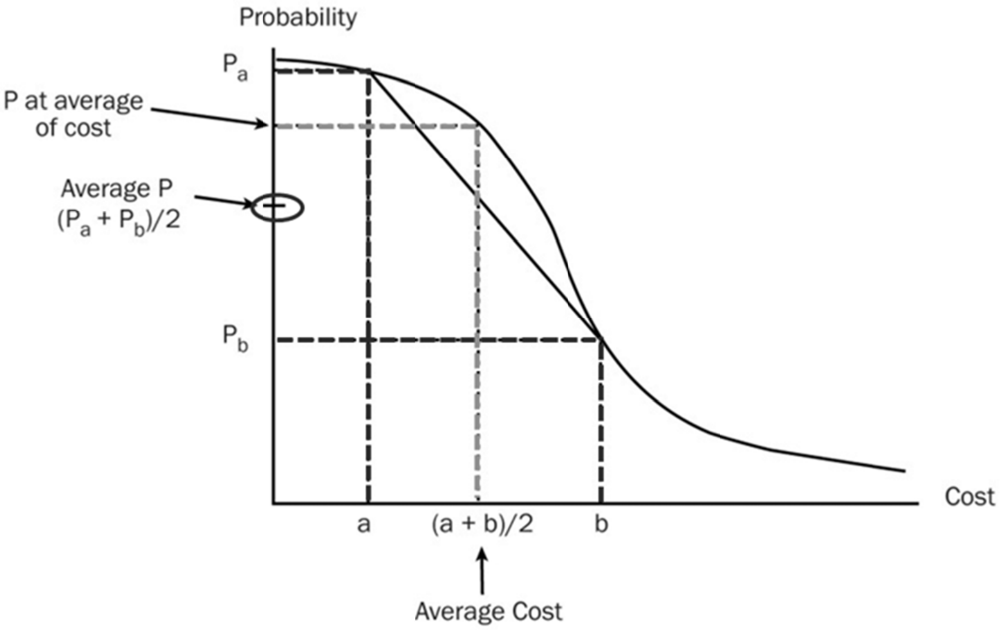

Figure 3.15. *Aggregation bias in application of logit models.*

Another aspect of aggregation bias is shown in Figure 3.16. The average impact of a change is not equal to the impact calculated at the average of the explanatory variables; this is symbolized by the tangents to the curve, representing slopes at each point. Again, the black lines represent the individual outcomes, and the gray line represents the slope corresponding to the averaged outcome. Because of the sigmoid (S-shape of the curve), the logit model is most sensitive (elastic) to change in inputs at its center region and is relatively less sensitive (inelastic) to changes in inputs at its top and bottom ends. This is one reason why some aggregate models predict larger shifts in response to scenario inputs changes than disaggregate models.

A real-life example might be a mode shift in response to a new toll charge. Imagine the perceived cost of the toll being affected by personal values of time, where Person A has a high willingness to pay (so perceived cost is not that onerous) and Person B has a low willingness to pay (so perceived cost is considered to be very onerous). Because both persons are already at the far ends of the distribution, they are less likely to react to a cost change by changing their baseline choices. By grouping travelers under a single average value of time, however, the perceived cost represents an average condition, the gray slope, and has the potential to overestimate the elasticity of response to the toll.

3.1.8.2

Computational Efficiency of Disaggregate Data Structures

In an aggregate model framework, used in most trip-based models, it is necessary to create and maintain a separate trip table for each sociodemographic segment that one wants to use as an explanatory variable in a model. For example, to represent household automobile ownership levels or income group affiliation in a mode choice model, there needs to be separate trip tables for each level of each variable. To add more variables, such as trip purpose or household type, requires creating separate trip tables

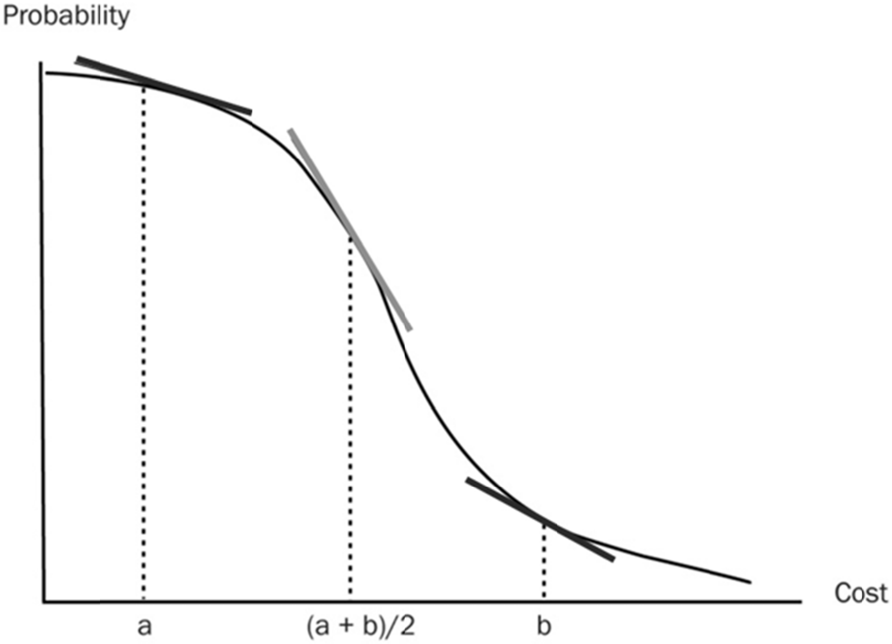

Figure 3.16. *Aggregation bias in application of logit models.*

for each level of each variable, a step that can be inefficient if not intractable for large numbers of variables. Each additional trip table leads to further fractional allocations of trips, increasingly sparse matrices, and proportional increases in computer memory requirements and hard-disk space.

In contrast, disaggregate models maintain representation in a list-table format. An example of the trip-list table format is shown in Figure 3.17, depicting a day's worth of activities for one individual. Each record represents a trip, and each column can represent an explanatory variable to be used in the model. To specify an additional variable in a model is simply a matter of adding a column to the trip-list table; the column addition has a relatively small impact on computational resources, compared with aggregate methods.

The trip-list table structure is also convenient for querying model outputs. The table format in the figure lends itself well to creating new variables and grouping outcomes by household or person attributes, geographic unit, activity purpose, trip or tour mode, and potentially other variables. For example, we might want to calculate activity and trip duration and add gender as an explanatory variable, so that we can summarize the amount of time spent shopping or commuting and make a comparison between women and men.

3.1.8.3
Monte Carlo Simulation

Prediction using simulation methods is another important difference between activity-based modeling systems and trip-based models. Table 3.1 uses mode choice models as an example since this is the one place where discrete

Hhid	**Perid**	**Dayno**	**Tourno**	**Tripno**	**Activity**	**OTAZ**	**DTAZ**	**Depart**	**Mode**	**Age**	**Inc**
626	1	2	1	1	Escort	39	82	7:00	HOV2	55	4
626	1	2	1	2	Work	82	1290	7:10	SOV	55	4
626	1	2	1	3	HHbus	1290	160	15:25	SOV	55	4
626	1	2	1	4	Shopping	160	96	16:10	SOV	55	4
626	1	2	0	5	Home	96	39	17:00	SOV	55	4
626	1	2	2	6	Jnt shop	39	87	19:00	HOV2	55	4
626	1	2	0	7	Home	87	39	21:00	HOV2	55	4

Figure 3.17. *Example of activity-based model trip-list table structure.*

TABLE 3.1. COMPARISON OF 4-STEP AND MICROSIMULATION IMPLEMENTATIONS

Conventional 4-Step Model-Mode Choice	**Activity/Tour-Based/Simulation-Mode Choice**
For each market segment, defined by trip purpose and household demographic group, predict the probability of each mode for each O-D pair.	Predict probability of each simulated chooser selecting each mode for a specific O-D pair and purpose.
Allocate the number of trips for each market segment and O-D pair to modes in proportion to their predicted probabilities.	Use Monte Carlo random draws to predict a single mode choice.
Sum over market segments to form trip tables.	Sum over choosers and purposes, grouped by O-D pair, to form trip tables for network assignment.

choice models are consistently used in trip-based modeling systems. In a trip-based model, market segments are defined by trip purpose and household demographic groups, and the model predicts the probability of each mode for each O-D pair. The model then allocates the fraction of trips for each segment and O-D pair to modes in proportion to their predicted probabilities. This is an aggregate prediction, which is then summed over all market segments to form trip tables.

In an activity-based model using simulation, the model predicts the probability of each simulated chooser selecting a mode for a specific O-D pair and purpose and then uses Monte Carlo random draws to predict a single mode choice, represented in integer format. To form trip tables for network assignment, the model aggregates over all of the individual trip records, grouped by O-D pair.

There are three basic steps in Monte Carlo prediction. Here mode choice is used to illustrate an example, but the same applies to any of the choice models discussed thus far.

1. Predict the probability and cumulative probability for each alternative outcome as shown in Table 3.2.
2. Draw a random number from a uniform distribution on the unit interval (0…1): for example, **Rand() = 0.76**.
3. Create lower and upper bounds for each alternative. Select the alternative with the range on the cumulative probability array that includes the random draw, as shown (bold and shaded) in Table 3.3.

Monte Carlo simulation has advantages and disadvantages compared with expected values used in trip-based models. The key advantage of Monte Carlo simulation is that explanatory variables can be included in models with little computational overhead (as opposed to aggregate models, in which each market segment increases the number of calculations exponentially). Outcomes of previous model components can be used as explanatory variables in subsequent components.

3.1.8.4
Simulation Variance

The key disadvantage of Monte Carlo simulation is that multiple runs are required in order to determine the expected values, or average results, for certain model outputs. This has implications for forecasting, but there are ways to compensate for the disadvantages that are employed in most practical activity-based models.

The amount of variability in model results depends on the number of agents making the choice decision and the size of the probability of the choice. For example, lower probability choices have more variability in their outcomes

TABLE 3.2. EXAMPLE OF MONTE CARLO PROBABILITY AND CUMULATIVE PROBABILITY

Monte Carlo	**SOV**	**HOV**	**Bus**	**LRT**	**Walk**	**Bike**
Probability	0.56	0.28	0.03	0.08	0.01	0.04
Cumulative Probability	0.56	0.84	0.87	0.95	0.96	1.00

Note: LRT = light rail transit.

TABLE 3.3. EXAMPLE OF MONTE CARLO LOWER AND UPPER BOUNDS AND ALTERNATIVE SELECTION

Monte Carlo	**SOV**	**HOV**	**Bus**	**LRT**	**Walk**	**Bike**
Lower Bound	0.00	**0.57**	0.85	0.88	0.96	0.97
Upper Bound	0.56	**0.84**	0.87	0.95	0.96	1.00

than higher probability choices. Because most outputs from activity-based models are aggregations of choices, one run of the model can be a sufficient indication of the expected outcome from an area-wide policy. Following the law of large numbers, as the number of model runs gets very large, aggregate outcome averages will converge to a consistent estimate.

In terms of variance, regional VMT, vehicle hours of travel (VHT), district-level tour flows, tours and trips by mode, and higher facility-type link estimates and transit line boardings tend to be very stable from run to run. For more disaggregate analysis, such as TAZ-level origins and destinations, lower facility-type link loadings, and lower ridership transit routes, can have more variation and therefore multiple runs of the model system may be required, where results are averaged across the runs.

There are ways of compensating for Monte Carlo variability. One way is to fix the random number seed in the functions used by the program to generate random numbers. While this can be a bit complex for a large number of choices, this results in the program generating the same sequence of random numbers for successive runs, which means that outcomes will only vary according to changes in inputs. This ensures stability from run to run but at the cost of representing only one possible outcome from the model. For some applications, it may be preferable to do many runs and average the aggregate results to obtain an expected value.

The ability to control the random seeds and sequences in model application is useful because it provides confidence that the model implementation runs consistently and that it produces the same outputs, given the same inputs. Once the random numbers are controlled, users are able to exploit this model feature to run the model system more efficiently and to produce better performance measures. Activity-based models should be run multiple times in order to account for simulation variation (also referred to as simulation error). The disaggregate outputs can be used to produce distributions and confidence intervals for core activity-based model measures, in addition to average values that can be used as inputs to traditional static assignment models. If regional-scale DTA and simulation models are adopted, use of disaggregate outputs to produce multiple network simulations may be desirable. Empirical testing of the number of runs required to produce results with confidence is also desirable, although only a limited number of regions have implemented this in practice. The number of runs is dependent on the spatial, temporal, or typological detail that is of interest. Analysis of smaller spatial, temporal, or typological segments requires more runs.

An additional important issue is how these performance indicators are transmitted and explained to decision makers. Because traditional 4-step models do not produce distributions of outcomes given fixed inputs, decision makers are most familiar with the single-point forecasts generated by these models. Thus, the communication and interpretation of activity-based models that include ranges of potential outcomes presents new opportunities and challenges. Distributions or ranges of outcomes provide the advantage of illustrating the degree of uncertainty around different outcomes, but may be misinterpreted by decision makers if not properly presented.

3.1.8.5

Convergence and Equilibration

As described in Chapter 2, linked demand-and-supply model systems such as activity-based model systems typically include processes of iterative feedback. These feedback processes are implemented in the network supply model as well as between the network supply model and the activity-based model components. Iterative feedback is used to ensure that the models are achieving convergence to an equilibrium, or at least a stable, condition. Convergence is important within the context of activity-based model systems because it provides confidence in the integrity of the model system and helps ensure that the model will be a useful analytic tool. To be useful in an application context, the model system must produce similar outputs when seeded with similar outputs, so that the analyst can have confidence that changes in model outputs can be attributed to changes in model inputs and not to "noise" resulting from the configuration of the model system.

The focus of this discussion is on the systematic and iterative exchange of information implemented between the activity-based demand model and a network assignment model in order to converge to a stable solution. The most general description of this process is that the activity-based demand model produces estimates of demand that are then used as input to the network assignment model. The network assignment model assigns this travel demand to network paths, producing estimates of link volumes and speeds, and O-D travel times and costs by travel mode, time of day, and possibly user class. This process is iteratively repeated in order to achieve stable estimates of travel demand, link volumes, speeds, and travel times and costs.

The simplest, naïve way to configure the model system to iterate between the demand-and-supply components is to feed the estimates of demand from the activity-based model directly into the network assignment model and then to feed the estimates of travel times and costs from the network model directly into the activity-based model. However, using this direct feedback approach may necessitate iterating between the activity-based model and the network assignment model many times before an acceptable level of stability in model system outputs is achieved. Given the time required to execute the entire model system, lengthy run times may result that can compromise the usefulness of the model in an application context.

To help the model system achieve an acceptable level of stability more quickly, a number of convergence strategies have been developed. First, enforcement strategies are often employed. These enforcement strategies are similar to those used in traditional trip-based models and include methods such as the averaging of travel demand across successive iterations before network assignment, the averaging of network skims or impedances before demand simulation, and the averaging of link-level volume or impedances before the generation of updated skims. Figure 3.18 illustrates two commonly used enforcement methods. Note that it is recommended to use both strategies simultaneously.

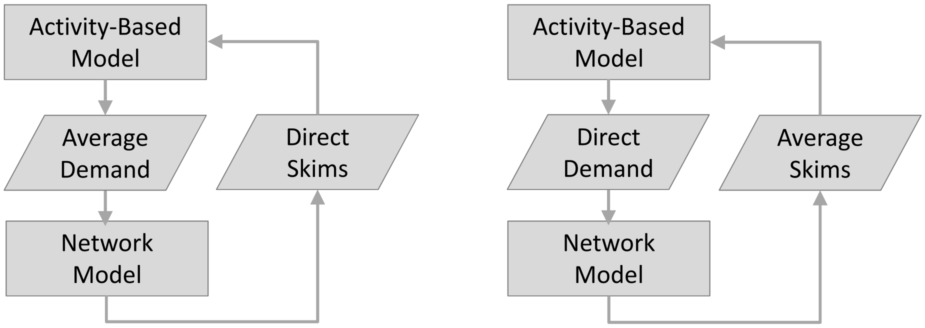

Figure 3.18. *Model system enforcement strategies.*

Second, the activity-based model sample rates are often varied. Because the activity-based model is implemented in a disaggregate Monte Carlo simulation framework, it is possible to run the model using only subsamples of the population; this option can significantly reduce model run times. Many activity-based model systems have been configured so that earlier iterations of the model run employ small subsamples, such as 10% or 25% of the regional population, while later iterations of the model run use a full 100% sample.

Third, the overall model system can be configured to run a fixed number of iterations or to run until a prespecified convergence gap criterion has been achieved. The gap criterion is typically based on changes in demand or changes in travel times. Note that if a convergence criterion is used in conjunction with an enforcement strategy, then the criterion must not use the enforcement metric. For example, if demand is averaged successively across iterations, changes in demand cannot be used as the convergence criterion. For model system convergence, it is more common in practice to assert a fixed number of iterations, typically between three and ten, than to use a convergence criterion. Use of a fixed number of iterations should be based on an empirical investigation that identifies the degree of convergence associated with different configurations.

Finally, note that different levels of convergence, and by extension different numbers and types of iterative execution of the model system, are required for different application contexts. For example, analyses of detailed geographic, spatial, modal, or demographic segments require higher levels of convergence in order to ensure that difference between alternatives are attributable to policy or investment being tested, and not because of the way the model system is configured.

3.2
DESIGN

This section presents concepts relevant to activity-based model system design and provides an overview of an overall approach to activity-based model design. The following sections first consider concepts related to spatial scale, temporal scale, and typological or market segmentation detail. As described in Chapter 2, the resolution, or level of detail, associated with these key dimensions is a critical consideration, and activity-based models are distinguished from trip-based models in two important ways. First, in contrast to the zone-based looping structure of most trip-based models, adding more zones, more time periods, more demographic segments, or more trip purposes does not greatly increase the run time of activity-based model components. Adding detail along all of those dimensions has not been practical in the past because the run time and data storage requirements in trip-based models are proportional to the square of the number of zones, times the number of population segments, times the number of trip purposes, times the number of time periods. In an activity-based demand microsimulation, however, the run time depends primarily on the number of different households and persons simulated. The amount of detail used in the various dimensions may add to memory requirements but will not substantially influence run times. This fundamental difference is what has made it possible to include more detail in activity-based models.

3.2.1
Spatial Scale

Activity-based models and, more generally, many travel demand models are intrinsically spatial models. The locations of households, employment, tour and trip origins and destinations, and many other model inputs and outputs are spatial. A number of core components of activity-based models systems, such as usual work and school location models, tour destination location models, and stop location models predict travelers' choices of locations.

Spatial scale refers to the resolution or level of detail used to define the spatial units that collectively make up the region and that are used to characterize key model inputs, outputs, and sensitivities. There is no correct spatial scale. Rather, when seeking to identify the appropriate level of detail to incorporate into the model system design, it is necessary to consider critical issues such as the types of sensitivities to policies and projects that the model system is required to have, in conjunction with considering the type and availability of spatial data needed to implement and apply the model.

Key model system data inputs for which spatial information is required include

- Household and population totals, potentially incorporating key demographic segmentations such as income, age, or other attributes;
- Employment information, often in the form of employment totals by industrial sector;
- School enrollment by grade;
- Parking supply and cost information;
- Hotel rooms and open space, and other urban form buffer or proximity-based measures;
- Skims of travel times and costs by mode and time of day; and
- Accessibility indicators.

Generally speaking, use of fewer, larger spatial units reduces model run times and also reduces the level of data preparation burden. But larger spatial units introduce aggregation bias and reduce the sensitivity of the model to effects such as the local land use mix or the distance to transit. Conversely, use of a greater number of smaller spatial units often increases model run times but also reduces aggregation bias and increases the sensitivity to small-scale land use and transportation system effects.

Multiple spatial scales may be used within a model system. For example, microzone or parcel geographies may be used to represent the locations of employment and population for measuring the attractiveness of locations, while TAZ geographies may be used to represent automobile travel times and transit access points used to represent transit travel times. It may be useful to use very small spatial units when estimating walk mode travel times and distances, either for entire trips or to access transit, but this may not be necessary when estimating the travel times and distances for long automobile trips. The spatial scale of the activity-based model should also be defined in coordination with the spatial scale used for the network assignment model. The following sections describe some of the spatial scales that are commonly used in activity-based model systems.

3.2.1.1

Zones

Travel analysis zones are used in most travel demand model systems. The term TAZ is generic and does not imply or refer to any specific scale. However, TAZs are often defined so that they are similar to or consistent with an existing geographic system such as a region's Census tracts or Census block groups. The number of TAZs in a region typically ranges from 500 to 5,000. However, within a region, there may be a fair amount of variation in size among the TAZs. TAZs defined for the purposes of trip-based models can be readily used in activity-based model development. As a result, implementing an activity-based model using a traditional TAZ-level of spatial of detail is relatively straightforward because TAZ-level information developed to support trip-based model implementation can be used directly, or easily translated to, the activity-based model implementation.

3.2.1.2
Microzones

Like TAZ, the term microzone is a generic term that does not refer to a specific scale. Instead this term is intended to describe a geographic system that incorporates more spatial detail than a typical TAZ system. In a number of regions, microzones have been defined at a resolution that is similar to that of Census blocks, although the block geography is usually modified to ensure that the individual microzones will be meaningful within the model system. For example, blocks that represent water features such as rivers or lakes may be combined with adjacent microzones. Developing microzone-level spatial information, especially for future-year scenarios, can be more involved than developing TAZ-level spatial information. However, there are a number of spatially detailed, publically available datasets that can be used to create these microzone-level assumptions. A typical model might include 30,000–150,000 microzones, an order of magnitude more than the typical number of TAZs but also less than a typical number of parcels in a region.

3.2.1.3
Parcels

Parcels have a more specific definition than TAZs or microzones. Parcel geographies are most often defined by local-level municipal and county tax assessors' offices. Parcels are usually extremely fine-grained, with each spatial unit often corresponding to the geography associated with a single building. However, as with TAZs and microzones, there is significant variation in parcel sizes. For example, large institutions that contain diversity of buildings, employment, and uses may be represented by a single parcel. Using a parcel-level spatial scale can provide the greatest ability to incorporate local-level, smaller-scale land use and transportation system attributes, such as the mix of employment within a short walking distance or the distance to the nearest actual transit stop. Developing, maintaining, and forecasting parcel-level attributes requires more effort than developing similar TAZ-level or microzone-level attributes, especially on the employment side. There are often inconsistencies and errors in the base-year or observed data sources, and developing future-year parcels requires careful consideration of the sources for detailed future population and employment assumptions and potentially methods and practices for splitting parcels as development occurs.

3.2.2
Temporal Scale and Scheduling

The explicit representation of the time-of-day and scheduling choices, and the relationship between these schedule choices and other choices of tour and trip destinations and travel modes, is one of the primary features that distinguishes activity-based model systems from trip-based models. In many trip-based models, travel demand is estimated at a daily level, and a set of fixed factors may be applied to disaggregate this daily demand to time periods in order to generate time-period-specific estimates of network performance, such a peak hour or peak period traffic volumes and speeds. But use of fixed factors renders the model system insensitive to many influences on travelers' choices of travel time, such as accessibilities and the number or type of other household and person activities. The following sections describe some of the issues of temporal scale, then address notions of activity scheduling, and finally explain how scheduling and time-of-day choice relate to other elements of the activity-based model system.

3.2.2.1

Temporal Scale

People experience time as a continuous phenomenon, with one moment seamlessly transitioning to the next; in activity-based model systems time is broken down into discrete intervals or time periods. As with the representation of space, the resolution used to define these time periods can vary from one activity-based model to another, and different temporal resolutions may be used even within the same activity-based model system.

The temporal scale used in the models defines the alternatives that can be used in the time-of-day and scheduling models. The earliest activity-based models tended to use a relatively coarse temporal scale of four or five broad time periods, typically defined consistently with the five or six time periods used in the network assignment model component of the overall model system. Shortly thereafter, more detailed temporal scales were incorporated into activity-based model systems, including hours and half-hours. Some activity-based model systems have incorporated the use of quasicontinuous time. These different temporal scales result in different model sensitivities, run times, and complexity. Because these time periods are often used in combination with each other (for example, jointly predicting the time a traveler leaves his or her home in the morning and the time he or she returns home in the evening), use of more detailed temporal resolutions leads to a multiplicative increase in the number of time-period combinations that the model system needs to consider. However, the potential benefit of this increased temporal detail is improved model sensitivity.

Often, different temporal scales are used within the same overall model system. Specifically, it is common practice to use detailed time periods such as hours or half-hours to support activity scheduling, while using only broad time periods when assigning travel demand in static network assignment models. Most activity-based models used in practice are linked to static network assignment models in order to generate an estimate of network impedances required for input to the model components such as the scheduling models. Static assignment models cannot reasonably be applied to large regions for very short time intervals because the time required to complete a given trip can exceed the boundaries of the static network assignment time period. As a result, many activity-based model systems are linked to static network assignments that use five to eight time periods in order to portray the main differences in network performance by time-of-day periods.

3.2.2.2

Activity Scheduling

Scheduling, or time-of-day, model components are included in activity-based models to represent the important fundamental dimension of time in activity and travel choice. At the simplest level, time-of-day models are used to predict when activities start and end, as well as their duration. In most activity-based model systems, there are two levels at which schedule choice is considered: the tour level and the trip level. Trip-level scheduling is constrained by tour-level scheduling.

Activity-based models have generally employed one of two primary approaches for representing the scheduling process. Most activity-based models used in practice have implemented a scheduling hierarchy to schedule tours first. Using this hierarchy, mandatory purpose activities such as work and school tours are scheduled first, followed by maintenance purpose activities, and finally discretionary purpose activities such as social/recreational tours. Some activity-based models also incorporate intra-household interactions, and these models typically schedule any joint travel made by members of the same household after scheduling individual mandatory activities but before scheduling any individual maintenance or discretionary activities. An alternative to the hierarchy-based approach is to build the schedule chronologically through the day, perhaps starting with an initial basic schedule.

It should be noted that even within those models that use a scheduling hierarchy, there are different approaches. For example, some activity-based models assume an initial overall daily framework describing when travelers leave their homes, when they return, and then populate the travelers' entire day by adding details such as stops and departure times. In contrast, other activity-based models define an initial set of primary activities and then build out the schedule for the day, ultimately resulting in information about when travelers leave home and when they return.

3.2.2.3

Time Constraints and Time Windows

An important aspect of activity-based models is properly representing the effect of time constraints on people's activity and travel choices. Some early activity-based models did not rigorously do this, allowing tours to be scheduled during overlapping time periods. However, more advanced activity-based models carefully account for time constraints to ensure that all tours and trips are made consistently, and also to more accurately incorporate the effect of time constraints on activity and travel choices. After an activity is scheduled, the time periods used are made unavailable for scheduling other activities. This blocking out of time may also incorporate the travel time expected when transitioning from one activity to the next. The remaining time periods are referred to as available time windows, and are available for other activities. This logic ensures that no person can be in more than one place at one time. Use of time windows also extends to the scheduling of joint activities in activity-based models with intra-household interactions. These models take into account the schedules of multiple persons within the household, scheduling joint activities only when all participants have sufficient time for the activity and associated travel.

3.2.2.4

Sensitivities

The scheduling and time-of-day models included in activity-based models system are sensitive to a broad range of factors, including person and household characteristics, trip and tour characteristics, accessibilities, and individual activity patterns and scheduling pressure. For example, these models reflect the fact that higher income workers may work longer hours, but that they tend not to work very early or late. These models can also show how, as more activities are scheduled during a day, the duration of these activities is reduced. One distinguishing feature of the scheduling and time-of-day models included in most activity-based models used in practice is the use of shift variables. Shift variables are used to concisely represent rescheduling sensitivities based on activity purpose, traveler, and other attributes including, importantly, travel time and cost. Shift variables allow for a single variable to affect the entire temporal distribution. For example, use of shift variables can capture the effect that longer travel times tend to lengthen the duration of work tour, shift departures from home to work earlier, and shift arrivals back home later. They also capture the tendency to shift travel out of the most heavily congested time periods or to avoid peak period tolls.

3.2.2.5

Linkages with Other Models

In most activity-based model systems used in practice, certain types of choices are made at both the tour level and the trip level, including choices of destination, travel mode, and time of day. The tour-level choices of destination, mode, and time of day are usually executed sequentially, followed by these same choices being made at the trip level. There is no single correct placement of scheduling and time-of-day models in relation to other models. At the tour level, some activity-based models place the scheduling model in sequence after tour destination choice but before tour mode choice, while other activity-based models incorporate two-stage tour scheduling, with a preliminary tour time of day selected before both tour destination choice and tour mode choice, and a final tour time of day selected after destination and mode choice. In most activity-based models, trip-level scheduling choices always follow trip stop location choices, although sometimes trip-level scheduling precedes, and other times follows, trip mode choice.

3.2.3
Sociodemographics and Population Synthesis

3.2.3.1
Sociodemographics

Sociodemographics refers to a set of attributes that characterize individual households and persons in a population. The household sociodemographic attributes that usually are of greatest interest in activity-based models are household size, number of workers, presence of children, age of the head of household, and household income, although many other household-level attributes are also used. The person-level attributes that are often used in activity-based models include age, gender, and worker or student status, although many other person-level attributes are also used.

Activity-based models are used to make predictions of whether, when, where, and how to participate in activities and to provide information about the travel required in order to engage in these activities. The sociodemographic attributes included in a travel demand model should provide information that helps explain how different households and persons make different activity-related and travel-related choices. Information about household size, household income, person age, and other sociodemographic attributes are included in activity-based models because they have been shown to provide meaningful explanatory power regarding these choices. Other variables such as housing type and own/rent status may become more commonly used in the future in cases where activity-based models are integrated with a land use model that predicts such outcomes.

3.2.3.2
Market Segmentation

In travel demand forecasting, market segmentation refers to the structuring of different decision-making units and different choice contexts into smaller groups in order to avoid issues of aggregation bias and to provide more accurate model sensitivities. Market segmentation is different in an activity-based model than in a traditional trip-based model. In a trip-based model, detailed market segments are defined at the beginning of the model stream, and this market segmentation is either held constant, or perhaps is simplified, in each subsequent step of the model system. For example, a trip-based model may include segmentation by automobile ownership level that reflects the fact that, relative to households that own private vehicles, households with zero vehicles may generally make fewer trips, may choose their trip destinations differently, and may choose different travel modes. Separate matrices representing zero-vehicle and nonzero-vehicle households are needed throughout the entire model system.

3.2.3.3
Synthetic Population

Market segmentation is also used in activity-based models but with a greater degree of flexibility. Activity-based models usually use a synthetic population that is essentially a list of all of the households and people within the modeled area and that includes detailed information related to key explanatory variables. Because the synthetic population is in a disaggregate list-based format and includes detailed sociodemographic information, there is greater flexibility with respect to the definition and use of market segments in activity-based models. Market segmentation is used in a number of ways in activity-based models.

First, the synthetic population process that generates this key input to the activity-based model is guided by a set of demographic "marginal controls" that represent the distribution of important attributes that impact travel demand choices of the population, such as household size and income. Second, once the synthetic population has been created according to the market segmentation implied by the control variables, it is common practice to calculate additional market segmentation attributes, such as person types. This person-type segmentation, which may include values such as "worker," "student," or "nonworking adult" is used to structure choices in the model system. For example, nonworking adults will not make choices related to usual workplaces or work tours. Finally, the specifications of the individual activity-based model components may include additional market segmentation. For example, although the synthetic population used in the model may include continuous variables such as those related to income and age, it is often better to group income and age into categories in order to achieve a better model fit. A key design question is determining how these categories should be defined. Note that the market segmentation used in any given individual model component does not necessarily need to correspond to the segmentation used to define the marginal controls, although it is good practice to align these segments to the greatest extent possible. A more detailed discussion of the development of a synthetic population can be found in Section 3.3.

3.2.4

Long-Term and Mobility Choices

Some of the important choices that influence day-to-day travel behavior are not made on a daily basis, but are made on a less frequent, longer-term basis. Examples of such choices include decisions of where to work (for workers) and where to go to school (for students). Other longer-term choices are related to the specific mobility options people and households decide to use. This can include owning automobiles, driving licenses, bicycles, transit passes, and toll transponders. Workers can also decide to follow specific types of work schedules and may or may not have a free or subsidized parking space available at the workplace. All of these mobility decisions can significantly influence the availability and attractiveness of different location, mode, and scheduling choices that create daily activity and travel patterns.

3.2.5

Activity Purposes and Joint Travel

Early activity-based models tended to include only 3 or 4 distinct activity purposes, such as work, school, other, maintenance, and discretionary. Recently, as many as 7 to 10 activity purposes have been included in activity-based models. Escort activities (also referred to as "chauffeuring" or "serve passenger") tend to have different characteristics from other activities, particularly in terms of mode choice, since they tend to involve automobile shared-ride tours. Meal activities can usefully be separated from other types of maintenance activities, because they tend to take place during certain periods of the day at locations where food service employment is located. Shopping is another type of maintenance activity that can be tied to specific attraction variables, such as retail employment, and tends to happen during store opening hours. Medical visits are another activity purpose that can be tied to a specific attraction variable (medical employment).

On the discretionary side, it can be useful to separate social visits as a separate activity purpose, as they often occur at residential locations, outside working hours. Outdoor recreation can be another useful activity category, as it can be tied to open space/parks/sport fields, and so forth, as attraction variables. In general, if the land use data have sufficient detail that will allow one to predict where specific types of activities are likely to take place, then the data can also be useful to distinguish those types of activities in the activity-based model components. In this way, the model can better predict which types of people tend to visit certain types of locations during certain periods of the day and can more accurately predict changes in behavior when the distribution of land uses or demographic characteristics of the population change.

3.2.6

Travel Modes

As described in Chapter 2, the set of modes used in an activity-based model is similar to the set that would be used in a trip-based model. These modes include automobile modes such as drive alone (DA), and shared ride (SR2, SR3), as well as transit modes and nonmotorized modes. However, the activity-based model is not limited to a simple representation of modal alternatives but can also include detailed submodal alternatives such as managed lanes, bus rapid transit, and commuter rail.

The representation of travel modes is related to the structure of the activity-based model, in which mode choices are made both at the tour level and the trip level. The tour mode is defined as the primary mode for the entire sequence of trips that make up the tour. However, the tour mode is not necessarily used for all the trips on a tour and is not even explicitly reported by travelers in a household travel survey. The tour mode is defined in the model design and is determined based on the nodes that are used for the trips on a tour. Tour modes may be defined at a relatively aggregate level. For example, a typical tour mode choice model might include the following alternatives:

- Drive alone (DA)
- Shared ride 2 (SR2)
- Shared ride 3+ (SR3)
- Walk (WK)
- Bike (BI)
- Walk-to-transit (W-TRN)
- Drive-to-transit (D-TRN)

The inputs to the tour mode choice model in an activity-based model are generally similar to the types of inputs to a traditional trip-based mode choice model. These common inputs include information about purpose, time of day, automobile ownership, and household income. However, there are some features that distinguish tour mode choice models. Perhaps the most significant difference is that tour mode choice models consider the travel times and costs for the entire round trip, including both the journey to the tour destination and the return from the destination to home. In order to accurately capture these times and costs the model uses time-period- and direction-specific multimodal network skims. Another significant difference is that, because the activity-based model is implemented using a disaggregate microsimulation framework, tour mode choice models often include detailed household- and person-level variables, such as person type, age, and parking subsidies that may significantly improve the explanatory power of the model relative to a trip-based mode choice model. Similar to trip-based mode choices, tour mode choice models are typically segmented by purpose and may include land use and other urban form variables.

The trip mode is the travel model that is used for each individual trip on the tour. Trip mode choice models may contain more detail, such as transit submodes or tolling alternatives. Consistency between the tour mode and the trip mode is essential, although this does not mean that all trips on a tour use the same mode. Rather, it requires a logical consistency across all of the choices made by an individual. Tour mode is defined in relationship to trip mode. In the simplest cases, all trips on a tour have the same mode. For example, if a traveler drives alone from home to work and back, there are two DA trips, and thus this tour can be easily classified as a DA tour. However, it is also common for travelers to use multiple different modes on the same tour. Common examples of this include tours in which the vehicle occupancy on a traveler's tour changes as a result of picking up or dropping off passengers, or in which a person uses both transit and walk modes on the same tour. For tours where multiple trip modes are used, a hierarchy is used to identify the tour mode. For example, if a person's tour includes both shared-ride trips and DA trips, the tour would be classified as a shared-ride tour. Similarly, if a tour includes both walk-to-transit trips and walk trips, the tour would be classified as a transit tour. These classifications are then used in model application to ensure that the predicted trip modes are consistent with the predicted tour modes. Table 3.4 illustrates the availability of trip modes by tour mode.

3.2.6.1

Accessibilities

Accessibility measures are critical to ensuring reasonable policy sensitivity at the various levels of the model to changes in infrastructure or land use, or both. In general, four types of accessibility variables are included in the models:

1. Direct measures of travel times, distances, and costs from modeled network paths;
2. Detailed logsums calculated across alternatives of models that include direct measures;
3. Aggregate (approximate) logsums calculated across alternatives of models that include direct measures; and
4. Buffer measures representing the activity opportunities and urban design surrounding each parcel or microzone (e.g., Census block).

The direct measures are used in all mode, destination, and time-of-day choice models wherever possible. Often, however, the model

TABLE 3.4. TRIP AND TOUR MODE AVAILABILITY

	Tour Mode						
Trip Mode	**DA**	**SR2**	**SR3**	**Walk**	**Bike**	**W-TRN**	**D-TRN**
DA	X	X	X				X
SR2		X	X			X	X
SR3			X			X	X
Walk	X	X	X	X	X	X	X
Bike					X	X	X
W-Bus						X	X
W-Rail						X	X
D-Bus							X
D-Rail							X

hierarchy makes it impossible to use a direct measure because it depends on a yet-unmodeled outcome. This would be the case, for example, for travel time in a destination-choice model that is higher in the hierarchy than mode and/or time-of-day choice, since in order to measure travel time directly it is necessary to know the mode and time of day. In such cases, detailed logsums can be calculated from the lower-level choice models and used instead of direct measures in the upper-level model. A typical example in practical activity-based models is the use of tour mode choice model logsums in higher-level models such as tour time-of-day choice, tour destination choice, and workplace location choice.

There are cases when it is not practical to use the most fully detailed versions of the logsums that are calculated on the fly during the simulation every time one is needed. To address this issue, a common approach is to precalculate more aggregate accessibility logsums to be used in models where using the more impractical ones would not be computationally or conceptually feasible. For example, some model systems use aggregate accessibility logsums calculated from each origin TAZ or microzone, to all possible destinations, via all possible modes, with the different modes and destinations weighted approximately as they would be in a fully detailed logsum across a tour mode and destination-choice model. Aggregate logsums are typically calculated for each combination of up to 4 or 5 critical dimensions, including

- Origin TAZ or microzone;
- Tour purpose;
- Household income group or VOT group;
- Household automobile sufficiency (automobiles owned compared with driving-age adults); and
- Household residence distance from transit service.

These few dimensions are typically chosen because they tend to be the most critical variables in mode choice models and will thus help determine how much influence the different available modes will have on the logsum measures. For example, the accessibility logsum for the zero-vehicle household segments depends critically on how accessible destinations are by nonautomobile modes from the given origin, while the logsums for the lowest income (or VOT) group will be most sensitive to travel costs such as tolls and transit fares.

Aggregate measures are used most often in the day-level models and some of the longer-term models, where the model is not yet considering a tour to a specific destination, but is considering, for example, how many tours to make for a given purpose from the home location during the day. In that case, the overall accessibility from the residence for each purpose can have an effect. It is through these types of variables that activity-based models can represent true induced trip and suppressed trip effects (as opposed to simply shifting destinations or modes).

Although it is important to be able to represent such effects, they are, both in reality and in the models, small relative to other types of choice responses that occur at the other levels of the model system. So, although it is important to include these effects, they may not be so substantial that it would be worthwhile trying to implement fully detailed logsums for all levels of the model system, a process that could increase model complexity and run times by an order of magnitude. For that same reason, it is typical to use less spatial and temporal detail in the aggregate logsums than is used in the fully detailed logsums.

For example, if the model uses parcels or Census blocks for the basic spatial unit, it may use only TAZ-level detail for the aggregate logsums. One reason is that they mainly represent accessibility over all distances for the entire region, while other measures such as buffer-based measures can be better at measuring very local accessibility over short distances. As another example, in many cases time of day is not included as an explicit dimension in the aggregate logsums. Instead, the model design might use the most typical times of day for each travel purpose to specify which time-of-day–related congestion levels to use in calculating the measures. It would be possible to use time of day as an added dimension, and that is another case where model designers trade off whether adding detail that is likely to have a small influence on the results would be worth the increase in computation time.

Finally, buffered measures represent the accessibility to very nearby destinations, as could be made by walk, bike, or very short car trips. The typical measures that are buffered include

- The number of nearby households;
- The number of nearby jobs of various types (as proxies for activity locations);
- The number of nearby school enrollment places of various school types;
- The number of nearby paid parking places, and their average price level;
- The number and average size of nearby parks and open space (for recreation);
- The number of nearby street intersections of various types (e.g., T-junctions, 4+ links);
- The number of nearby dead-ends and cul-de-sacs; and
- The number of nearby transit stops.

As seen from these variables, the buffer measures represent the neighborhood characteristics in terms of land use and urban design along a number of dimensions. The two different types of measures for street system design can be used to represent the positive accessibility of having a dense network versus the negative accessibility of a layout with many dead-ends and cul-de-sacs.

The traditional way to calculate buffer measures has been to use a simple radius, such as a quarter-mile or half-mile, and count up everything within that radius, giving everything an equal weight. This method provides a simple density measure within a circle.

Clearly, these measures are most relevant when the spatial units themselves are much smaller than the radius of the buffer area. Thus, using buffer-based measures is really only useful when the spatial unit of the model is the parcel or (at the largest) the Census block. Also, the measures are more important to include in the models in such cases, because they represent the neighborhood effects around the spatial alternatives of interest. For example, one may be more likely to shop at a parcel (or block) where there are additional shopping (or meal) opportunities located nearby. In models using fairly large TAZs as the main spatial unit, these neighborhood effects are already included to some extent, but in a less consistent way, because the relevant nearby attractions may not be in the same TAZ.

One way to make the buffer measures more accurate and relevant is to use on-street shortest-path distance to measure the distance to the edge of the buffer, rather than using straight line (as the crow flies) or Euclidean distances. In this way, the buffers represent the effects of possible obstacles such as rivers, freeways, rail yards, as well as street layouts with poor connectivity. A second way to make the measures more relevant is to use distance-decay weighted measures rather than simply counting up everything within a certain distance and weighting equally. This makes the measures more behaviorally relevant, with nearer attractions being weighted more highly, and also helps to avoid some of the boundary effects and arbitrariness of using a single fixed radius.

3.3

COMPONENTS

This section introduces the major types of components included in most activity-based model systems. The various types of components are then described in greater detail in the following subsections. Although the exact structure of implementations in specific regions or software packages is not described in detail, the similarities in the design of those implementations are highlighted. In certain cases where important differences can be found among the existing U.S. implementations, the design differences and main options are introduced and discussed. If the reader wishes to find more detailed information regarding specific model implementations, the authors recommend consulting the references. The material from the Travel Model Improvement Program (TMIP) activity-based model webinar series (Resource Systems Group 2012a) can also be a useful source of detailed information, as many of the webinar series topics follow the same sequence as the model component subsections that follow.

Figure 3.19 depicts the main component sections of applied activity-based model systems. Between the model inputs and outputs, the figure shows

- Longer-term choices;
- Mobility choices;
- Day activity patterns (DAPs);
- Tour and trip details; and
- Trip assignment.

Going from top to bottom in the figure, each model component is conditional on the choices simulated in the higher components. This is termed “downward integrity,” meaning that the choices are consistent with previously predicted choices. For example, the number of tours for each purpose predicted in the DAP

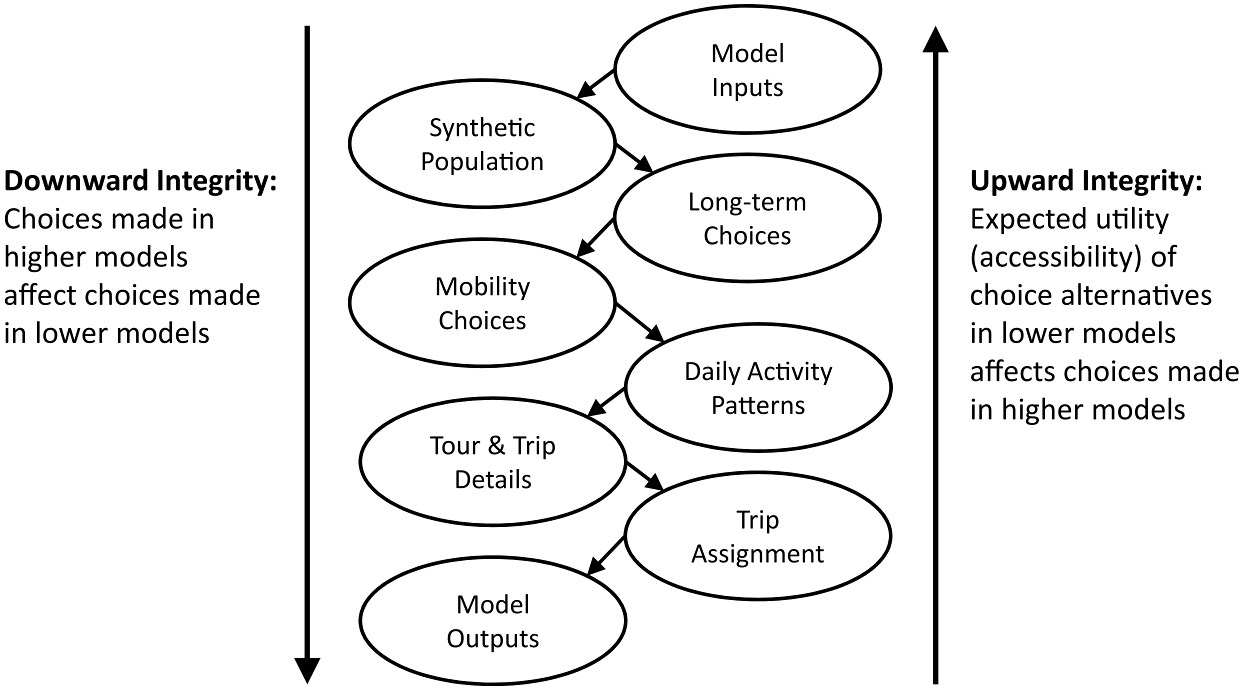

Figure 3.19. *Downward and upward model integrity.*

model components determines which tours will be simulated in the "Tour & Trip" details components. In well-designed model systems, information also flows from the lower components to the higher components. The term "upward integrity" refers to accessibility information from the available choices in the lower-level model components affecting the choices simulated in the higher-level models. Upward integrity is achieved mainly through the use of various types of accessibility measures that approximate the expected utilities (logsums) from the lower-level models. Next, each of the various types of components in Figure 3.19 is described in greater detail.

3.3.1

Population Synthesis

3.3.1.1

Purpose

In the activity-based model system, households and persons are used as the core decision-making units, making choices about key considerations like the number of vehicles a household chooses to own, the type and amount of activities that occur, and the locations of key destinations such as work and school. Activity-based model systems typically employ microsimulation, in which these choices are represented at the level of individual household or individual person. Population synthesis is used to create the lists of households and persons, or synthetic population, that are the basis for simulating these choices. The choice models that make up the activity-based model system should be specified to use only demographic variables that are available in the synthetic population, and the synthetic population should include all of the demographic attributes that are used in the choice models that compose the model system. Creating a synthetic population is the first step of running the activity-based model system.

3.3.1.2

Design

The first step in creating a synthetic population is designing its structure. This design process involves

- Selecting the sociodemographic variables that are going to be controlled (the marginal controls).
- Identifying sources of information for these variables.
- Determining the categories used to classify these variable.
- Specifying the geography that will be used.
- Identifying the source of the household and person data that will be sampled to create the synthetic population.

The selection of sociodemographic variables can be influenced by known relationships between these variables and travel demand choices as well as by anticipated policy application and analysis needs of the model system. Typical variables that are controlled in household population synthesis include

- Household size;
- Household income;
- Age of householder;
- Number of household workers; and
- Presence of children.

Some population synthesis tools also include the ability to simultaneously control person-level attributes, most frequently age and gender.

Information describing the distribution of these attributes in the population can be derived from a number of sources. Base-year data are often derived from the decennial Census, the ACS, or other TAZ-level control totals used for trip-based modeling or other regional planning efforts. Future-year data may be derived from regional socioeconomic forecasts, land use models, or other tools. It is common that agencies may have only limited or no forecast information on some of the marginal controls included in the population synthesis. In these cases, base-year distributions may be assumed to remain fixed, although such an assumption will influence the distribution of other marginal controls.

A key concern when selecting marginal controls for population synthesis is to choose a sufficient number of variables that are not highly correlated with each other. Using too few control variables may produce a synthetic population that doesn't accurately reflect the true population. Conversely, using too many control variables may result in too many sparse cells in the multidimensional distribution. Note that this multidimension distribution is created not only regionally but also ideally at smaller geographic levels such as TAZs. However, it is possible to specify control attributes at multiple spatial resolutions or geographic units, provided that the smaller geographies nest within the larger geography.

An additional concern with specifying marginal control distributions is to minimize the use of control variables or categories that may result in a sparse matrix for certain cells. A sparse matrix may make it difficult to find samples in the PUMS data or in the household survey data that match these rare combinations. And even if some samples are found, the relative rarity of these samples may mean that they are repeatedly drawn into the synthetic population an unreasonable number of times.

In general, it is desirable to use the smallest geography for which data are available, although in some instances this geography may be larger than the base geography used in the model system. For example, the activity-based model may use parcels as the basic spatial unit, but the population synthesis may be performed at the TAZ level. The synthetic population may then be allocated to parcels using a set of rules or assumptions. It is also necessary to acquire household and person data files that will be sampled to create the synthetic population. In the United States, this disaggregate sample has typically been derived from Census PUMS data. It is also possible to use household survey data as a data source for this sample.

3.3.1.3

Implementation

After the synthetic population design has been established and all required input data collected and prepared, a population synthesis software tool is typically used to actually create the synthetic population. There are a number of available tools that are differentiated by their unique features. However, most all of these perform two basic functions: (1) creating the joint multidimensional sampling distribution from the set of independent marginal controls, and (2) drawing samples of households and their associated persons into the population in such a way as to match this sampling distribution.

The first step of creating the multidimensional sampling distribution involves fitting or balancing the multiple control dimensions of the design. Most frequently, this is achieved through the use of an iterative proportional fitting (IPF) process, although other approaches exist. This process produces, at the level of geography specified in the design, the set of shares of households within each sampling type, based on the marginal controls. Alternative approaches to IPF exist and have advantages such as the ability to control both household-level and person-level marginal controls simultaneously. In addition, these methods can avoid some of the limitations and distortions that can be an outcome of a simple IPF process. For example, when there are significant structural changes in the population between a base year and a forecast year, a simple IPF procedure can distort the expected distribution. An IPF also can produce distorted distributions when there are a number of empty cells in the seed marginal distributions.

The second step involves drawing the PUMS or household survey-based samples according to these shares so that they match the targets and marginal distributions both in aggregate and at the more detailed spatial geographies. Before running this sampling, the estimated shares are applied to the input totals and converted to integer values using rounding in order to generate the targets required for sampling. Selection probabilities are calculated for all samples based on the target distribution, and random Monte Carlo simulation is then usually used to draw samples in order to create the synthetic population. There are a number of other methods for drawing samples to create a synthetic population that may involve more complex algorithms but also provide more features.

After the population synthesis tool has produced the population, the results are usually validated against the marginal distributions that were used as input to the process to ensure that the results are reasonable. It is also common for the synthetic population to be postprocessed in order to calculate new variables (e.g., person type) that will be used in the activity-based model system.

3.3.2

Long-Term Models

Some of the important choices that influence day-to-day travel behavior are not made on a daily basis but are made on a less frequent, longer-term basis. One such choice is the decision of where to live. In most activity-based model systems, residential choice is implicit in the population synthesis process, described in the preceding section. Related choices are the decisions of where to work (for workers) and where to go to school (for students). Other longer-term choices are related to the specific mobility options that people and households decide to use. These can include owning automobiles, driving licenses, bicycles, transit passes, and toll transponders. Workers also can decide to follow specific types of work schedules, have usual modes for work travel, and may or may not have a free or subsidized parking space available at the workplace. All of these mobility decisions can significantly influence the availability and attractiveness of different location, mode, and scheduling choices that create daily activity and travel patterns.

Figure 3.20 provides a schematic overview of how the longer-term and mobility choices fit into an activity-based model system. These choices are simulated for each household and person in the synthetic population. Then, conditional on these predicted choices, a travel day is simulated by running the day-pattern, tour-level, and trip-level models. After the simulated trips are assigned to the networks, the travel times and accessibility measures can be recalculated for another iteration of the model system,

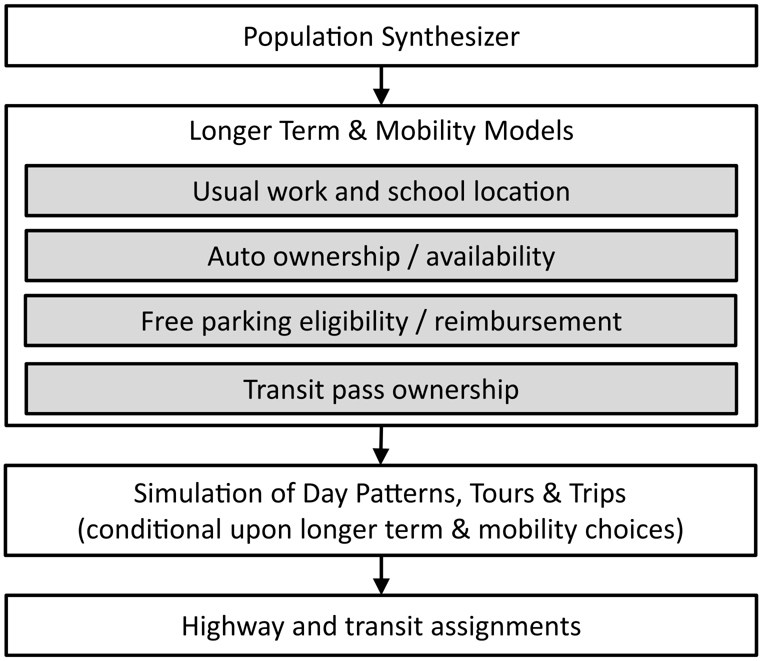

Figure 3.20. *Longer-term and mobility choice models in an activity-based model.*

including the longer-term and mobility models (see Table 3.5).

3.3.2.1

Usual Location

Most workers and students have a usual place where they go to work or study. Although they may go to a different location on some days (e.g., a business meeting away from the office or a field-trip away from school), they are most likely to visit the usual location on any given day. As a result, this location does not depend on the activity pattern followed on a specific day, and thus it can be modeled at the upper level, before modeling the day activity pattern or subsequent choices. Also, the usual work and school locations can be important anchor points for other travel-related choices, such as where one typically goes to shop or do errands, or the likelihood that household members will carpool together to work and/or school. One possibility for the usual work location is to work from home on a regular basis (as is done by more than 5% of workers in the United States, with the percentage growing over time).

Models of usual work and school location are quite similar to tour or trip destination-choice models in that they predict the choice of a single location from among many alternative destinations.

Table 3.6 lists the types of variables that tend to influence location choice models. Key variables are the accessibility variables, including the mode choice logsum measuring the

TABLE 3.5. A CLASSIFICATION OF LONGER-TERM AND MOBILITY CHOICE MODELS

Model	Household Decision	Person Decision	Worker Decision	Student Decision
Location Models			• Work location • Work at home	• School location
Vehicle Models	• Auto ownership • Auto type • Bike ownership • Toll transponder	• Auto allocation • Driver's license		
Personal Mobility		• Transit pass		
Worker Mobility			• Work schedule type • Pay to park at work	

TABLE 3.6. TYPICAL VARIABLES IN A LOCATION CHOICE MODEL

Households	Persons	Land Use	Accessibility
• Income • Size • Children • Seniors • Automobiles	• Worker status • Occupation • Driver • Gender • Telecommuter	• Employment density by type • Household density • Student enrollment • Mixed use • Parking density • Intersection density • Agglomeration and competition effects	• Distance or distance-decay functions • Mode choice logsum • Mode/destination logsum

attractiveness of traveling between home and a potential work location across all available modes of travel. Although a change in accessibility may not cause a person to change his or her work location from one day to the next, over the longer term it will influence the distribution of O-D commute patterns.

In contrast to aggregate zone-based 4-step models, it is not necessary to include all zones as choice alternatives for each case. Because many thousands of different workers, students, or tours are being simulated, it is most efficient to use only a subsample of the possible locations as choice alternatives in the model. This is particularly true when modeling at the microzone or parcel level of spatial resolution, in which case there may be many thousands, or even millions of different choice alternatives in the region. An efficient form of selecting a set of alternative locations for the model (in both model estimation and application) is importance sampling of alternatives, as described in Ben-Akiva and Lerman (1985). The general concept is to use a simple weighting function to determine the sampling probabilities that approximates the choice probabilities in the model itself. In this case, a typical sampling weight is calculated by using a fairly simple attraction function and impedance function for each alternative, resembling the functions used in a gravity model (but typically much simpler than the utility functions in the location choice model itself).

One important aspect of work location models is that the number of jobs available in any zone or geographic district is typically an input to the model system, so the total predicted number of people with their usual workplace in a given area should be approximately equal to the number of jobs available in the area. In other words, the usual work location model should be doubly constrained, both at the home end and the work end. In practice, this is achieved in activity-based models by using an iterative "shadow price" method, whereby the utility of each possible work location area is varied between iterations so that the total demand for jobs will converge to total available supply. A shadow price procedure can also be used for usual school destinations, particularly for types of schools that attract longer distance commutes, such as colleges and universities.

One final point that can be very important in some regions: When balancing demand and supply for jobs, it may be important to take account of workers who commute from outside the modeled region, as well as workers who commute from inside the region to jobs outside the region. In locations near regional boundaries, the proportion of such workers can be quite substantial. In those cases, a common approach is to estimate the number or percentage of internal-external (IX) and external-internal (XI) commute trips from other sources (e.g., a more aggregate model of external trips), and use those input data to modify the simulation so that a certain percentage of jobs in each area are prefilled by external workers, and a certain percentage of workers from each area are simulated to have a workplace outside the region.

3.3.2.2

Automobile Availability

All activity-based models used in practice have a model to predict how many automobiles are owned and available for use by each household. The number of vehicles available, relative to the number of adults or workers in the household, tends to be one of the most important and significant variables in subsequent models, such as those of tour generation and mode choice. The most significant variables in automobile ownership models tend to be household size, composition, and income. Accessibility from the residence location to destinations of various types by automobile versus nonautomobile modes is also an important input, as people who live in areas where a wide variety of activities can be reached without an automobile tend to own fewer automobiles, all else equal. The automobile and nonautomobile accessibility to the usual work locations of any workers in the household is also a key variable, and that is a key reason for predicting automobile ownership conditional on the usual work and school locations. An implicit assumption in this structure is that it will be possible for most households to increase their automobile ownership level if doing so will allow them to take advantage of better employment opportunities. If automobile ownership costs were to increase to the point where that is not the case, then a different model hierarchy might be more appropriate.

Table 3.5 lists a few other possible types of vehicle-related models including

- Automobile type choice (e.g., body type and/or fuel type);
- Toll transponder ownership;
- Driving license ownership;
- Automobile allocation among household drivers; and
- Bicycle ownership.

Although it is possible to include all of those models within an activity-based model structure, most of those choices are not represented in most of the applied activity-based models in the United States. Regarding bicycle ownership, the cost of owning a bicycle is low enough that the cost of ownership is not one of the more significant factors discouraging greater bicycle use in the United States. There are more important aspects to bicycle use, such as provision of safe infrastructure, that are more crucial to predicting bicycle use.

A similar argument has been made for modeling ownership of a driving license—almost anyone who wants to use an automobile can easily get a license, so it is not necessary to model license-holding to explain automobile use. Recently, however, it has been noted that a lower percentage of teenagers have obtained a license, so there may be a renewed interest in modeling license-holding to help explain how travel preferences may be shifting across generations.

Ownership of a transponder for electronic toll collection (ETC) may be useful for predicting which types of households are most likely to use tolled facilities like high-occupancy toll (HOT) lanes and express lanes, at least in the short term. In the longer term, it may be that ETC technologies become so ubiquitous that they will no longer be relevant as a predictive variable.

The two vehicle-related models that may be most valuable to enhance activity-based model systems are models of vehicle type choice and vehicle allocation among household members. The type of vehicle(s) that a household owns and the travel pattern of the person in the household who uses each one can have a significant influence on the pollutant emissions generated by travel, including greenhouse gas emissions. With a great deal of progress being made in traffic simulation models and related vehicle emissions models, it could be valuable for activity-based models to be able to predict the type of vehicle used to make each simulated trip.

3.3.2.3

Other Long-Term Models

As previously shown in Section 3.3.2, Table 3.5 lists three other potential types of mobility models that may be valuable to include as longer-to-medium-term choices. Two of these models are included in several of the activity-based model systems used in practice.

Transit pass ownership: This is typically modeled as a binary yes-or-no choice, although it would also be possible to model the type of transit pass that a person owns. The key aspect of owning a transit pass is that once a pass is purchased the marginal cost of using transit becomes zero. Thus, a person who buys a transit pass or receives a subsidized transit pass for commuting to work might also be more likely to use transit for other purposes as well. When modeling transit pass ownership, it is also important to simulate the price of purchasing a pass and the effect of that price on pass ownership, so that pass owners are not represented as being totally unresponsive to transit fare policies.

Availability of free parking: Parking price data input to activity-based models typically represent the average price of paid parking spaces within a certain zone or area. In reality, however, not everyone who parks within the area will need to pay for a parking space. That is particularly true for workers, many of whom received free or subsidized parking places at or near the workplace. A simple way to incorporate this within an activity-based model structure is to include a model that predicts whether or not each worker has a free parking space available at work, or whether they are subject to paying the market price for a parking space. This type of model also provides a way of simulating employer-related parking policies.

A final type of mobility model that could be valuable in activity-based model systems is to predict the type of work schedule that each worker has, including the variability and flexibility of the work schedule from one day to the next. People with different types of work schedules may exhibit quite different peak-spreading sensitivity to changes in congestion profiles across different times of day, and modeling this aspect of work behavior would provide a means to more accurately model employer-based policies that allow or encourage different types of work schedules.

3.3.3

Day-Pattern and Tour- and Trip-Level Models

Figure 3.21 shows a somewhat different overview of activity-based model components, expanding on what is predicted below the

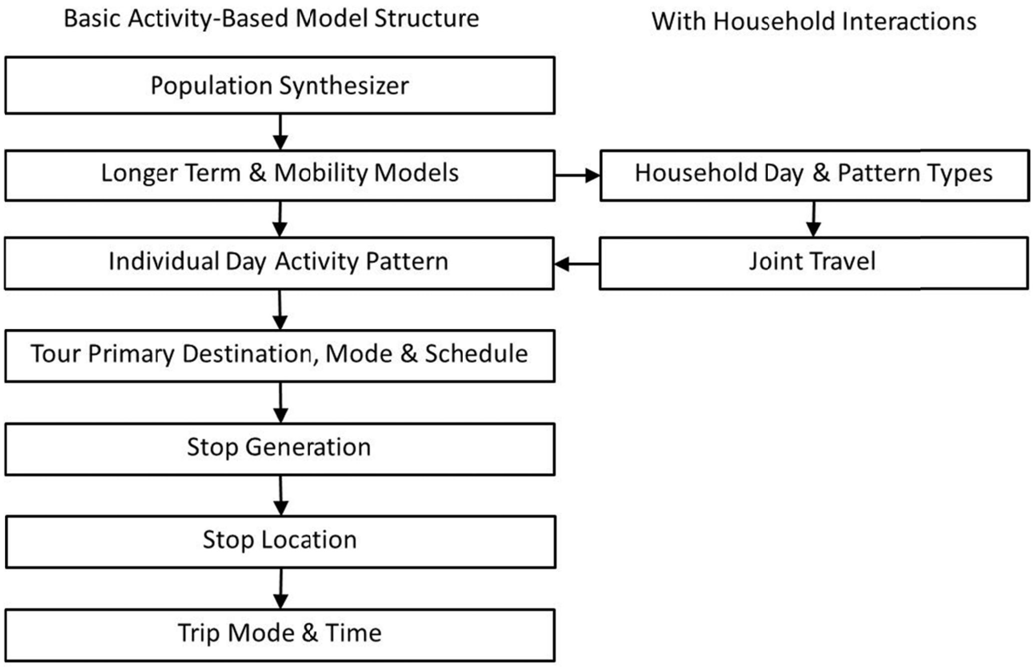

Figure 3.21. *Typical activity-based model structures.*

longer-term and mobility models. In the "Basic Activity-Based Model Structure" column at the left, the "Tour & Trip Details" from Figure 3.19 are shown as split into a number of different subcomponents. The tour-level models of primary destination choice, mode choice, and scheduling are shown in one box, with the models of intermediate stop generation and location below the tour level, and the trip-level models of mode choice and departure time choice as the lower level. This general sequence of modeling the different types of choices is followed in virtually all practical activity-based model systems in the United States.

In many activity-based model systems, the day activity patterns are predicted separately for each individual in the household, predicting the number of tours each person makes in the day for each activity purpose (and possibly some other aspects of the full-day pattern as well, depending on the specific model system design). Although there is some influence of household size and composition through the use of household characteristics as exogenous variables in the day-pattern models, there are no explicit linkages or interactions simulated between the day patterns of different household members.

The column at the right indicates that there is a second class of models that does include explicit simulation of intra-household interactions. Such models contain extra subcomponents in the day-pattern part of the model system, first predicting DAP types at the household level and then predicting joint travel activities and tours involving multiple household members, and using those predictions to condition the individual DAP for each person in the household. The lower tour- and trip-level models then take into account the fact that some tours involve multiple household members, while others do not. Such distinction between models systems with and without explicit intra-household interactions is discussed in more detail in the following section.

3.3.3.1

Day-Pattern and Tour Generation

The DAP part of activity-based model systems is where the model system designs vary most widely across practical implementations in the United States. The common feature of all of those designs, however, is that the main focus of the day-pattern models is tour generation. Regardless of the exact sequence and specification of choices that are simulated, the main output is the exact number of tours that each individual makes for each of a number of different activity and tour purposes. Often, the purposes are grouped into three different types, indicating their general importance and priority in structuring the day's activity and travel pattern:

- Mandatory purposes
    - Work
    - School
- Maintenance purposes
    - Escort (pick up, drop off, accompany others)
    - Medical
    - Shopping
    - Personal business (e.g., errands, civic activities)
- Discretionary purposes
    - Meal (eating out)
    - Social visit
    - Recreation

The exact grouping and number of different purposes considered in the models may vary somewhat from one example to the next, but all of them tend to treat mandatory (work and school) tours as the highest priority activities and tours around which any remaining tours in the day are arranged and scheduled. It is also important to remember that any tour may contain multiple activity stops for different purposes and that a tour is classified according to the activity at the primary destination of the tour. The primary destination is typically determined by prioritizing all stops based on some combination of the activity purpose (mandatory purposes highest priority, discretionary purposes lowest) and the duration of stay at the destination (activities of longer duration having higher priority).

While the common feature of DAP models is that they generate tours for different purposes, one can find a number of variations in the way the models are specified and arranged. Following is a summary of some of the key differences found between different models used in practice.

Inclusion of intermediate stops

In some cases, the DAP models also predict some aspect of extra (intermediate) stops made during the day. For example, the model can predict if there are any additional stops made for each different activity purpose. A reason for including these details at the day-pattern level is that there may be substitution between making additional home-based tours versus making additional stops to be chained into a smaller number of tours. People who live in dense urban areas nearby many activities tend to be able to return home more easily between activities and have less need for chaining multiple activities into tours, all else equal. This type of trade-off can be captured most explicitly by including some aspect of intermediate stops in the day-level choices. The alternative is to generate all intermediate stops in the tour- and trip-level models, as indicated by the "Stop Generation" box in Figure 3.21. Note that all activity-based model systems include models of stop generation and allocation to tours at that lower level. Modeling some aspects of stop generation at the higher day-pattern level simply conditions those lower-level models so that they already have some information about certain activities that need to be allocated to tours.

Scheduling of mandatory tours

In some model systems, work and school tours are generated and scheduled before the generation of additional tours for nonmandatory purposes. As discussed further in the next section, the rationale for this structure is that mandatory activities tend to be of long duration and block out much of the time in the day so that it is not available for scheduling other activities. Thus, all else equal, those who make mandatory tours of the longest durations are less likely to make additional tours during the same day.

Explicit modeling of intra-household interactions

This feature is probably the most substantial distinction among the model systems used in practice, because it adds quite a bit of information as well as complexity to the model system. The models simulate joint household choices of various types including the following:

- **Joint household DAP types.** Often, household members will tend to coordinate their overall travel patterns, for example, whether they stay at home all day, go to work or school, or leave the house for some other nonmandatory purpose. For example, if a child stays home from school because of illness, it is more likely that a parent will stay home from work that day as well. Modeling pattern coordination can be important, because it can increase the possibilities for joint travel across household members.
- **Fully joint tours.** A fully joint tour is one in which two or more household members leave home together, travel together to all of the same locations along the tour, and return home together as well. This type of tour accounts for a substantial percentage of the observed tours for nonmandatory purposes and for a substantial percentage

of observed multioccupant vehicle tours (ridesharing) as well. The fact that a tour is jointly made by multiple household members can be important to condition the tour scheduling and tour mode choice models [i.e., the drive alone (SOV) mode choice alternative is not available for such tours].

- **Joint half-tours to work or school.** There are a number of possibilities for household members to coordinate their work or school commute travel. Examples are one adult dropping another adult off at work, or two children traveling together to the same school. The most common example is a parent dropping children off and/or picking them up at school. These types of coordination are typically modeled as half-tours rather than full tours, because the participants do not necessarily travel together for the full home-based tour. For example, a parent may drop a child at school and then return home or drive on to their workplace, and then the other parent may pick up the child at school in the afternoon. Because of the many different possibilities for this type of travel, the model specification tends to be quite complex, and the recent examples found in practice use somewhat different model structures.
- **Allocation of household maintenance tours.** Some model systems have modeled the generation of maintenance tours (such as shopping, escort, and personal business) at the household level and then allocated each tour to a specific household member. However, this type of model has not gained widespread use in practice. Possible reasons are that it is not apparent that including such a model substantially affects the model forecasts, and also that the coding of activity purposes in most survey data is not precise enough to know when someone is performing an activity on behalf of the household versus for the individual (e.g., grocery shopping versus shopping for personal items).

From a conceptual standpoint, the inclusion of intra-household interactions adds aspects of behavioral realism to the models. There has not yet been a direct comparison of forecasts from models based on the same data with and without such interactions, so it is not yet clear how much the model predictions tend to be influenced by adding this additional level of modeling.

3.3.3.2

Scheduling

The topics of this section and the two following sections—scheduling, location choice, and mode choice—are relevant at both the tour level and the trip level. There is no standard practice for the exact hierarchy to be used between the three choice dimensions, and, in fact, all three of the structures shown in Figure 3.22 can be found in the models in practice in the United States. The common feature of these three structures is that mode choice is estimated conditional on destination choice, which is standard practice in the United States in both trip-based and activity-based modeling (but is not always standard practice in other countries). Time-of-day choice, however, has been modeled in all three possible positions relative to the other tour-level choices.

In reality, there is some degree of simultaneity across all three of these choice dimensions, and there is no obviously correct way to model it. The best structure statistically may vary by tour purpose, although there are yet few models in practice that allow different model structures for different tour purposes. The best structure also will tend to depend somewhat on what level of temporal detail is used to model time of day and scheduling decisions. As discussed previously, a number of different levels of temporal detail have been used in practice in activity-based models including the following:

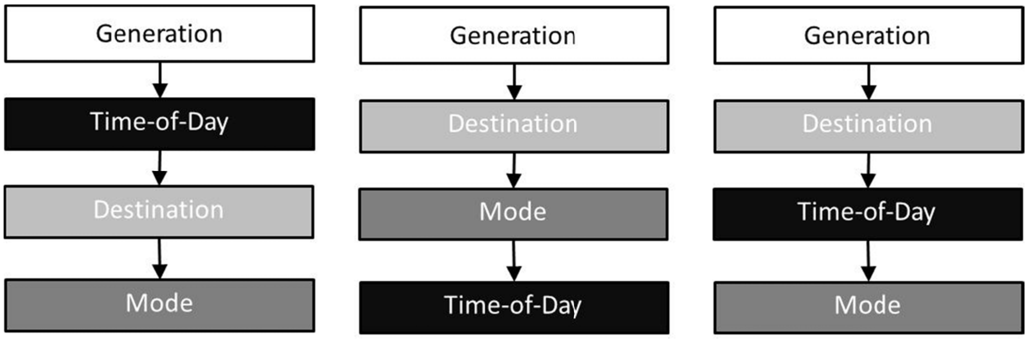

Figure 3.22. *Tour-level model hierarchies found in practice in the United States.*

- Four, five, or six broad time periods of the day (e.g., early, a.m. peak, midday, p.m. peak, and late);
- One-hour periods (24 periods in the day);
- Half-hour periods (48 periods in the day);
- Ten-minute periods (144 periods in the day);
- Five-minute periods (288 periods in the day); and
- Continuous time (e.g., 1,440 one-minute periods in the day).

The earliest activity-based model systems tended to use four or five time periods in the day, similar to 4-step model systems. In general terms, the broader the time periods, the higher in the tour hierarchy the time-of-day choice should be modeled, since the choice will tend to be less sensitive to shifts in the input variables. So, the models that place time of day above destination choice tend to be the activity-based models that use the broad time periods. The more recent trend has been to use greater temporal detail and to model time of day below destination choice, either above or below mode choice.

An impediment to using many time periods at the tour level is that most tour-level time-of-day models simultaneously predict the time that the tour (or the primary tour activity) begins, as well as the time that it ends. This simultaneous choice means that instead of the model having N choice alternatives, where N is the number of choice periods, it has $N * (N + 1)/2$ choice alternatives. So, a model that uses 48 half-hour time periods in the day has 1,176 possible scheduling alternatives. This dimensionality issue tends to make it impractical to use periods much shorter than 30 minutes at the tour level. At the trip level, however, the choice is only one-dimensional, predicting the trip departure time conditional on what has already been predicted at the tour level and for any preceding trips in the tour. So, it can be practical to use periods as short as 5 or 10 minutes to predict time of day at the trip level. Of course, it is unlikely that separate highway travel time skims will be available for each different period when one uses such short periods. Nevertheless, using short periods still has advantages in terms of modeling the scheduling of travel and activities across the day, as discussed below. Also, with increased interest in using activity-based models together with DTA and/or network microsimulation, it can be very useful to be able to predict trip departure times to a high level of detail.

An additional advantage of using shorter time periods is that it allows a more continuous treatment of time, approaching a duration model but using discrete time. So, instead of simply using alternative-specific constants for each time period, one can model factors that tend to shift departure times earlier or later, or shift activity durations shorter or longer, using continuous variables in the model specification periods (Vovsha et al. 2004).

An important concept in tour and trip scheduling models is that of the time window. The time window is the time period in which no other travel or activities have yet been scheduled in the simulated day. Figure 3.23 illustrates this concept. Initially, there is no tour scheduled for a person, so the available time window is a 24-hour period stretching from 3 a.m. to 3 a.m. (the most typical boundary from one day to the next used in travel surveys and activity-based models). Tours are scheduled in priority order, with mandatory (work and school tours) typically scheduled first, then joint tours scheduled in any remaining time windows, and then finally individual nonmandatory tours scheduled last. The figure shows a work tour scheduled first from 8 a.m. to 5 p.m., and a joint tour including multiple household members scheduled from 8 p.m. to 11 p.m. If another tour is generated during the day, there are three remaining time-window segments possible to schedule it in: from 3 a.m. to 8 a.m., 5 p.m. to 8 p.m., and 11 p.m. to 3 a.m. For most tour purposes, tours that are scheduled very early in the morning or very late at night are relatively rare, so this tour would be mostly likely to be scheduled in the period from 5 p.m. to 8 p.m. and would not necessarily need to span that entire 3-hour window. The time-window constraint affects not only the timing of this additional tour, but also its destination and mode; small time windows rule out, or make less attractive, destination–mode combinations that require a lot of travel time. Note that one of the complexities of modeling joint tours is that the available time window must then consider all of the household members participating in the tour, not just a single individual.

One important difference found in practice is the manner of scheduling any additional stops and travel time within the tour. Figure 3.24 illustrates two different approaches for a home-based work tour. In Approach 1, the tour scheduling (time-of-day) model predicts the times arriving at work (8 a.m.) and the time departing from work (5 p.m.), and then the trip-level models simulate the additional tour details outward, generating a shopping stop on the way home with a duration of 70 minutes. When the travel times between home and the

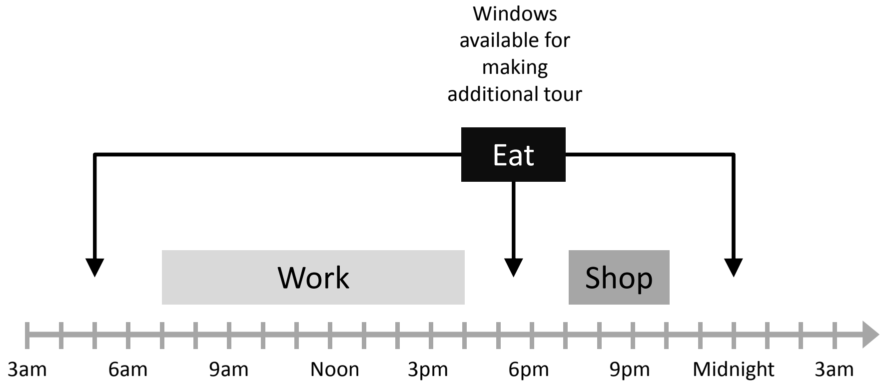

Figure 3.23. *Scheduling of tours using time windows.*

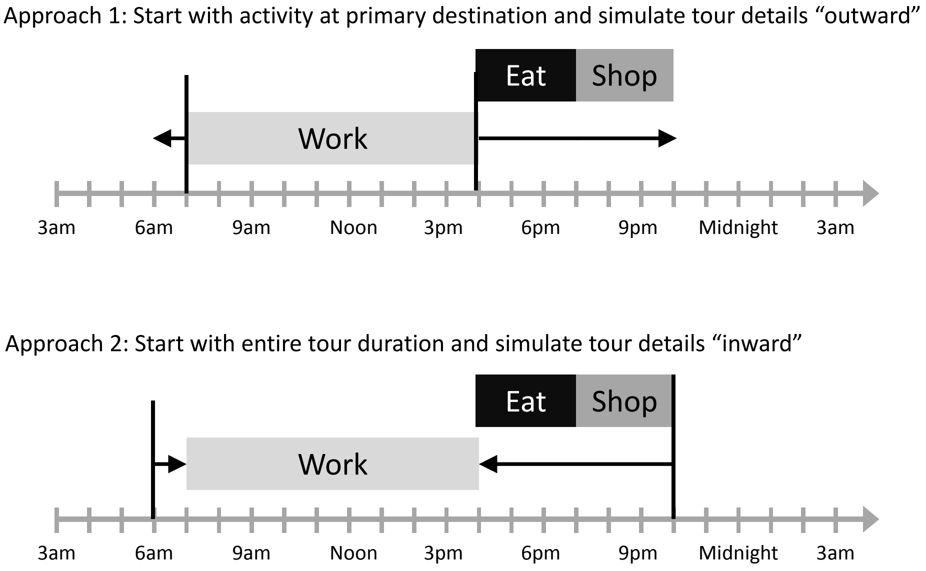

Figure 3.24. *Two different approaches for scheduling travel tours.*

two tour destinations are added in the result is that the person leaves home at 7:30 a.m. and arrives back home at 7 p.m. Approach 2 works in the opposite direction, first predicting the time leaving home and the time arriving back home and then simulating the tour details inward from those times, toward the primary activity at work.

These two approaches have relative advantages and disadvantages for modeling. The rationale for Approach 1 is that the duration of the activity at the primary destination, especially for work and school tours, is of high priority and should condition the participation and timing of activities on intermediate stops. Approach 2 may fit better with a model structure that includes some aspect of scheduling at the day-pattern level but generates all intermediate stops at the lower level after the tour duration has been simulated, since the full duration of the tour already includes the time needed to schedule any intermediate stops. With either approach, simulating feasible activity schedules can be a complex process, as it may not always be possible to travel to a feasible stop location and then on to the next destination within the available time window. For this reason, most activity-based model software includes capabilities to re-simulate day patterns if a feasible schedule is not simulated the first time. This issue can be prevented to some extent by incorporating time/space constraints in the model specification to the greatest extent possible, and thus not including choice alternatives that cannot be physically reached within the remaining time window available.

3.3.3.3

Location

Destination choice is perhaps the most difficult choice dimension to explain adequately in travel demand model systems. This is partly because there are so many possible alternative locations for any activity; our input data tend to tell us fairly little about those locations. As for using data at the parcel level, there may be a fair amount of quantitative information about the land use on the parcel, but even that does not relate the qualitative information that may be most important in actual travel choices.

The main variables to include in models of tour primary destination choice are the same as listed earlier in Table 3.6. For tour locations, however, there may be additional information, such as the tour purpose, the remaining time window available for the tour after other tours have been scheduled, and whether or not the tour includes multiple household members. For models of work and school tour destination choice, we also know the person's usual work and/or school location, so those are included as a special alternative, which is the most likely one to be chosen. (In some model systems, it is assumed that all school tours go to the usual school location, so there is no separate destination-choice model for school tours.)

Another type of location model is the model to predict the location of any intermediate stops along the tour. This model is more complex because it must consider accessibility relative to both the tour origin and the tour destination (or the location of the previously simulated intermediate stop, in cases where there is more than one stop on a half-tour). The location choice models use the generalized cost of going from the tour origin to the stop and then to the primary destination (or the other way around if the stop is on the way home from the primary destination). If an intermediate stop has already been simulated, then the location choice models use the generalized cost of going from Stop 1 to the primary destination. Because the tour mode choice model has already been applied by this point, the generalized cost is typically calculated assuming that all trips along the tour are by the main tour mode (even though the trip mode choice model, which is run below this model, might predict that the trip mode is different from the tour mode for a small percentage of cases). See Figure 3.25.

The fact that an intermediate stop location must be predicted relative to two other locations is a major reason that the tour-based approach is so difficult to implement within the aggregate zone-based software framework typically used for 4-step models. The stop location model would need to be run for every O-D pair in the region. This is not such an issue in a stochastic microsimulation model, where the model only needs to be run once for each intermediate stop that is simulated.

When applying destination-choice models in practice, it is often noticed that the fact that an O-D pair crosses particular types of boundaries, such as river crossings or county or state borders, appears to have an inhibitory influence on destination choice that was not captured in the models. Thus, it is best to include

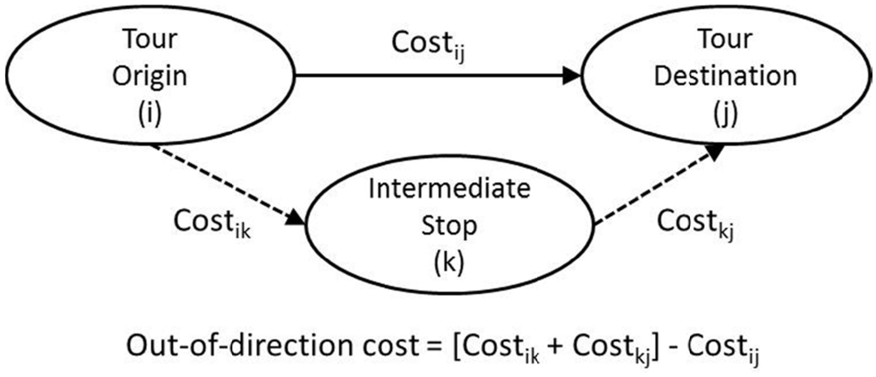

Figure 3.25. *Determining generalized cost for intermediate stop locations.*

such effects in the original model specification, but without going to the extreme of adding a variable (k-factor) for every district pair. (Even observed trip O-D matrices are typically derived from survey data and may include significant measurement and/or sampling error, so should only be used as an indication of actual O-D flows rather than absolute targets.)

3.3.3.4
Mode

Mode choice is modeled at both the tour level and the trip level. Tour-level mode choice models are very similar to their trip-level counterparts, but they consider all segments of the roundtrip tour. Because people tend to use the same mode for an entire tour in the large majority of cases, it is logical to model this as a single, tour-level decision. Subsequent trip-level models are used to represent the infrequent cases of multimodal tours, as well as cases of changing automobile occupancy along tours as the driver may pick up or drop off passengers at stops. Alternatives such as park-and-ride are also modeled at the tour level, because users have to return to the same park-and-ride lot to retrieve their cars on the way home.

Tour mode choice models typically used nested logit modeling, either using a predetermined nesting structure (e.g., from previous stated preference research) or letting the estimation data decide which nesting structure performs best. The nesting structure may vary depending on activity purpose, available modes, or other local characteristics.

One fairly typical mode choice structure is shown in Figure 3.26. This particular structure has nesting on the shared-ride, transit, and non-motorized alternatives, although other models may have different structures. Also of interest are the path type alternatives below the main mode alternatives. For the automobile alternatives, these alternatives can include whether or not the path includes a tolled facility. For transit, the path type can indicate which tran-

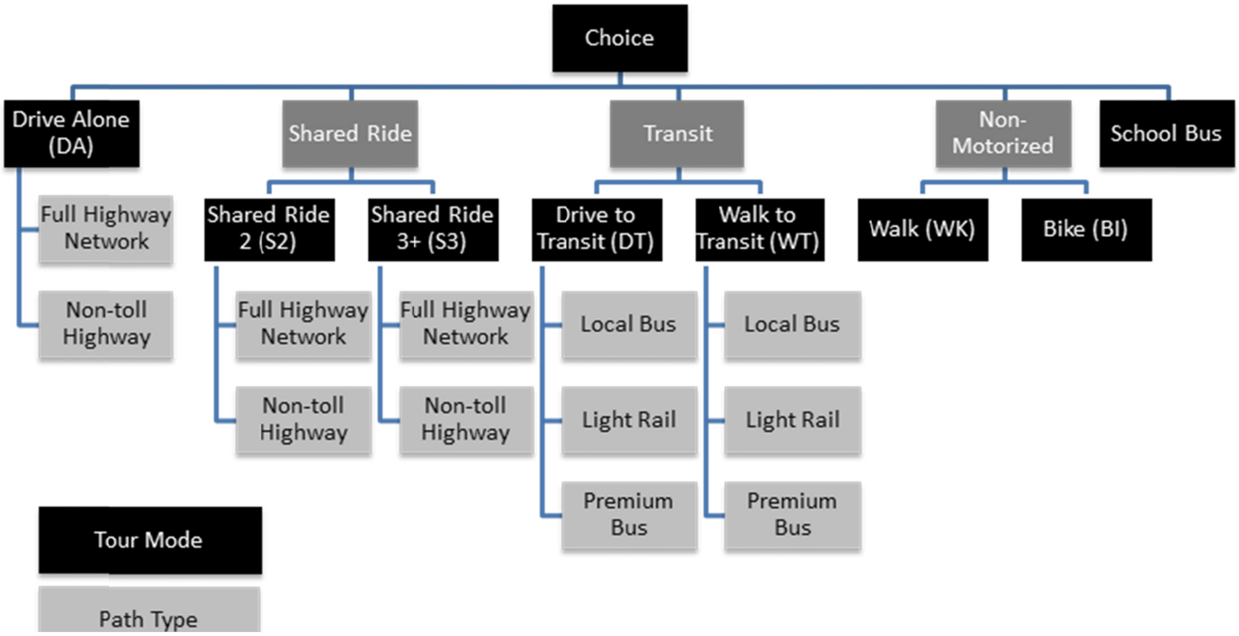

Figure 3.26. *Typical mode choice alternatives and nesting structure.*

sit submode(s) are used along the transit path. (Some regions may have more types of transit than are indicated in this figure.) There is no clear consensus whether it is better to include these path type choices in the activity-based model mode choice structure or to let the network software path-finding process find the best path along all possible path types and just pass one set of skims for the best alternative across all path types. One can find examples of both approaches in practice. Including the path type choices within the activity-based mode choice structure has the advantage of giving the user more control over the types of variables used and amount of disaggregation in the utility equations, and also allows the logsum effect of a mode being more attractive overall when there is a choice among two or more attractive available path type alternatives.

Table 3.7 provides a list of variables found in mode choice components of activity-based model systems. The variables at the left are traditional variables that are included in most model systems, including aggregate trip-based models. The variables at the right are additional explanatory variables that can be used in disaggregate activity-based models. Several of these variables are choice outcomes predicted by higher-level models at the longer-term/mobility and day-pattern levels. Including these variables can greatly increase the explanatory power and policy-relevance of the mode choice models.

3.3.4

Component Linkages

Activity-based models include a number of subcomponent models that interact and are intended to provide behavioral realism by addressing numerous choice dimensions such as activity generation, destination choice, mode choice, and time-of-day choice. These subcomponent models are linked and executed in a manner that is intended to realistically represent the interaction of the various important dimensions of choice that individuals and households face in carrying out their daily activities and travel, as discussed in an earlier section (Bowman 1998). Typically a set of multinomial logit and nested logit choice models is estimated and implemented (Bowman 1998). The activity-based model components do not equilibrate explicitly, although measures of accessibility from lower modes such as mode choice are fed back up to higher-level models such as automobile ownership. Most activity-based models are implemented using Monte Carlo simulation, which means that they are

TABLE 3.7. VARIABLES COMMONLY USED IN ACTIVITY-BASED MODE CHOICE MODELS

Traditional Variables	Variables Possible with Disaggregate Simulation
• Purpose and time of day • Travel time and cost • Car ownership/sufficiency • Household income • Household size • Urban density • Pedestrian friendliness	• Tour complexity • Travel party • Escorting arrangement • Transit pass • Free parking eligibility • Toll transponder • Person type • Age • Gender • Daily schedule, time pressure

subject to some degree of simulation variation. In some regions, multiple activity-based model simulations are executed and averaged before being used as input to the network assignment model.

It should be noted that all choices modeled in an activity-based system are interdependent to some degree, but it would not be possible to estimate a model along all dimensions simultaneously. So then one of the key aspects that differentiate different model designs—even within the same "family" of designs—is which model components are modeled and applied jointly versus which ones are modeled and applied sequentially.

3.3.5

Execution Sequencing

In most U.S. model systems, work (and school) locations are predicted before automobile ownership on the assumption that one can more easily buy or sell an automobile to fit one's commuting needs than one can find a different job to match one's car ownership level. In reality, these two choices are interdependent and have sometimes been modeled that way.

An important design option at the tour level is the hierarchy to use for the three types of models: destination choice, mode choice, and time of day. Nearly all activity-based models used in the United States have included destination choice above mode choice, meaning that tour mode choice is conditional on the chosen tour destination. (There are one or two exceptions that use joint mode and destination models.) This is similar to the 4-step model hierarchy in which mode choice is modeled after trip distribution. For tour purposes with specific, unique destinations such as work, school, medical visits, social visits to friends or relatives, and so forth, it makes sense behaviorally to model destination choice above mode choice, using the logsum across all modes as an accessibility variable for each destination. (See the section on accessibility variables.) For other tour purposes where many different destinations may be reasonable alternatives, such as grocery shopping, doing errands, it might make more sense, behaviorally, to model destination choice conditional on which tour mode a person prefers, as the choice of mode may be more constrained than the choice of destination.

In the theory of nested discrete choice models, however, the best hierarchy depends on the unexplained variance in the data used for model estimation. Typically, we have a more substantial range and accuracy of the variables in our models to explain the attractiveness of travel modes than we do to explain the attractiveness of particular destinations, particularly when those destinations are aggregate zones consisting of many different possible activity locations. This means that the unexplained error in the destination choice tends to be greater than the unexplained error in the mode choice, and so the statistical error terms will tend to be more highly correlated across alternative destinations than across alternative modes. When estimating a nested logit model, either simultaneously or sequentially, this will tend to result in estimation results that indicate that destination choice should be modeled below mode choice. In fact, that is the nesting order that is typically used in applied models in several European countries, such as the United Kingdom. However, common practice in the United States has remained to model destination choice above mode choice. In nested models, it is typically thought that parameters on accessibility logsum terms should be in the range between 0 and 1 in order to obtain models that give reasonable policy responses in practice. So, in many applied activity-based models, the parameters on the mode choice logsum variables in the destination-choice models have been constrained to values not exceeding 1.0, after values have been estimated that are above 1.0. (Additional approaches have been used to obtain valid logsum parameters, such as including distance impedance variables in the destination-choice models in addition to the mode choice logsum variables.)

What potential activity-based model users should take away from this discussion is that the best way to model destination choice in relation to or in combination with mode choice remains an issue that could benefit from further research and testing in practice. It is likely that future model designs will include more flexibility where tour mode and destination choice are modeled simultaneously in nested (or cross-nested) logit models, with the data deciding which order of nesting (mode choice above or below destination choice) determined primarily by what the estimation results indicate is the best structure for each tour purpose.

There is no clear consensus on where in this hierarchy the tour time of day models should be placed. In the earlier activity-based models that only used four or five broad time periods across the day, tour time-of-day choice was typically modeled above both destination choice and mode choice. When there are different automobile and transit level-of-service skim variables for different time periods, this hierarchy has the advantage that the time-of-day models indicate which time-of-day-related level-of-service measures to use in the mode choice and destination-choice models (i.e., use a.m. peak congestion levels or midday congestion levels to model the home-to-destination half of the tour?).

Research and practice have indicated that the more detailed the time periods used in the time-of-day models, the more likely that travelers are to shift time periods, and thus the lower down in the choice hierarchy that the time-of-day models should be. More recent activity-based models have moved toward more continuous time models with periods of 15, 30, or 60 minutes in length, and these model systems have tended to place tour time-of-day choice either below destination choice and above mode choice or below both destination choice and mode choice. A third option is to estimate simultaneous nested tour-mode/time-period models, and let the estimation data indicate which is the best nesting structure to use for each tour purpose. However, each level of nesting added to the estimation stage makes the model estimation much more complex, particularly when destination sampling must be used. For example, there is still no example of a joint simultaneously nested tour destination/mode/time-of-day model, including all three levels of tour choices.

An alternative to estimating complex multidimensional nested models is to assume a nesting structure and estimate and apply the models as sequential nested models. This may mean estimating a mode/time-of-day logsum across all possible mode and time-of-day combinations for use in the destination-choice model. The advantage of calculating all the accessibility logsum variables across all times of day is that the upper-level models can be made sensitive to policy changes that vary by time of day. The disadvantage is that it can greatly increase the runtime of the model, particularly if there are many different time periods used.

These design considerations affect the vertical integrity of the models—the idea that although each choice in the hierarchy is conditional on the choices simulated above it, each choice alternative also receives information about the expected utility across all of the remaining choices alternatives at all levels below it, if it were to be chosen. The more different types of choices and choice levels that are incorporated into the design, the more difficult it has become to maintain the ideal vertical integrity of a fully branched tree of nested models from top to bottom.

Just as at the tour level, the relative ordering of the trip mode and departure time models can vary from one model design to the other. In this case, however, it is not as critical because the trip-level models do not have as much influence on the model results as the tour-level models—they simply provide some more detail based on the tour-level choices.

For example, most model systems use a hierarchy to determine the main mode of a tour, and that in turn constrains which modes can be used for any trips in the tour. A typical hierarchy from lowest to highest is

- Walk;
- Bike;
- Drive alone;
- Shared ride; and
- Transit.

This would mean that a walk tour could only contain walk trips, a bike tour could only contain bike and walk trips, and so forth, while a transit tour can also contain trips by any other mode. In practice, the most common variations in mode along a tour are variations in car occupancy along the tour as a result of picking up or dropping off passengers. For example, the mode can shift from shared ride 2 to drive alone if a passenger is dropped off at the destination, or can change from shared ride 2 to shared ride 3 if a passenger is picked up. One of the main tasks of the trip mode choice model is to get the right vehicle occupancy for the various trips along the tour, depending on factors such as whether the trip is leaving or returning home, whether it is leaving or going to an escort (serve passenger) activity, and so on. Otherwise, the most common type of mixed tour is one where a person uses transit for one half of a tour but gets a ride by car (or walks) for the other half of a tour.

For model systems where the tour time-of-day model already models the main tour arrival and departure times at the most detailed level (e.g., 30 or 60 minutes), then the trip-level departure time model only needs to be used to model the departure time from any intermediate stops, typically at that same level of temporal detail. In some recent model systems, however, even more detailed time periods have been used at the trip level, with periods as detailed as 5 or 10 minutes. Since the trip-level choice is only one-dimensional (compared to the two-dimensional tour time of day choice), it is more feasible to use smaller time periods at the trip level. Also, the choice is constrained by the previous choices at the tour level, so there may not be many available alternatives to choose from in any case.

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Part 2

ISSUES IN ADOPTING INTEGRATED DYNAMIC MODELS SYSTEMS

4

INTRODUCTION

BACKGROUND

Travel models are analytic tools that provide a consistent framework with which to understand the effects of transportation, land use, and demographic, economic, and policy changes on transportation system performance. Traditional 4-step or trip-based travel models are composed of a series of subcomponent models that individually address aspects of travel demand and supply, such as trip generation, distribution, mode choice, and route choice, and which collectively generate estimates of travel demand choices and transportation system performance. While trip-based models have been applied extensively over the past 40 years, there is an increasing recognition that these models are unable to represent the dynamic interplay between travel behavior and network conditions and, as a result, are unable to reasonably represent the effects of transportation policies such as variable road pricing and travel demand management strategies. This recognition has led to interest in developing integrated dynamic models that link advanced activity-based demand model components with dynamic network traffic assignment model components.

Activity-based models and dynamic network models have evolved in recent decades and offer the opportunity to overcome many of the limitations of traditional trip-based models. Activity-based models consider individual and household travel choices using a consistent framework that includes an explicit representation of timing and sequencing of travel, using tours and trips as fundamental units of travel demand, and incorporating interrelationships among many long-term and short-term dimensions of travel. There are numerous examples of the successful implementation and application of activity-based models in large metropolitan regions (Vovsha et al. 2004).

Dynamic network assignment models were created to address deficiencies in more traditional static network assignment models. Note that the more generic term “network assignment model” is used in this guide to include both dynamic network assignment models and dynamic transit assignment models. Because static assignment models use broad time periods, typically multihour and in some cases even daily time periods, they are unable to capture the impact of travel demand on network performance for shorter time periods. Static assignment models also do not adequately represent important network operational attributes like capacity and do not represent traffic dynamics such as the buildup and dissipation of congestion (Lawe et al. 2011). As a result, they may provide unrealistic estimates of transportation system performance.

Integrated models that incorporate both activity-based and dynamic network assignment components can capture the interplay between travel behavior and network conditions and provide greater policy and investment analytic capabilities. By incorporating greater temporal and spatial detail, as well as by better reflecting the heterogeneity of users of the transportation system, integrated dynamic models can better represent the effects of pricing alternatives, transportation systems management and travel demand management strategies, and capacity improvements; offer more robust aggregate forecasts; and provide more detailed outputs to inform investment, air quality, and equity analyses.

But despite the recent advances in activity-based demand models and dynamic network assignment models and their increased adoption by transportation planning agencies, there are very few examples of integrated dynamic models that include activity-based and dynamic network assignments components. The limited number of examples is likely a result of integrated dynamic network model costs and development schedule, data requirements, institutional issues, and software and hardware requirements. As a result, the potential benefits from these recent advances have not been fully realized. Two notable successes in integrating these advanced models are the recent SHRP 2 C10 projects; Projects C10A and C10B projects have established integrated activity-based and dynamic network assignment model systems and subjected these model systems to a set of validation and sensitivity tests. In addition, a number of MPOs have recently embarked on integrated dynamic model development efforts, although these efforts are still under way. These examples represent the first forays into a rapidly maturing field toward which industry practice is moving. These model systems demonstrate the capabilities of the new integrated dynamic network model paradigm and also provide instructive information about the challenges faced when developing and applying these new model systems.

PURPOSE

The purpose of Part 2 is to examine the practical issues that MPOs, state DOTs, and other transportation agencies face if they are considering migrating from traditional to advanced travel demand forecasting approaches using SHRP 2 travel demand forecasting products. In this part of the guide, advanced models refer to model systems that incorporate activity-based travel demand models and dynamic network models, and in which these primary components exchange information in a systematic way to reach a stable solution. These integrated dynamic models are of interest because they can provide a common analytic framework with which to evaluate a wide range of planning and operational strategies to address local and regional goals (Resource Systems Group et al. 2014).

Advanced models as described represent an area of travel behavior research and practice in which theory, methods, and tools are rapidly evolving. Because of the dynamic nature of this field, this part of the guide identifies general implementation challenges and potential next steps for addressing these challenges and is intended to inform efforts by state DOT, MPO, and other transportation agency staff as they consider and pursue the development of integrated dynamic models.

In order to understand the practical issues associated with integrated dynamic models, the authors begin with four case examples that briefly summarize integrated dynamic models that have been developed or are under development. While there are numerous academic research efforts as well as other regional integrated dynamic model development efforts currently under way, the four case examples described are distinct because they have all been used or will be imminently used to evaluate investment and policy alternatives. However, not all model systems are at the same level of development. The integrated model systems developed as part of the SHRP 2 C10A and C10B projects are fully integrated in that both model systems incorporate activity-based models systems and regional-scale dynamic network models that exchange information in a systematic way. The model systems developed for the San Francisco County Transportation Authority (SFCTA) and the Maricopa Association of Governments (MAG) are only partially integrated. The SFCTA model system includes an activity-based model and an all-streets network, but this network covers only a portion of the entire region for a portion of the day, and network performance measures from the dynamic network model are not fed back to the activity-based demand model. Similarly, although the MAG dynamic network model is very large, it does not cover the entire region or entire day, and the network performance measures from the dynamic network model are not fed back to the activity-based travel model.

Following the case examples, there is an examination of critical integrated dynamic model development considerations, including development costs and schedule, data requirements, application challenges, institutional issues, and software and hardware requirements.

5

CASE EXAMPLES

SHRP 2 C10A JACKSONVILLE, FLORIDA, AND BURLINGTON, VERMONT

Objective

The primary objective of the SHRP 2 C10A project was to make operational a regional-scale dynamic integrated model and to demonstrate the model's performance through validation tests and policy analyses. The model system was designed to capture changes in demand, such as time-of-day choice and peak-spreading, destination, and mode and route choice, in response to capacity and operational improvements such as signal coordination, freeway management, and variable tolls. An additional goal was to develop a model system that could be transferred to other regions, as well to incorporate findings from other SHRP 2 efforts. The model system was implemented in two regions: Jacksonville, Florida, and Burlington, Vermont. In both regions, implementation of the model system was primarily performed by a consultant team, with the Jacksonville MPO and the Florida DOT providing data and support (Resource Systems Group et al. 2014). The information presented in this example was gathered from project reports and interviews with project team members.

Model System Design and Components

The SHRP 2 C10A model system comprises two primary components. They are DaySim and the TRANSIMS Router and Microsimulator. DaySim is an activity-based travel demand forecast model that predicts household and person travel choices at a parcel level on a minute-by-minute basis. The TRANSIMS Router and Microsimulator is dynamic network assignment and network simulation software that track vehicles on a second-by-second basis. DaySim simulates 24-hour itineraries for individuals with spatial resolution as fine as individual parcels and temporal resolution as fine as single minutes, so it can generate outputs at the level of resolution required as input to dynamic traffic simulation. The TRANSIMS network microsimulation process assigns a sequence of trips or tours for individual household persons between specific activity locations to paths on a second-by-second basis for a full travel day. The network includes detailed information regarding the operational characteristics of the transportation facilities that may vary by time of day and by vehicle or traveler type such as the number of lanes; the lane use restrictions; traffic controls, signal timing, and phasing plans; turning restrictions; and tolls and parking fees (Resource Systems Group et al. 2014).

The C10A model system was implemented for two regions. The Jacksonville model includes four counties in northern Florida with a population of approximately 1.2 million people, while the Burlington model includes one county in Vermont with a population of approximately 150,000 people. The model system employs multiple spatial resolutions—the base spatial data describing employment and households are at the level of individual parcels, while the network performance indicators are available at either the TAZ level or the activity location (AL) level. The model system also employs multiple temporal resolutions. On the demand model side, the core time-of-day models within DaySim operate at temporal resolutions as fine as 10 minutes and are subsequently disaggregated to individual minutes. On the supply model side, TRANSIMS follows vehicles on a second-by-second basis, measures of link-level network performance are typically collected using 5-minute intervals, and measures of O-D network performance (or skims) are also generated using temporal resolutions as fine as 10 minutes, consistent with the demand side time-of-day models. The DaySim model incorporates significant typological detail, including basic persontypes, as well as identifying trip-specific values of time reflective of travel purpose, traveler income, and mode. This value-of-time information is incorporated into the TRANSIMS network assignment process using approximately 50 value-of-time classes. TRANSIMS also generates network skims by value-of-time class for input into DaySim. The model system is configured to run a fixed number of assignment iterations and system iterations and is designed to achieve sufficient levels of convergence as necessary to generate meaningful performance metrics for planning purpose (Resource Systems Group et al. 2014).

Lessons Learned

Developing the inputs to the DaySim activity-based demand model components was relatively straightforward, though significant cleaning was required. Transferring the DaySim activity-based demand component from Sacramento to Jacksonville radically reduced the amount of time required to implement the activity-based demand model component of the model system. In contrast, developing detailed and usable networks for microsimulation required a significant level of effort, although this effort was mitigated by using TRANSIMS tools to perform network development tasks and the availability of spatially detailed network data. Correcting topological errors; resolving attribute discontinuities; coding intersection controls; and iteratively evaluating, adjusting, and testing the networks by running simulations is time-consuming. In addition, there are numerous challenges when developing future-year or alternative network scenarios (Resource Systems Group et al. 2014).

As noted in the SHRP 2 C10A final report, “Configuring DaySim to generate temporally, spatially, and behaviorally detailed travel demand information for use in TRANSIMS was straightforward, as was configuring TRANSIMS to generate the skims for input to DaySim. More sophisticated methods of providing TRANSIMS-based impedances to DaySim, such as implementing efficient multistage sampling of destinations (and corresponding impedances) at strategic points in the DaySim looping process or integrating DaySim and TRANSIMS so that DaySim can call TRANSIMS to extract the required measures quickly, could potentially be implemented.” (Resource Systems Group et al. 2014).

The new model system is more sensitive to a wider range of policies than a traditional travel demand model system, and this sensitivity is further enhanced by the detailed representation of temporal dimension. Extensive testing of the model system was necessary to determine the number of network assignment and model system iterations required to ensure that differences between alternative scenario model results were attributable to these policy and investments and not obscured by noise in the model system. Extracting, managing, and interpreting these results was not difficult; however, the level of effort required to effectively test different types of improvements varied widely, from as little as an hour to as more than a week. It is safe to say that a higher degree of knowledge and patience is required when interacting with the new integrated model system than is required when using a traditional trip-based model system (Resource Systems Group et al. 2014).

SHRP 2 C10B SACRAMENTO, CALIFORNIA

Objective

As with the SHRP 2 C10A project, the primary objective of the SHRP 2 C10B project was to make operational a regional-scale dynamic integrated model and to demonstrate the model’s performance through validation tests and policy analyses. However, there are two notable distinctions between the scopes of the C10B and C10A projects. First, the size of the Sacramento, California, region used in the C10B project is approximately twice as big as the Jacksonville region used in the C10A project, and more than 10 times as large as the Burlington region used in the C10A project. Second, and more significantly, the C10B project included a dynamic transit demand network assignment model in addition to a dynamic roadway network assignment model. Even though many dynamic roadway network assignment models represent interactions between transit vehicles and private vehicles, there are very few models that provide the capability to assign transit demand and represent the effect of this demand on network performance. Although the development of the integrated model system was primarily led by a consultant team, SACOG staff were actively involved in the C10B effort, such as performing the model sensitivity test runs (T. Rossi, personal communication, Oct. 17, 2013). The information presented in this example was gathered primarily from interviews with project team members and from project reports.

Model System Design and Components

The SHRP 2 C10B model system comprises three primary components: DaySim, Dynus-T, and FAST-TrIPs. DaySim is a travel demand forecast model that predicts household and person travel choices at a parcel level on a minute-by-minute basis. Dynus-T is the dynamic roadway traffic assignment tool, which tracks vehicles on the network on a second-by-second basis, and FAST-TrIPs is the dynamic transit demand assignment tool, which tracks transit travelers on a second-by-second basis (Cambridge Systematics, Inc. et al. 2014). DaySim simulates 24-hour itineraries for individuals with spatial resolution as fine as individual parcels and temporal resolution as fine as single minutes, so it can generate outputs at the level of resolution required as input to dynamic traffic simulation. Dynus-T assigns a sequence of trips or tours for individual household persons between specific activity locations to paths on a second-by-second basis for a full travel day and incorporates significant capabilities to adjust the input demand in order to generate more realistic results. Dynus-T operates at a mesoscopic scale, which is different from the microscopic simulations of the TRANSIMS, TransModeler, and Dynameq software used in the other integrated model development efforts described in this document, although Dynus-T shares some similarities with microscopic car-following-based models (Cambridge Systematics, Inc. et al. 2014).

FAST-TrIPs is a transit assignment tool that is designed to accurately represent transit operations, to capture the operational dynamics of transit vehicles, to provide both schedule-based and frequency-based transit traveler assignment, and to generate skims for feedback to the activity-based travel demand model (Cambridge Systematics, Inc. et al. 2014).

The C10B model system was implemented in the Sacramento, California, region, which includes approximately 2.3 million people. Like the C10A project, the C10B model system employs multiple spatial resolutions—the base spatial data describing employment and households are at the level of individual parcels, while the network performance indicators are available at the TAZ level. The model system also employs multiple temporal resolutions. On the demand model side, the core time-of-day models within DaySim operate at temporal resolutions of 30 minutes, which are subsequently disaggregated to individual minutes. On the supply model side, Dynus-T and FAST-TrIPs follow vehicles on a second-by-second basis, and ultimately skims of O-D network performance are generated using a temporal resolution of 30 minutes, consistent with the demand side time-of-day models. The model system is configured to run a fixed number of assignment iterations and system iterations and is designed to achieve sufficient levels of convergence as necessary to generate meaningful performance metrics for planning purposes (T. Rossi, personal communication, Oct. 17, 2013).

Lessons Learned

The most important lesson learned from this effort is that it demonstrates the feasibility of implementing a regional-scale integrated activity-based model and dynamic traffic and transit assignment models. The project clearly illustrated the potential benefits of a more continuous representation of time such as the ability to generate more detailed network performance skims, as well as the ability to more precisely characterize the location, extent, and duration of congestion (T. Rossi, personal communication, Oct. 17, 2013).

However, implementing the model system was a significant undertaking. Extensive efforts were required to develop and calibrate the roadway and transit assignment models, and additional efforts are likely required to achieve a level of confidence required to support project evaluations. Applying the model was also complicated by the relatively long model system run times, and by the fact that the integrated model system requires a relatively high level of modeler involvement to execute a complete integrated run. Interpretation of model results also proved to be challenging, and further work is required in order to ensure that the network assignment models and the overall model system are reasonably well converged before being suitable to support policy and investment analyses. Stochasticity in the model results appears to be an issue that will require further investigation. Finally, the project team felt that the iterative development and expansion of modeled area may not be the most effective method for getting to a full regional model implementation (B. Griesenbeck, personal communication, Oct. 17, 2013).

SAN FRANCISCO COUNTY TRANSPORTATION AUTHORITY'S "DTA ANYWAY"

Objective

The goal of the San Francisco County Transportation Authority's "DTA Anyway" project was to develop an application-ready tool that the SFCTA could use to evaluate projects throughout the city. SFCTA staff were particularly interested in understanding the effects of congestion pricing on transit performance and traffic diversion, representing operational strategies, and producing realistic traffic flows in which the forecast demand does not exceed assumed capacities. This citywide dynamic network model built on an earlier dynamic traffic (or network) assignment (DTA) model built for the northwest quadrant of the city that had been successfully applied to analyze construction phasing for a major roadway project. Beyond being able to use the model to support SFCTA's planning activities, SFCTA staff also sought to assist future DTA deployment efforts by building a toolkit in Python programming language that provides capabilities such as network data exchange and conversion procedures and reporting capabilities. Additionally, SFCTA staff tried to fully document the process and assumptions used in implementing the citywide DTA model and to reveal DTA performance in the context of a congested grid network in which there is significant interaction with transit vehicles and demand (Parsons Brinckerhoff and San Francisco County Transportation Authority 2012).

Model System Design and Components

The SFCTA DTA Anyway model system comprises two primary components: the SF-CHAMP activity-based model system and the Dynameq network simulation model. SF-CHAMP is an activity-based travel demand forecast model that predicts household and person travel choices. Dynameq is microscopic traffic simulation model with sufficient detail to consider lane-level modeling. The SF-CHAMP activity-based model generates demand for the entire San Francisco Bay Area region, while the DTA Anyway model implementation covers San Francisco County only. In order to bridge these different spatial extents, a subarea extraction process using a static network assignment model is used in which vehicle flows into and out of San Francisco are summarized. This method can be effectively applied in San Francisco because of the unique geographical features that define the city.

SF-CHAMP forecasts DAPs for all regional residents using a spatial resolution of very small TAZs within San Francisco and a temporal resolution of multihour time periods. SF-CHAMP is sensitive to the impact of travel times and costs on time of day, mode, destination, and activity generation, and generates lists of person-level tours and trips. However, these tours and trips are not used directly in the model. Rather the trips lists are aggregated to matrices of flows by time of day and mode, these flows are assigned to SF-CHAMP's static model networks, and subarea matrices are derived from this assignment.

The Dynameq traffic microsimulation model assigns discrete vehicle trips to a detailed San Francisco network. This network includes information on the actual signal and timing plans for all traffic signals in the city (there are more than 1,100) as well as the locations of other intersection controls, such as more than 3,000 stop-sign locations. The network also includes detailed information regarding the operational characteristics of the transportation facilities that may vary by time of day and by vehicle type or traveler type such as the number of lanes, lane use restrictions, traffic controls and signal timing and phasing plans, turning restrictions, tolls, and parking fees. The network simulation also includes transit vehicles, which are an important segment of the vehicle fleet operating in transit-rich San Francisco. A key challenge in integrating the SF-CHAMP activity-based demand model and the Dynameq traffic microsimulation model is the different temporal resolutions used by these two tools. It is necessary to temporally disaggregate the broad time-period demand produced by the activity-based model down to the finer time slices used by Dynameq. In the San Francisco Dynameq network model, changes in network performance by time of day that are used to build paths are represented using 7.5-minute intervals, although the simulation of vehicle interactions uses a significantly finer temporal resolution. The network simulation is performed only for the 3-hour p.m. peak period, although a one-hour warm-up period, and a one-hour cool-down period are also simulated. During this time period, approximately 450,000 vehicle trips are assigned. It should be noted that because of the limited temporal and spatial extents of the traffic microsimulation model, it is not feasible to generate skims for feeding back input to the activity-based model. Thus, the integration of the model is one way.

Lessons Learned

SFCTA staff and their consultant team members learned a number of meaningful lessons from the development of the dynamic traffic model for the city and the integration of activity-based demand into this model. From a practical perspective, the automated procedures for aligning the Dynameq and SF-CHAMP data assumptions proved to be invaluable when applying the model to evaluate project alternatives. An additional data-related conclusion was that it is much better to use actual data rather than synthesized data, to the greatest extent possible. Actual data can include observed signal timing information when building networks, observed traffic flow properties when calibrating traffic flow parameters, and traffic counts and speeds when validating network model results. This effort also proved that it is not necessary to use matrix-estimation techniques to create input demand; this finding is significant because the use of matrix estimation in the context of future or alternative scenarios is problematic. A limitation of the current integration scheme that may be addressed in future model development phases is the lack of temporal information when extracting subarea demand.

This effort also revealed to SFCTA staff a number of traffic microsimulation model sensitivities. For example, the traffic simulation model proved to be very sensitive to small changes in input assumptions. Staff described how a one-foot increase in the effective vehicle length caused systemwide network performance issues. Similarly, a bottleneck at a single intersection could also cause the entire network simulation to crash. Regarding using the model to evaluate alternative scenarios, staff discovered the following two points: The dynamic network model generally predicts more traffic diversion than static assignment techniques as a result of the sensitivity to actual capacity constraints, and stochasticity can be an issue when comparing scenarios, necessitating higher levels of convergence in order to draw meaningful conclusions. Finally, SFCTA staff advocated that sensitivity testing is an essential part of the model calibration and validation process (Parsons Brinckerhoff and San Francisco County Transportation Authority 2012).

Next steps for model development include development of a disaggregate dynamic transit assignment model and better representation of parking behavior within San Francisco. Other key development tasks include the development of a full 24-hour simulation and the associated development of dynamic network-model-based skims for the entire day (Parsons Brinckerhoff and San Francisco County Transportation Authority 2012).

MARICOPA ASSOCIATION OF GOVERNMENTS INNER LOOP TRAFFIC MODEL

Objective

The Maricopa Association of Governments developed the Inner Loop Traffic Model to support the Central Phoenix Transportation Framework Study. The purpose of this study is to identify the transportation strategies and investment needs for the central portion of the Phoenix region. The Phoenix core freeway system is still relatively new, but there are a significant number of chokepoints. Rather than only consider capacity expansion investments, the region wanted to have a tool that provided sensitivity to operational strategies in order to be able to more fully understand the interactions between the region’s highway system and regional arterials, and to strategically identify how arterials can accommodate projected travel demand. In addition, significant investments in transit are being made by the region, and there is a tremendous focus around planning and developing high-capacity transit corridors. In order to have sensitivity to these strategies, it was determined that a more detailed network model than found in the trip-based demand model would be required. The development of the Inner Loop Traffic Model is considered the first part of a multiphase effort to develop regional simulation capabilities. This initial effort demonstrated the proof of the concept that it is feasible to develop and calibrate a regional-scale traffic simulation model (R. Hazlett, personal communication, Oct. 3, 2013). The information presented in this example was gathered from interviews with project team members.

Model System Design and Components

The focus of the Inner Loop Traffic Model development effort was to establish a large-scale network simulation model rather than to fully integrate the regional travel demand and network simulation components. The traffic model is only loosely linked with traditional trip-based travel demand model, and there is not yet an integrated demand–supply model runstream. Travel demand from the region's trip-based model was used to seed the traffic simulation calibration effort, but the trip-based model demand was refined by applying a dynamic O-D matrix-estimation process that uses 15-minute counts. As a result, the present version of the model is more oriented toward shorter-term operations and engineering analyses rather than long-term future demand analyses. The project team is developing a process for creating detailed future-year simulation demand by pivoting off of the future demand model outputs. At present, network performance indicators, such as travel time and cost skims, are not being fed back to the trip-based demand model.

The spatial extent of the simulation model is approximately 530 square miles. The model maintains a consistent geographic resolution with the trip-based model, including approximately 800 internal zones and 90 external or interface locations, but there are significantly more network loading locations than in the trip-based model. The original model design called for the simulation and calibration of two 3-hour peak periods, but ultimately the model included a broader temporal extent. This inclusion of the broader temporal extent was necessary to calibrate the 3-hour period that precedes each of the peak time periods in order to ensure reasonable peak period network performance. This approach was especially necessary for the p.m. peak period. In the a.m. peak approximately 900,000 trips are simulated, while in the p.m. peak approximately 1.2 million trips are simulated (D. Morgan, personal communication, Oct. 3, 2013).

The project team was able to implement a microscopic model for the entire modeled area that incorporates the accurate representation of signals, meters, and bus routes and schedules. Use of a microscopic scale model provides better sensitivity to operational phenomena like traffic across lanes, weaving, merging, signals, and bottlenecks. The dynamic user equilibrium seeking solution method implemented in the model does not rely on the traditional method of successive averages as many dynamic network models do. Rather, at every iteration, every driver's paths are informed by the latest network performance information. This approach is similar to the methodology used in the SHRP 2 C10A project. The model uses a temporal resolution of 15 minutes for network pathbuilding, and a temporal resolution as fine as 0.1 seconds for the simulation step size (D. Morgan, personal communication, Oct. 3, 2013).

The model development work was performed almost exclusively by consultants, although MAG staff received some training, and MAG has dedicated a staff person to ongoing model management. Agency staff are also now performing testing of the model to ensure that the tool is incorporating realistic assumptions and is producing reasonable results. The consultant selected to implement the model is a developer of one of the major traffic simulation software packages, and this familiarity with the software was one of the primary factors in selecting this consultant.

Lessons Learned

The most important lesson learned from this effort is that it is possible to build a regional-scale microscopic traffic simulation. Microscopic models can provide better sensitivity to operational phenomena such as traffic across lanes, weaving, merging, signals, and bottlenecks than mesoscopic models. Microscopic models have longer run times, but given operational considerations of interest to MAG, this trade-off was acceptable. Learning how to harness current hardware and software in order to achieve better run times was a key learning component of the project.

An obvious lesson learned—but one that still bears repeating—is that regional simulation models require lots of good data and that it is preferable to use observed data rather than synthesized data. However, there are limitations on the availability of actual data; it is unavoidable that some assumptions and synthesis of data are necessary in establishing the model. In addition, calibration of the model system is challenging.

Stochasticity, or random variation, was a particular focus of the team in development of the model. Stochasticity is intrinsic to the simulation model, as well as intrinsic to the real world, and this effort revealed there is significant investigation to be done to understand how the models can be run and how the results can be applied, interpreted, and communicated to member agencies and to the public.

Two primary next steps are envisioned for this model. First, the regional network simulation is to be expanded to cover the entire region, rather than just the core 500 square miles. This work is currently ongoing. Second, MAG has also been developing a regional activity-based model system. Although the initial version of this activity-based model system incorporates a traditional static network assignment component, it is anticipated that at some point the activity-base demand model and regional traffic microsimulation model will be linked (R. Hazlett, personal communication, Oct. 3, 2013).

These case examples confirm the potential for integrated dynamic models to give more comprehensive and more detailed information to decision makers and to provide sensitivity to a wider set of policy and investment alternatives. The C10A and C10B projects demonstrated these enhanced capabilities through a set of diverse policy sensitivity tests, while the SFCTA's DTA Anyway project illustrated how an activity-based and dynamic network model model system could be used to inform real project choices. The SFCTA as well as the MAG efforts are also indicators of future directions in travel demand forecasting practice, as both agencies intend to move toward more fully integrated dynamic model systems with future model development efforts. However, these case examples also illustrate issues (e.g., integration strategies and computational resource requirements) with developing an integrated model. In addition, implementing an integrated dynamic network model necessitates addressing the issues independently associated with implementing an activity-based model and a regional-scale dynamic network model. The following sections in Chapter 6 consider some of the critical issues faced when implementing integrated dynamic model systems.

6

IMPLEMENTATION ISSUES

The purpose of this chapter is to identify implementation issues that agencies face as they consider adopting new advanced integrated model tools and approaches. These issues have been grouped into five categories that describe institutional issues, cost and schedule concerns, data requirements, software issues, and application challenges. Following the description of each issue is a set of potential next steps that agencies may consider to address these implementation issues.

INSTITUTIONAL AWARENESS AND CAPACITY

Knowledge of Tool Capabilities

As with any new technology or methodology, a significant challenge to broader adoption is simply that people are unaware of the new capabilities. This challenge is especially true with advanced integrated model systems. Although many of the largest MPOs have developed, or are in the process of developing, activity-based model systems, relatively few mid-sized and small MPOs have implemented activity-based models. As a result, one of the reasons for limited knowledge about tool capabilities is that there are relatively few peers that agencies can turn to for guidance and experience with developing and applying these models. This situation is even more acute with regional-scale dynamic network models. Thus far, large-scale dynamic network models have almost exclusively been developed only in research contexts, although a few agencies have recently initiated regional-scale dynamic network model development efforts. And, at present, no agencies have yet independently developed and applied operational integrated dynamic models.

In addition to having a conceptual understanding of the capabilities of integrated dynamic models, it is also important that agency staff have an understanding of how these capabilities can be exploited to support policy and investment analyses. It is also essential that agency staff have an understanding of the limitations and interpretation required in the current applications of existing tools. However, such an understanding is more likely to arise from seeing examples from other regions or from hands-on experience working with integrated models. Thus, there is a conundrum that agencies are less likely to develop and apply advanced integrated models until there are more examples of agencies developing and applying such models.

Lack of institutional knowledge may be attributable in part to the nature of how these tools have been used in the past. Activity-based models have primarily been developed as long-range planning tools by MPOs (although some state DOTs have also developed such tools) and are oriented toward providing information on the effects of policy and investment choices such as mode, automobile ownership, work and other location choices, and regional-level static network assignments. In contrast, dynamic network models have more typically been developed on a project-specific basis by state DOTs or by local agencies to evaluate traffic operations and facility design. As a result, agencies may have developed knowledge and experience working with one, but rarely both, of these types of models (AECOM 2010).

It is clear, however, that there is significant interest in both the research and practice communities in integrated dynamic model systems, as evidenced by the C10A and C10B projects, as well as independent efforts by agencies such as the SFCTA, MAG, the Chicago Metropolitan Agency for Planning (CMAP), and the San Diego Association of Governments (SANDAG). These efforts can inform and support efforts to expand understanding of integrated dynamic model system tools and capabilities.

Potential Next Steps

- Develop more hands-on experience and sensitivity testing of integrated models, either by building on existing federal efforts such as the SHRP 2 C10A and C10B projects, by building on existing regional integrated dynamic model development efforts led by agencies (such as MAG, SANDAG, CMAP, SFCTA), or by initiating new integrated dynamic model deployment efforts.
- Disseminate more knowledge by consultants and agencies about integrated models through outreach efforts such as webinars, conference sessions, peer reviews, and practitioner-oriented documents.
- Consult with other agencies that have activity-based models, dynamic network models, or integrated dynamic model systems to better understand model capabilities and challenges.
- Facilitate information exchange among staff members, within a single agency and across multiple agencies.

Staff Resources

Developing and applying integrated activity-based models and dynamic networks models requires a broad range of skills. Modelers, analysts, and managers must be knowledgeable in discrete choice theory and other demand modeling techniques, traffic flow theory, simulation techniques, computer programming, geographic data management, and statistics, and must also be cognizant of the broad spectrum of concerns, from long-range planning questions to small-scale traffic operations issues.

The overall pool of individuals with relevant experience in developing and applying either activity-based models or dynamic network models is relatively small, and the set of individuals with experience in both domains is even more limited. Agencies that are able to identify and hire staff with the appropriate understanding and skills may still face challenges in ensuring that these staff can be devoted to advanced integrated model development and application and not redirected to fulfill other agency responsibilities. This problem may be especially acute in an era of shrinking state, regional, and local transportation planning agency staff. Public agencies also continue to face the challenges of retaining qualified staff because consulting firms often are able to offer more attractive salary, benefits, and growth opportunities to the most highly qualified individuals. Overall, it is challenging for any agency to maintain sufficient numbers of staff members with the necessary skills to competently develop and apply advanced integrated models (AECOM 2010).

Ensuring sufficient staff resources is dependent on recognizing the need for the capabilities that integrated dynamic models can provide and necessitates a commitment of funding to these efforts. Staff resources can be developed through training and application opportunities, ensuring that knowledgeable staff are retained by agencies, and by establishing means of preserving and transmitting institutional knowledge.

Potential Next Steps

- Identify dedicated staffing for integrated model development and application efforts.
- Strengthen noncompete clauses to disincentivize consultants from attracting skilled modelers from public agencies.

Consultant Assistance

Public agencies contract with external consultants to provide expertise that they may not have in-house or to supplement the capabilities of agency staff. Such arrangements are advantageous to agencies, because they provide the ability to deploy resources flexibly to where needs are greatest and for limited periods of time. Most agencies have relied on contractors for activity-based model and dynamic network model implementation. This reliance has allowed these advanced models to be implemented more quickly than would have been possible if relying solely on agency staff. In addition, using contractors facilitates the transfer of advanced modeling techniques across regions, which is especially critical in emerging areas such as integrated, dynamic models. However, an obvious risk in relying on contractors is that agencies do not develop the necessary staff resources to fully understand, maintain, and apply advanced models. An additional risk is that agencies are often reliant on a single consultant rather than having a pool of diverse competitive consultants with whom to work. Given the long-term strategic nature of the development of these models, developing and maintaining institutional knowledge is essential.

Overcoming a reliance on consultants can be achieved by ensuring that agency staff are involved in all aspects of model development and application, by providing professional growth opportunities for staff, and by building collaborative relationships with other public agencies with whom to share knowledge and experience.

Potential Next Steps

- Involve agency staff in all aspects of model development, enhancement, and application.
- Include participation of multiple agencies from different regions in parallel integrated model implementation efforts.

Interagency Coordination

Activity-based models and dynamic network models have often been developed by different types of agencies for different purposes. The complexities of developing and applying these models increase further as they are integrated into dynamic model systems, which require substantial technical understanding and significant amounts of diverse data. Many agencies lack either the technical expertise or the data to develop and apply these models, necessitating coordination across multiple agencies. This coordination could involve the sharing of tools, data, or simply experiences, and might involve agencies within a single state or region, or across multiple states or regions. However, achieving such coordination across different agencies can be challenging due to different institutional goals, staff availability, and schedules (AECOM 2010).

Despite these differences, agencies can develop strategic partnerships based on existing agency capabilities and on practical common concerns such as cost-effectiveness. For example, primary responsibility for developing and maintaining detailed operational networks may be most effectively led by agencies whose analytic requirements necessitate the use of these detailed data.

Potential Next Steps

- Define common data standards to facilitate model development.
- Include participation of multiple agencies from a single region in a unified integrated model implementation effort.
- Include participation of multiple agencies from different regions in multiple parallel integrated model implementation efforts.
- Develop a forum for agencies to exchange integrated model development experiences, data, and tools.

COSTS AND SCHEDULE

Model Development Costs

Costs for developing activity-based models and dynamic network models have been reduced in recent years. On the activity-based model side, these cost reductions can be attributable to a number of factors. First, software development costs have been substantially reduced since the earliest activity-based models were developed as a result of standardization. Model estimation costs have also been reduced as it has become increasingly common for models or model components to be transferred between regions, a practice that that has been validated empirically and statistically. Dynamic network modeling software has also significantly improved in recent years, with a number of software options providing improved run times, robust user interfaces, and tools to facilitate data development.

But despite these software cost reductions and performance improvements, overall development costs for dynamic advanced integrated models are still higher than those for static model systems (AECOM 2010). Some of these higher costs are attributable to data development. Activity-based models require more information than traditional static, trip-based models, such as synthetic populations. Similarly, dynamic network models require detailed network information, such as intersection controls and signal timing. The greatest contributor to these higher costs is the amount of time required to calibrate and test dynamic integrated model components and the overall dynamic network model system (Resource Systems Group et al. 2014). In particular, the amount of time required to calibrate and validate regional-scale network components of integrated models is significantly higher than the time required for static network models. Because dynamic network models provide a much more detailed and realistic representation of the transportation network and traffic flows, these models are much more sensitive to small-scale network coding assumptions. As described in the earlier case studies, small-scale coding assumptions can produce global changes in network performance. Iteratively refining network coding assumptions for an entire region can consume significant amounts of agency and consultant resources.

Implementing and testing the dynamic integrated model framework is another source of higher development costs. While activity-based and dynamic network assignment tools and practices have been improved and refined in recent years, there have been very few efforts that integrate these models. Because methods for integrating activity-based models and dynamic network assignment models are evolving, a significant amount of resources are required to implement and investigate different integration methods. These investigations must consider issues such as the levels of spatial, temporal, and typological detail that can be exchanged between the model system components, as well as overall model system dynamics, convergence, equilibration, schedule consistency, and other factors directly related to the applicability of these advanced integrated models.

While costs for developing both activity-based models and dynamic network models have come down in recent years, these costs may still be prohibitive to some agencies. In addition, costs for developing integrated dynamic model systems are still relatively high given the newness of these approaches. However, the trajectory of reduced costs can be furthered through the development, dissemination, and refinement of common software tools and knowledge sharing.

Potential Next Steps

- Develop, use, and continuously support data preparation and data management tools developed by other agencies.
- Perform model calibration and validation automation and documentation.
- Adapt existing integration and sensitivity testing strategies.

- Continue research into model transferability.
- Include software development training.

Model Maintenance Costs

All model systems, whether traditional trip-based model systems or advanced integrated dynamic model systems, can be expected to require ongoing maintenance (AECOM 2010). This maintenance may involve the updating of networks or socioeconomic input assumptions, the recalibration and revalidation of model components to ensure consistency with observed traffic and transit count data, or possibly even the re-estimation of model components to incorporate new travel behavior data. However, dynamic integrated models will likely have higher model maintenance costs for the same reason that they have higher development costs: They require more detailed input data, they are sensitive to these more detailed input data, and the models produce more complex transportation system dynamics that require more time to examine and understand. Even though most MPOs that have implemented activity-based models dedicate staff or consultant resources to the ongoing maintenance of these models, few agencies devote resources to the ongoing maintenance of dynamic network models, usually because such models are developed in support of projects that have defined schedules. Because integrated dynamic model systems are still in the early phases of development, model system maintenance costs are largely unknown, although they can be expected to exceed the combined costs of activity-based models and regional dynamic network models.

Potential Next Steps

- Use and adapt data preparation and data management tools developed by other agencies.
- Ensure there are software maintenance standards.
- Consider long-term support contracts with software developers.

Development Times

Improvements in activity-based model and dynamic network software as well as the availability of detailed data have greatly reduced the amount of time required to implement initial working versions of these models at the regional and corridor levels, respectively. However, it is typical that substantial amounts of additional resources must be invested before each model component, and the overall model system, is ready for application to policy or investment analyses. For activity-based models, lengthy development schedules have typically resulted from the need to collect local travel survey data and other data development, the development of software, the need to calibrate and validate the new model to acceptable levels, and the need to educate agency staff. For dynamic network models, lengthy development schedules are often the result of the need to iteratively refine network assumptions because of the sensitivity of the networks to small-scale coding changes, the relatively long run times required to reach acceptable levels of equilibration, and the evolution of software to provide new capabilities and handle ever larger networks. In addition to the schedules required to implement the activity-based and dynamic network components, time is also required to design, implement, and evaluate methods for integrating these components.

At present, lengthy development times for advanced integrated models may be unavoidable given the emerging nature of these tools and the lack of established practice. However, as the industry moves toward the broader adoption of these tools, development times will be reduced. Model transfers will facilitate quicker model implementations, calibration and validation methods will become better defined, and the research aspects of integrating dynamic model components will diminish. Detailed, user-focused documentation of model development efforts may help facilitate the adoption of these tools.

Potential Next Steps

- Use model transfers to reduce the need to collect extensive local survey data and the need to estimate local model.
- Encourage staff participation and training during model development, so that testing and application can occur immediately.
- Document advanced integrated model development efforts.

Funding Sources

In the past, most dynamic network models were oriented toward a specific project or corridor, and the funding for the development of these models was tied to an individual project. In most cases, dynamic network model development has been funded by state DOTs or by local agencies (AECOM 2010). In contrast, the vast majority of activity-based model development efforts have been regional in scale, and the development of activity-based models has typically been funded by MPOs as strategic long-term investments that are intended to support a broad range of policy and investment analyses.

The different rationales for tool development and the different agencies funding the development of these tools have complicated the development of advanced integrated dynamic models. Because agencies have developed activity-based models as longer-term strategic investments, they have been more willing to proceed incrementally over longer periods of time, collecting regional household survey data, and making incremental improvements to data inputs and model components and sensitivities. Funding is typically included as an ongoing budget line item with occasional increases to fund major improvements or data collection efforts. Until recently, most of dynamic network model development efforts have not been designed to support the analysis requirements of multiple projects. While agency experience and institutional knowledge increases with each project-specific dynamic network model implementation, the resources devoted to data development, model implementation, and model calibration and validation work performed in support of one project may not directly benefit other projects and may not contribute to the long-term development of a regional-scale dynamic network model.

Agencies like SANDAG and CMAP have recently initiated the development of integrated dynamic model systems as long-term strategic investments, similar to traditional trip-based model systems. These efforts, as well as the case examples of MAG's Phoenix Inner Loop Travel Model and SFCTA's DTA Anyway projects, point to shifts in how future model development efforts will be conceived and funded.

Potential Next Steps

- Consider intra-regional, intra-state, or inter-state funding strategies that support the development of an integrated model framework that can serve local, regional, and multiregion (within state) needs.

DATA

Data Requirements

Activity-based models and dynamic network assignment models provide greater behavioral realism and more detailed information about the impacts of policy and investment choices. In order to provide these enhanced capabilities, advanced integrated models require additional types of information beyond those required by traditional trip-based demand models and static assignment models, and this information must be provided at more-fine-grained levels of resolution.

Regarding new types of information, dynamic network models incorporate assumptions and parameters that describe traffic flow characteristics such as vehicle effective lengths, saturation flow rates, and response times. Although some of this information can be transferred from other regions or geographical or organizational contexts, in other instances it may be necessary to collect region-specific information and calibrate these dynamic network model parameters to local conditions. Similarly, activity-based models also typically include detailed information not included in traditional 4-step models, such as detailed sociodemographic variables, transit passholding, and time-window availability.

The resolution of information required for input to advanced models is also greater than required for traditional static models. For example, dynamic network models may require detailed information about intersection controls, signal timing and phasing, network loading locations, and street grade. Like static network models, observed vehicle count and speed data are essential, but dynamic network models require that these data be provided for much finer-grained time periods, typically 15 minutes, rather than broad multihour time periods. Although some of these data may be available for subsets of the regional network, developing a comprehensive data set that covers all facility types may be costly and difficult to collect.

Also, for both the activity-based and dynamic network components of the integrated model system, it is often necessary to synthesize data from multiple existing data sources, such as parcel data, business databases, and existing static model networks. Whether the data is derived from new data collection efforts, from existing data sources, or from synthesized data, the quality of data is often not known, and significant time may be spent cleaning existing data or rectifying multiple inconsistent data sources (Resource Systems Group et al. 2014).

However, the burden of data development diminishes as integrated dynamic models become more broadly adopted. Data sources and data collection and processing tools are becoming better understood and established, and the continued adoption of these methods will only further reduce data requirement burdens.

Potential Next Steps

- Identify sources of input data and assumptions that must be local and able to be transferred from other regions.
- Develop, adapt, and maintain automated data collection, preparation, and synthesis procedures or tools.

Future and Alternative Assumptions

The detailed nature of the inputs to activity-based models and dynamic network models presents challenges when seeking to define future-year or alternative scenario assumptions in the context of an integrated models system. For example, activity-based model systems may employ spatial inputs defined by fine-grained geography, such as Census blocks and parcels, and fine-grained typological categories, such as employment by detailed industrial sector. Populating alternative scenarios with these levels of spatial or typological detail presents both methodological and institutional challenges. Similarly, dynamic network models use detailed information describing operational attributes such as signal timing and phasing. Observed base-year data describing operation controls may not be appropriate for use under conditions of higher future-year demand. This issue is further complicated by the sensitivity of dynamic network components to small-scale coding assumptions. Significant effort is required to debug and optimize different networks. It is critical to ensure that this debug and optimize effort is done in such a way that conclusions drawn from comparisons between alternatives are reasonable (Resource Systems Group et al. 2014). It is inevitable that, as integrated dynamic models are increasingly applied to real-world project analyses, methods for identifying appropriate future and alternative assumptions will become better established.

Potential Next Steps

- Develop or adapt automated data collection, preparation, and synthesis procedures or tools.

Data Management and Maintenance

Previous sections have described some of the challenges associated with developing the information required to implement and apply integrated dynamic model systems as well as developing these model systems as long-term strategic investments, potentially resulting from the collaboration of multiple agencies. As with all models, these model systems require ongoing data maintenance and management. Many dynamic network models have used network inputs that were created on an ad hoc basis for a particular subarea or corridor. Such development limits the ability of agencies to revise and expand these network inputs as new information becomes available and analysis requirements are expanded. A key issue facing agencies developing advanced models is how to reduce burdens on agency staff while also maintaining and updating the information that drives the model system. Ideally, such maintenance can be streamlined by the identification or establishment of known data sources and the automation of data collection and data cleaning to the maximum extent possible.

Potential Next Steps

- Develop or adapt automated data collection, preparation, and synthesis procedures or tools.

METHODOLOGY AND SOFTWARE

Methodology and Software Maturity

The case examples described earlier in this part reveal that there are numerous approaches to integrating activity-based travel demand and dynamic network models and that implementing an integrated dynamic model systems involves making myriad design decisions. Agencies and their consultants must consider whether and how to estimate local traffic flow models and how to define the spatial, temporal, and typological resolution and segmentation used to link the model system components. Fundamental questions about learning and decision-making processes and notions of convergence and equilibrium must also be considered, and the sensitivities of the model should be systematically evaluated.

Tremendous advances in both activity-based travel demand and dynamic network model theory and implementation have been made in the last 15 years. A number of viable software implementations of these models have been realized in the public and private sectors by academic researchers, consultants, and software companies. While this proliferation of software reflects the recognition of the importance of these tools for planning and operation analyses, there are a number of challenges that agencies confront when attempting to select software for inclusion in an integrated dynamic network model system. These challenges include understanding the unique capabilities of the different software options, the quality and performance of these options, and the level of support that can be expected.

Agencies need guidance on how to identify the most appropriate activity-based travel demand and dynamic network model components, given their expected applications contexts. For example, most dynamic network models of greatest interest are either mesoscopic or microscopic simulation models. Mesoscopic models consider the movements of vehicles or packets of vehicles using traffic flow theory. Such models often provide faster run times than microscopic models but do not include the same levels of network detail, and thus, may limit the types of alternatives that can be evaluated by an agency (Chiu et al. 2011). In contrast, microscopic models typically simulate the movement of vehicles (and sometimes individuals) using detailed car-following, lane-changing, and gap acceptance models, but usually take longer to run.

A very limited number of network simulation packages offer the ability to model transit pathbuilding and assignment.

A key design consideration in developing an integrated dynamic model system is how the primary components will interact and exchange information. This interaction and information exchange involves addressing issues such as the levels of spatial, temporal, and typological detail that each model considers, and whether additional modifications or capabilities must be developed to facilitate this exchange of information.

Because dynamic network model and activity-based model software have been rapidly evolving in recent years, the software code often contains bugs that may not be revealed until alternatives are being evaluated. This potential for software bugs often results in the need to rerun alternatives, which can be problematic given the typically long run times, an issue discussed in a subsequent section. In addition, it may be difficult for agencies to calibrate and validate model components or to identify the sources of problems or unexpected results without the involvement of the software developers. Model features, design, or assumptions are often not well documented.

However, because both activity-based model software and dynamic network assignment software have been developing so quickly, agencies can be confident that software capabilities and reliability will continue to improve and will achieve improved levels of maturity. By carefully considering their analytic needs, and by working collaboratively with software developers, other organizations, and consultants, agencies can help support this process.

Potential Next Steps

- Assess model usage needs and use of existing documents, agency experiences, and other resources to understand features, capabilities, and performance of existing tools.
- Include the participation of multiple agencies from different regions in parallel integrated model implementation efforts, in collaboration with outside consultants or vendors.
- Provide ongoing software engineering support.
- Ensure there is a common, open source, integrated, dynamic model codebase.

Computational Resource Requirements

One of the most significant challenges to integrated dynamic model implementation is long model run times. Long run times are unsurprising given the tremendous increase in the amount of detail represented in both the demand and supply components of these model systems relative to static model system. However, in practice, these long run times seriously compromise the ability of agencies to use integrated dynamic models for investment and policy analyses.

Long run times are the result of a number of factors. The underlying theory guiding the structure of each individual model component influences run times, such as whether the activity-based model considers intra-household interactions when simulating daily activity patterns, or whether a mesoscopic or microscopic dynamic network modeling approach is used. The amount of spatial, temporal, and typological detail also influences model system run times, with increasing levels of detail resulting in longer run times. The level of convergence or stability that is achieved with the dynamic network component, as well as within the overall model system, influences run times, with higher levels of convergence necessary to support detailed project analyses requiring more iterations and longer run times. Agencies must carefully consider the types of alternatives that are expected to be evaluated and the detail with which these alternatives must be considered as part of the integrated dynamic model design process.

Potential Next Steps

- Continue ongoing software performance enhancement.
- Use cloud computing or establish strategic partnerships with organizations with large computing resources.
- Establish automated input data quality assurance/quality control procedures and output data summary and interpretation procedures.

APPLICATION

Project Requirements

Many alternative projects or scenarios could potentially benefit from the enhanced sensitivities and detailed information produced by an advanced integrated model, but a much more limited set of alternatives actually require the use of such an integrated model. However, this limited set of alternatives is quickly expanding as agencies seek new investments intended to manage system performance and demand rather than investments that simply expand physical capacity. Given the significant staff and consultant resources and the length of time required to develop an integrated model, agencies must carefully consider the trade-offs of the costs of investing in these advanced analytical tools and the benefits of the significantly expanded analytic capabilities.

Potential Next Steps

- Provide training for an agency's decision makers and staff members about the analytic capabilities and limitations of integrated dynamic model systems.

Regional-Scale Model Systems

As more activity-based travel demand models have been implemented by MPOs, these models are increasingly being used to support investment and policy analyses, and there are numerous examples of such tools being used in conjunction with static network models to evaluate regional transportation plan alternatives, congesting pricing alternatives, and other scenarios. Similarly, there are many examples of dynamic network models being used to evaluate operational improvements and strategies. However, because so few integrated dynamic model systems have been established, there are fewer examples of how such integrated tools can be applied to evaluate regional and subregional policy and investment alternatives. Both model systems implemented as part of the SHRP 2 C10 projects were used to evaluate a set of alternative scenarios, but significant research and investigation remains to be done.

Potential Next Steps

- Make additional integrated dynamic model research, development, and application efforts.

Integration Standards and Procedures

SHRP 2 C10 projects focused on integrating two types of tools, activity-based travel demand models and dynamic network models, which have been evolving independently from each other over recent decades. These research efforts demonstrated the feasibility of establishing linkages between these models and created new integrated dynamic network model systems that significantly improve the exchange of data between travel demand and supply models, specifically along the temporal dimension. However, the realm of fully disaggregate and temporally detailed dynamic models is an emerging field with few established rules or conventions. The sequential, iterative processes implemented in the SHRP 2 C10 projects reflects the availability of current tools, but it is not the only possible approach to developing a disaggregate dynamic model. Significantly more conceptualization, design, implementation, and research is required in order to understand the capabilities and sensitivities of this integration approach and to identify means of improving model system sensitivities. These improvements could range from more comprehensive data exchanges or improved equilibration techniques to entirely new formulations of how people and households structure and revise their travel patterns throughout the day or across multiple days.

Potential Next Steps

- Document integrated model methods by agencies and consultants.
- Research systematic, application-focused evaluations of integrated dynamic network model components and integration methods.

Calibration and Validation

Models require calibration, validation, and sensitivity testing in order to ensure their usefulness as analytic tools. However, advanced integrated model users have reported challenges in calibrating and validating these models and in producing reasonable results. There are a number of reasons for these difficulties. First, the activity-based demand models and dynamic network models that make up the integrated model system are significantly more complex than traditional static models in the following ways:

- They have more components and incorporate more complex linkages among these components.
- They operate at fundamentally more detailed spatial, temporal, and/or typological levels.

- They are stochastic simulations.
- They often take a long time to run.

Second, dome software components include automated calibration and validation tools, but the performance of these capabilities are still being explored. Finally, because these models have only recently been deployed at regional scales, there is a need for established guidelines for the calibration and validation of activity-based models and dynamic network models.

Potential Next Steps

- Research, test, and document automated model convergence, calibration, and validation procedures, including sensitivity testing.
- Research the stochastic aspects of model system performance, including sensitivity testing.

Stability

Replicability of results is an important quality of any model system. When provided the same input information, model systems should generally produce the same results. This does not imply that the model system must necessarily produce identical results from a single run. In fact, as a result of the stochastic nature of many advanced travel demand and network supply components, a distribution of results from multiple runs provides the most comprehensive indication of model sensitivity. In the integrated dynamic models developed as part of the SHRP 2 C10 projects, the instability of model results was primarily a product of the dynamic network model components. Achieving convergence to stable solutions, if not fully equilibrated solutions, proved challenging, even when the model systems were allowed to repeatedly iterate. This challenge of sufficient convergence can affect the repeatability, stability, and reasonableness of solutions. However, it must be recognized that stochasticity is intrinsic to the integrated dynamic network models used as well as to the real world. Solution methods that address this variation must be identified and evaluated if these models are to be used in practice.

Potential Next Steps

- Research and test integrated model methods to ensure sufficient network convergence and model system convergence.

7

CONCLUSIONS

The case examples described, as well as the experiences of other agencies and consulting firms, illustrate some of the opportunities and challenges to developing integrated dynamic model systems. These case examples also provide guidance regarding potential next steps for parties who wish to pursue the advanced analytic capabilities that such models can provide.

MIGRATION PATH

It should be noted that there are a limited number of integrated dynamic model system development efforts that have been attempted. The case examples describe two fully integrated model systems. In these integrated model systems an advanced activity-based model system provides estimates of travel demand for input to a dynamic network assignment model, and the dynamic network assignment model in turn provides estimates of network performance for input to an activity-based model. The case examples also include two partially integrated model systems, in which a travel demand model provides input to a quasiregional–scale dynamic network assignment model but in which there is no feedback of network performance indicators from the assignment model to the demand model. Two other regions in the United States have recently initiated integrated dynamic model systems, but these efforts are still early in their development cycle.

Of the four fully or partially integrated model systems, two primary migration paths are observed. In the first migration path, an activity-based model system was implemented first, and a regional-scale dynamic network assignment was implemented second. For the SHRP 2 C10A project, a regional-scale DTA model was implemented in a single effort, while for the SHRP 2 C10B and the SFCTA DTA Anyway projects, the DTA model was iteratively expanded geographically from a smaller regional subarea. In the second migration path, the regional (or quasiregional) dynamic network assignment was developed in advance of the availability of an activity-based model, although the intent is to ultimately integrate the activity-based model with the dynamic network assignment model. Because this is such a nascent field, it is not possible to draw any conclusions as to whether one path or the other offers advantages in terms of development time, costs, or capabilities.

MODEL IMPLEMENTATION ISSUES

The preceding sections identify and describe five primary types of integrated dynamic model implementation issues and present some potential next steps associated with each type of issue:

- Institutional awareness and capacity;
- Costs and schedule;
- Data;
- Methodology and software; and
- Application.

Related to these types of implementation issues, a number of conclusions can be drawn from the lessons learned presented in each of the case studies. Some of these conclusions offer guidance about known challenges, while other conclusions identify issues where there are still significant uncertainties. Of course, there are also challenges and issues that have yet to be revealed, given the emerging nature of these tools.

Development of base-year data does not represent a significant challenge to implementing an integrated dynamic model because of the availability of many tools and utilities provided by the software developers to facilitate data development. These tools can be used to help build activity-based model inputs and dynamic network assignment networks from existing geospatial data sources. Experience has shown that the use of actual, rather than synthesized, data is preferable in order to ensure that the baseline results are reasonable. However, developing future-year or alternative networks is considerably more difficult than developing base-year data, primarily because of the complexities and fine-grained details required for the development of dynamic network assignment network assumptions.

Model application is an area in which significant investigation needs to occur. Extensive efforts have been required to develop and calibrate the roadway and transit assignment models, and additional efforts are likely required to achieve a level of confidence required to support project evaluations. Applying the model was also complicated by the relatively long model system run times. Extensive testing of the model system was also necessary to determine the number of network assignment and model system iterations required to ensure that differences between alternative scenario model results were attributable to these policy and investments and not obscured by noise in the model system. This stochasticity, or simulation variation, is intrinsic to the simulation model as well as to the real world, and these efforts have revealed that additional investigation is required to understand how the models can be run and how the results can be applied, interpreted, and communicated to member agencies and to the public. Model application will reveal additional issues that have likely not yet been identified by researchers and model developers.

It should be noted that the more fully integrated model systems have been applied only to hypothetical policy and investment tests. Further work is required to understand their usefulness when subjected to the increased scrutiny of a real project. However, the partially integrated model system in San Francisco has been used in a real project application context and was found to be useful because it generated more plausible results than a traditional static network model-based approach.

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RELATED SHRP 2 RESEARCH

Improving Our Understanding of How Highway Congestion and Pricing Affect Travel Demand (C04)
Dynamic, Integrated Model System: Jacksonville-Area Application (C10A)
Transferability of Activity-Based Model Parameters (C10A)
Dynamic, Integrated Model System: Sacramento-Area Application (C10B)

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