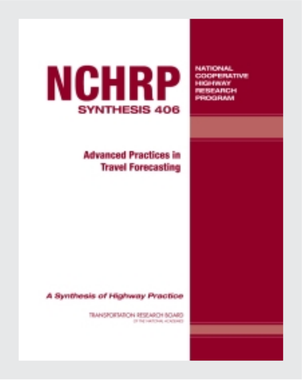

Advanced Practices in Travel Forecasting

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 406

Advanced Practices in Travel Forecasting

A Synthesis of Highway Practice

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WASHINGTON, D.C.
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The authors wish to express their indebtedness to Rick Donnelly who provided guidance and leadership throughout this project. As well, Bill Davidson provided critical insights into the technical aspects of advanced modeling practices. We benefited from thorough reviews by the NCHRP 40-06 Topic Panel, which comprises eleven travel modeling experts from MPOs, state agencies, and the federal government. This work was made possible through the assistance of 23 agencies that work with advanced models and were willing to share their experience in the interviews.

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

By Jon M. Williams
Program Director
Transportation Research Board

This study explores the use of travel modeling and forecasting tools that represent significant advances over the current state of practice. The study includes five types of models: activity-based demand, dynamic network, land use, freight, and statewide.

Information was gathered through literature review; detailed interviews among federal, state, and metropolitan agencies, and consulting firms; and case studies.

Rick Donnelly, Greg D. Erhardt, Rolf Moeckel, and William A. Davidson of Parsons Brinckerhoff, Inc., collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

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ADVANCED PRACTICES IN TRAVEL FORECASTING

SUMMARY

At the beginning of the 21st century, clear indications of a paradigm shift in transportation modeling are apparent. A growing number of agencies across the United States are abandoning established traditional modeling techniques and exploring advanced practices in travel forecasting. This synthesis report evaluates the benefits advanced models might offer, summarizes implementation and institutional issues that may form barriers to change, and distills lessons learned from those agencies that have invested in advanced modeling practices. The findings are based on narrative interviews with more than 30 agencies that have pioneered these models, literature reviews, and practical experience gained by leaders in the field of advanced travel forecasting.

Advanced transportation modeling is defined as those practices that go beyond the traditional four-step travel demand modeling approach. Specifically, this includes five areas of modeling: tour- and activity-based models, land use models, freight and commercial movement models, statewide models, and dynamic network models. All of these advanced models, with the possible exception of dynamic network models, have been successfully used to address policy and investment options at urban and statewide levels. Several of these analyses simply could not have been credibly evaluated with traditional four-step models.

Once advanced models were applied and implementation obstacles overcome, most agencies reported significant benefits from them. A frequently mentioned example is the elimination of non-home-based trips in tour- and activity-based models. This trip purpose is the most uncertain one in traditional models, as neither origin nor destination is at the home and, therefore, no socioeconomic data can be associated with or used to constrain these trips. In tour-based models, an individual may make several trips throughout a day, and their home location, work location, income, and modal availability are known for every trip simulated. Each trip can be attributed to single individuals or households, which allows analyzing; for example, vehicle-miles traveled generated by different neighborhoods or the impact of a toll road on low- and high-income households.

Activity-based models allow for the splitting of time-of-day into much finer temporal units than traditional models that commonly differentiate at most four periods of the day. If the effects of congestion pricing are to be analyzed, activity-based models permit the tracking of how far different household types are willing to deviate from their preferred travel time to reduce or avoid a toll. These models further explicitly consider household interactions, such that if in a one-car household someone uses the car for a work trip other household members cannot use it for a different trip at the same time. Another important advantage of microscopic modeling approaches is its flexibility, in that the structure and internal relationships can usually be far more easily changed than in purely mathematical models. For example, an agency might wish to test the impact of only allowing vehicles with license plate numbers ending with odd or even digits within a congested area. The microscopic model simply extends the characteristics of vehicles by including the license plate numbers and is then ready to simulate such a policy.

Dynamic network models are developed to keep track of single or small groups of vehicles on the network and therefore are able to define speeds and congestion with much higher

accuracy and precision than traditional static assignments. This allows for identifying bottlenecks in the network, as well as a much more precise estimation of traffic emissions.

Land use models are implemented for two reasons. On the one hand, they allow the testing of land use policies, such as an urban growth boundary or transit-oriented development. On the other hand, they can be integrated with travel models to simulate the interaction between them. This interaction includes the effects that a new highway may trigger in land use patterns as well as new land use development that may worsen congestion.

Freight and commercial movement models are implemented to account for their growing share of traffic congestion. Freight and commercial vehicles react quite differently to many transportation policies and network conditions. Depending on the commodities transported or the service provided these trips may be much more sensitive to changes in travel time or tolls, requiring models that are appropriately sensitive to such dynamics.

Statewide models are implemented to analyze policies at the regional level. Although an additional highway may relieve congestion locally, it may alter long-distance trip routing significantly. Regional models, which in an ideal world are integrated with local travel models, reveal the impact of policies on the big picture, beyond the often artificial boundaries of a city or metropolitan planning organization. Table 4 in chapter three summarizes the benefits offered by these advanced practices in transportation modeling.

The majority of agencies that decided to move toward advanced travel models were motivated by the need to address policy issues that go beyond simple traffic analysis. In a policy context where the questions asked are more complicated than “how many lanes?,” the development of advanced models turned out to be more likely, as there was more support by decision makers to build models beyond the four-step travel model.

As clear as the advantages of advanced travel models are for many agencies, implementation and institutional issues have hindered their adoption in many cases. This is hardly surprising, as most paradigm shifts call for taking risks and overcoming difficulties with new approaches. It is interesting to note that the pioneers in advanced modeling mostly perceived changes associated with the paradigm shift to be gradual. By contrast, those who have begun the transition to advanced models more recently tended to view such changes as more radical and revolutionary.

Several practitioners noted the perceived complexity of advanced modeling techniques as a significant barrier. They explained that such increased complexity pervaded all aspects of advanced models, including their structure, data requirements, and computational burden. However, it was pointed out that explaining an advanced modeling approach to decision makers and the public may actually be easier, because simulated behavior is closer to reality and requires less abstract thinking than aggregate traditional approaches. Furthermore, complexity is often necessary for policy analysis, such as having a time-of-day model that addresses peak spreading when peak period pricing is introduced versus a traditional model with fixed time-of-day factors that is arguably simpler, but cannot answer the policy question.

Model calibration becomes more challenging as more simulated detail equates to more output variables that need to be analyzed. Accepted standards on how to validate these advanced models is an open question. That said, it is reasonable to expect that advanced models would validate at least as well as traditional four-step models.

Being in an early stage of development, very few advanced models have been transferred from one location to another. The development costs are a significant issue, because no commercial standard software for activity-based models exists. Currently, Atlanta and

San Francisco are jointly developing an activity-based model and sharing the software development costs. Most activity-based and land use models developed to date have been based on open-source code that is further customized to conform to the particular agency's needs. In contrast, most dynamic network models are supported by commercial vendors.

The hardware requirements are significantly greater for most advanced travel models than for traditional models. Even with clusters that consist of several computers, long run times remain a significant issue. Many agencies defined overnight runs (up to 16 h) as the upper limit for reasonably making use of an advanced model for policy advice.

Data requirements are typically not more onerous for activity-based models than for traditional four-step models. The methods required for travel surveys are quite similar, although larger sample sizes might be required if highly detailed travel markets are to be analyzed (as is also the case for traditional models). Land use models require additional zonal and regional data, although many of them are generally available with a reasonable level of effort. For freight modeling and dynamic network models, however, lack of data may be a serious impediment to their development, validation, and application.

Most advanced models took more time to develop than anticipated. It was noted, however, that this undesirable outcome is hardly unique to the advanced models considered in this report. Meeting the schedule was revealed as a bigger obstacle than finding the necessary funding. In most cases, funding was provided by the metropolitan planning organization or state department of transportation. Although funds were generally available for model development, the same was often not true for education and training. Developing a model in phases, with well-defined milestones, has emerged as one effective method for reducing the risk of schedule delays or financial losses on such projects.

Another frequently mentioned issue by those interviewed was the lack of sufficiently trained staff. Several of the agencies fortunate enough to have appropriate staff noted that they have to cover a wide range of assignments, often leaving them too little time to focus on model development and application. If a consultant delivers a model, the importance of extensive training throughout the life of the development work was emphasized several times by agencies interviewed during this study.

Every interview was concluded by asking the respondent(s) what they would do differently if they had the chance to repeat the process. This provided interesting insights that are important for the profession at large to learn from. The respondents made it clear that the model must be designed to meet the needs of each agency. Planning departments that only report highway volumes at an aggregate level might not need to depart from traditional four-step models. However, in cases where complex policy and investment questions that transcend just transportation are being asked, the value of advanced models was readily apparent. The changing policy environment and current policy issues, most of them not anticipated when traditional models were developed, are pushing the development of advanced models forward.

A large number of agencies reported that a multi-year travel model development plan was invaluable for justifying an investment in advanced transportation models. Such a plan was used to educate staff and decision makers as well as to justify funding. The written document guided the ongoing effort, reminded executives of the modeling vision agreed on, and established milestones and criteria for success. All successful advanced modeling projects reviewed here were guided by such a long-range plan.

A champion to lead the modeling effort was identified as the key ingredient for success by those agencies that have moved toward advanced modeling. This champion was not necessarily the technical leader of the modeling team, but often someone who was closer to decision makers and able to translate policy needs into modeling concepts. Having the support of mentors or key executives strengthened the role of the champion. In a few cases, the role of the champion was fulfilled by a consultant. However, those agencies with an in-house champion tended to be more successful in the long term, because the model was used in application after the initial development project was completed and the consultant contract finished.

The critical importance of staff education and professional development was mentioned in many interviews, as technical skills alone were not sufficient to ensure success. Model developers being equally interested in using them in studies and application appears to be uncommon. In most cases the software development had to be outsourced, limiting the ability to later make adjustments to the model with internal resources. No universally satisfying solution was found, underscoring the necessity of continuous education and training of staff members.

Some of the most successful models analyzed in this report followed the Agile Development paradigm, which proposes to start with the simplest model possible and then continually evolve it over time. This approach proved to be more successful than starting with the "big design upfront," which tries to build large complex models in one step.

Interviewed agencies repeatedly brought up for discussion how much work could be outsourced versus completed in-house. For some tasks it appeared to be more efficient to outsource the work, because special training of staff members would be required that could be applied only once. In other cases, however, outsourcing reduced the possibilities for agency staff members to further develop their own competence in advanced modeling, making the agency more dependent on external support.

Overall, the study identified a large number of planning agencies that have implemented or wish to implement advanced transportation models. Although not every detailed methodology is the right fit for every agency, the planning problems at hand as well as those expected in the near future could guide the selection of the appropriate approach. It was encouraging to see how many agencies are making significant contributions in answering challenging policy questions with advanced travel modeling.

Several important themes were identified throughout the report. The most significant is that the motivation and need for advanced models tends to follow the nature of the planning issues faced by the agency. Those agencies focused largely on expanding the capacity of the existing transportation system are inclined to employ modelers in search of the greatest accuracy possible. Evidence could not be found at this time to demonstrate that advanced models are inherently more accurate or more capable of replicating observed traffic flows than their predecessors. Those agencies focusing on capacity expansion will likely find advanced models of limited appeal.

The users and proponents of advanced models, by contrast, reported that the benefits of advanced models are not in the incremental refinement of existing capabilities, but in their ability to answer a range of questions that could not even be asked of traditional models, and to provide a range of performance measures that could not be obtained from traditional models. Agencies dealing with issues of system management, smart growth, pricing, and equity often found themselves compelled to develop advanced models so that they could respond to these issues in a timely and credible manner.

Although numerous obstacles were overcome along the way, and even more so with subsequent implementations, it is fair to say that tour- and activity-based models are a proven technology that can succeed if supported by capable staff with adequate resources. Land use models have been used successfully for policy analyses. Freight and commercial models and dynamic network models are a few steps behind, and do not yet enjoy the same track record of success. They do, however, hold significant promise for those willing to push the practice forward.

CHAPTER ONE

INTRODUCTION

PURPOSE OF STUDY

For half a century, transportation modeling has been an established field of practice for infrastructure planning and policy analysis. The four-step model, which separates trip generation, distribution, mode choice, and assignment, is an established approach widely used in today's transportation modeling. In the last decade, however, policymakers have begun asking more complex questions, such as about the impacts of road pricing distinguished by vehicle types, occupancy, time-of-day, or level of congestion. How far may rising fuel prices affect travel behavior with regard to mode choice, trip chaining, or the choice of locations for living, working, shopping, and leisure activities? What is the impact of alternative growth scenarios, such as transit-oriented development or smart growth strategies, on traffic volumes? How do rising freight volumes impact traffic flows at different time-of-day periods? These and other questions asked by policymakers are difficult if not impossible to answer with traditional modeling approaches; therefore, a new type of modeling was needed. At the same time, science has made significant progress by learning from large-scale projects such as TRANSIMS and other more disaggregated approaches. Since the beginning of this century, more and more agencies have explored the benefits of advanced modeling.

It is important to define at the outset what is meant by the term, "advanced modeling." It undoubtedly means different things to different people. In preparing this Synthesis the definition cited in *TRB Special Report 288: Metropolitan Travel Forecasting: Current Practice and Future Direction* was followed. That is, advanced modeling generally encompasses practices beyond the four-step sequential modeling paradigm traditionally used in travel demand forecasting and its close variants. Although often considered synonymous with tour- and activity-based travel modeling, advanced modeling includes other nontraditional approaches, such as region-wide dynamic traffic assignment and traffic microsimulation, land use transport modeling, freight and commercial vehicle modeling, and explicit linkages to statewide travel models. Each is discussed in this report. A few other equally compelling practices, such as mobile source emissions modeling, carbon footprinting, and analysis of greenhouse gas effects arguably fall into the same category, but were not examined as part of this work.

Being a relatively new field of practice, two questions about advanced modeling are central to this report. The first question explores the reasons why agencies may want to move to advanced models. If a traditional model is established and major efforts both in budget and time are required to move to advanced models, it is important that an agency explore carefully the rationale for abandoning a working traditional model and moving to advanced modeling techniques. This report explores the limits of traditional models and highlights policy questions that may motivate switching to advanced models. The findings may help agencies discover the most suitable approach for every modeling task. Second, common obstacles encountered when moving toward advanced models are listed and analyzed. By addressing the obstacles many advanced modeling projects have encountered, those agencies that decide to move toward advanced models may be able to circumvent some difficulties faced by other agencies. Topics addressed included institutional issues, funding, project organization, and the technical implementation. The literature reviewed supports some findings with a theoretical background.

Ultimately, stimulating the discussion about advanced models in general is an underlying purpose of this report. Even if some agencies—for various reasons—decide to continue using traditional models, an intensified discussion about the advantages and shortcomings of different modeling approaches can do nothing but improve everyone's competence in transportation modeling.

STUDY METHODOLOGY

A comprehensive review of current and past efforts in advanced modeling informed this report. A list of all known existing modeling projects in North America was assembled at the outset of the project, based on study team knowledge of or participation in the work, review of the literature and recent conference proceedings, and leads from TRB staff and the topic panel. These known projects were categorized by their progress to date, as shown in Table 1. Portland (Oregon) is somewhat unique in this regard, as it has the experience of having abandoned earlier efforts, only to start anew several years later. The Oregon Department of Transportation (DOT) has progressed to a second generation of models, but the rest of the advanced models summarized in the table are first generation efforts. Understanding these projects and the lessons learned were the focus of this study.

TABLE 1
AGENCIES SELECTED FOR FURTHER STUDY (AS OF AUGUST 2009)

Domain	Evaluated	Evaluated and Plan to Move Forward	Work in Progress	Operational Model	Abandoned
Person Travel	Michigan DOT St. Louis Washington, D.C.	Chicago Dallas-Fort Worth Florida DOT Portland Tampa Bay	Atlanta Calgary Denver Ohio statewide Oregon statewide Phoenix San Diego San Francisco (MTC) Seattle	Columbus Lake Tahoe New York City Sacramento San Francisco (SFCTA)	Boise Portland
Freight	Atlanta	Tampa Bay	Ohio statewide	Calgary Oregon statewide Portland	
TRANSIMS			Atlanta Sacramento	Washington, D.C.	Dallas-Fort Worth Portland
DTA/Other Large-Scale Simulation			Atlanta Austin San Francisco (SFCTA)	Baltimore Chicago Knoxville	
Land Use		Minneapolis Eugene-Springfield (OR)	Atlanta Baltimore California statewide Honolulu Ohio statewide San Diego San Francisco (SFCTA) Seattle Tampa Bay	Huntsville (AL) Medford (OR) Oregon statewide Portland Sacramento	

DTA = dynamic traffic assignment.

The study team interviewed more than 30 practitioners and researchers during the course of this study. Most were selected because of their involvement in the implementation, application, or evaluation of one or more of the efforts listed in Table 1. Others were chosen because of their work in research and development in advanced modeling or recognized expertise in one of the subareas identified earlier. It was hoped that these individuals would be able to share success stories and important lessons learned from developing and using such models within metropolitan planning organizations (MPOs). An interview approach was chosen instead of a questionnaire because of the flexibility afforded, as those contacted covered a wide spectrum of experiences. Many of the issues were complex and better understood through discussion.

The interviews were conducted by phone or in person, with the latter being carried out when there were others reasons for study team members to be in the area. Participants were first contacted by e-mail, which was accompanied by an *Interview Preparation Guide* consisting of questions in five broad topic areas. The *Guide* is shown in Appendix A. Although the interviewers used the *Guide* to orient the discussion, the respondents were not asked to return the completed *Guide,* rather they were asked to make notes on it as they thought about the questions. It was hoped that over the several weeks between being initially contacted and interviewed that the respondents would have several occasions to add thoughts or notes that would help with recall during the interview process.

The interviews typically lasted between one and three hours each. The interviewers identified and initially focused on the topics the respondent was most interested in or had the most to say about. Respondents were asked to rank a list of issues in the *Guide*. These rankings helped orient the interview toward those topics the respondent believed were either not significant or important to them. Toward the end of the interview the interviewer typically asked for responses to those questions not already covered. In some instances a second or third contact was required to obtain information about the cost of model development and implementation, information eagerly sought by many practitioners and agencies contemplating a move to advanced modeling.

The study team discussed the highlights of each interview, with the interviewer(s) summarizing the key topics and discussion items. As the number of completed interviews increased, most of the effort was devoted to identifying recurring and significant issues and themes from the collective responses. Those major findings defined the structure and content of the following chapters.

ORGANIZATION OF REPORT

The findings of this synthesis are summarized in the next five chapters. Following this introductory chapter, chapter two provides a description of current advanced modeling practices across the United States. The efforts described were summarized from the literature, unpublished documentation, online searches, and the interviews carried out as part of this project. The focus is on emerging and operational models in use by MPOs and as such does not attempt to encompass the large amount of parallel academic work.

Chapter three describes the benefits ascribed to advanced models by their users. Their advantages over other analytical approaches, to include traditional modeling practices, are discussed at length. Although the benefits of advanced models are taken for granted by their proponents, considerable debate about the case for moving to them persists among practitioners. Many practitioners noted that their criteria for acceptance of such models were different than for academics. This chapter attempts to build the case for advanced models in the words of the practitioners.

Implementation and institutional issues faced by practitioners are highlighted in chapter four. These issues were gleaned from the review of practice and the interviews, and include a variety of methodological, data, cost, and institutional issues unique to practitioners. This chapter describes some of the barriers that have been encountered and how the various agencies dealt with them. Issues unique to a particular agency are documented, because they might apply to others reading this report. However, the primary focus has been to deal with recurrent themes across most of the agencies. Success stories are highlighted where available.

Chapter five presents the lessons learned by the developers and users of these advanced models. During the interviews this was couched as the following open-ended question: “If you had it to do over, what would you have done differently?” Most respondents reported that they would have followed substantially the same path, but all were able to point to a few or more ideas or improvements. Many were already adapting their work to take advantage of their new insights. The degree to which these lessons are broadly applicable or widely transferable remains to be seen. It is interesting to note that most respondents asked during the interview what lessons had already been reported and largely agreed with the wisdom shared by their contemporaries.

Chapter six presents several case studies that underscore and expand on some of the primary themes presented in earlier chapters. Each illustrates a slightly different view on advanced modeling:

- San Francisco was one of the first activity-based models put into practice, and has the largest number of applications in real-world studies.
- Sacramento recently completed the implementation of an activity-based travel model that has been used for studies of the effect of the built environment on travel.
- Portland (Oregon) was also an early leader in activity-based modeling that switched its focus to TRANSIMS and is now approaching activity-based modeling again.
- Lake Tahoe’s activity-based travel model was imported from Columbus (Ohio), making it an interesting study in model transferability.

Chapter seven summarizes the major findings from the study and recounts the next steps suggested or desired by the respondents. As such, it offers more of the collective ideas on how to move advanced modeling forward than it does the views of the study team.

The references and a list of abbreviations are provided at the end of the report. The *Interview Preparation Guide* is included as Appendix A and the list of survey respondents is shown in Appendix B.

CHAPTER TWO

GENERAL DESCRIPTION OF ADVANCED PRACTICES

The goal of this chapter is to provide the reader with enough background knowledge to understand the key aspects of advanced models, providing a foundation for the remainder of the report. As noted, the report will focus primarily on activity-based travel demand models and their integration with land use models and dynamic network models. Freight models are also considered, as they are reaching the same levels of sophistication and are based on much of the same data, principles, and mindsets. Most of the models described in this report have been applied at the urban and metropolitan levels; however, nothing precludes them from being applied at the statewide level as well, and several examples of such applications are presented. A separate discussion of statewide models and issues unique to their scale are provided to contrast them with the more familiar urban models. Regardless of the specific application, many of the institutional issues associated with implementing advanced models and lessons learned are the same.

Many of the models described can easily be labeled as a "demand model" or "supply model." Indeed, practitioners often describe themselves as falling into one camp or the other. Many developers of activity-based travel models place themselves in the first camp, whereas network modelers identify with the latter. Users of traffic simulation models have traditionally worked outside the orbit of both groups. One of the biggest promises of the advanced modeling paradigms discussed in this report is the fusion of these heretofore separate areas of practice. For example, several researchers are exploring the integration of activity-based travel demand and dynamic traffic assignment models. Much has already been learned from land use modelers who for some time have tightly coupled the demand supply sides of their model. Although the discussion in this chapter follows the literature and practice to date—which stops just short of merging these two camps—it is clear that the convergence of these two streams of research and practice is close at hand.

TOUR- AND ACTIVITY-BASED TRAVEL MODELS

Over the past decade, several activity-based models have been developed in the United States, and applied successfully in practice, and more are in the process of being developed. The locations of these models are shown in Figure 1. The first generation of those used extensively in practice includes models in New York, San Francisco, and Columbus (Ohio), with more recent applications in Oregon, Sacramento, and Lake Tahoe (Nevada). Activity-based models are currently being actively developed in locations including Atlanta, Denver, Ohio (statewide), Portland, San Diego, the San Francisco Bay Area, and Seattle. With this breadth of applications, activity-based models are making a major advancement with the greatest penetration into practice.

The general characteristics of such models are described in this section and compared with traditional trip-based models. The goal of this section is not to provide a comprehensive guidebook for these models, but to describe them in just enough detail so that the reader is provided with some context for the remainder of this report. Recognizing that each model developed so far is different, the focus remains on the commonalities among these models, rather than the differences between them. When comparing activity-based and trip-based models a representative "good practice" model is described for each, rather than the model implemented in a specific location.

Trips, Tours, and Activities

Traditional models use a trip as the basic unit of analysis, hence the moniker "trip-based models." A trip is defined as a unit of travel connecting two locations. Figure 2 shows an example of a day containing five trips. The trips connect four locations: home, work, a store, and a park. At each of these locations some activity or set of activities occurs, which might include working, eating a meal, shopping, and recreation.

In a trip-based model, each trip is modeled as an individual unit with no knowledge of its context beyond its endpoints. Therefore, in the example, trip 5 has no knowledge that it is the reverse of trip 4, nor does trip 3 know that it is related to trip 2. In this example, trips are categorized by what happens at either endpoint into three purposes: home-based work (HBW), home-based other (HBO), and non-home-based (NHB).

Home-based trips are trips with either end at home, whereas NHB trips have neither end at home. This distinction is important in a trip-based model, because if the trip has one end at home then the model can take into consideration the demographic characteristics of households in that home zone. Conversely, for NHB trips, the model cannot consider any demographic characteristics because doing so would

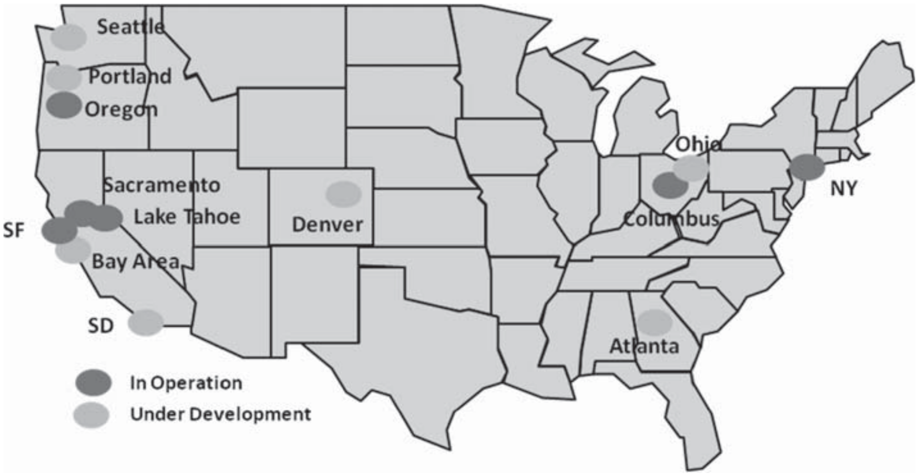


FIGURE 1 Activity-based models in the United States.

require tracing beyond the trip's endpoint and therefore beyond the scope of knowledge for that trip.

The second major distinction within the home-based trip purposes is between work trips and other trips. HBW trips are of particular importance owing to the significance of home-to-work commutes to travel during the congested peak periods and to transit markets.

Note that even though trips 2 and 3 add up to a work commute with a stop on the way home, neither is classified as a HBW trip. Therefore, when these two trips are modeled there is a loss of knowledge in the model—knowledge that the two trips are related, that the stop is likely to occur somewhere between home and work, and that the time-of-day and mode preferences associated with work commutes are relevant. Trip-based models work best in situations where there is ample direct "there and back" travel between home and a single location. The loss of knowledge in a trip-based model is higher in situations where there is a lot of trip chaining—the linking together of more than two trips while away from home—and therefore a high share of NHB trips. In the United States, the share of NHB trips has been increasing in recent decades as auto ownership and the number of multi-worker families has increased and as suburban land use patterns have become more dominant.

In Figure 3 the same five trips are grouped into two tours, where a tour is a sequence of trips that starts and ends at home. This is the type of grouping that occurs in a tour-based model, where the tour becomes the primary unit of analysis. For each tour, a primary purpose is assigned based on the most important activity that happens on that tour. In this case there is one work tour and one other tour. Each tour is assigned a primary destination (where the primary activity occurs) and a primary mode. Tour-based models ultimately consider decisions made at the trip level, but the choices for trips are constrained to be consistent with the tour of which it is a part. For Tour 2 in this example, both trips would be forced to occur between the same two zones in opposite directions. In Tour 1, the second trip must start from the work location, and the stop location on the return commute would be chosen based on how far it deviates from the work to home path.

With the grouping into tours, tour-based models overcome much of the knowledge loss associated with trip-based models because the trips in the model have some knowledge of their context. Furthermore, because information can be traced back to the home, demographic characteristics of the traveler can be considered for all trips, not just home-based trips.

An activity-based model goes further in recognizing travel as a derived demand. That is, the demand for travel is derived

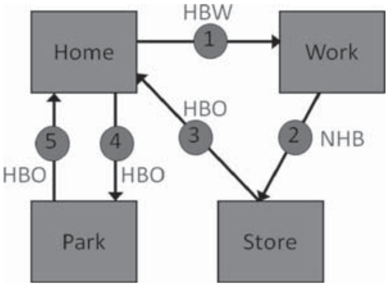


FIGURE 2 Example of trips.

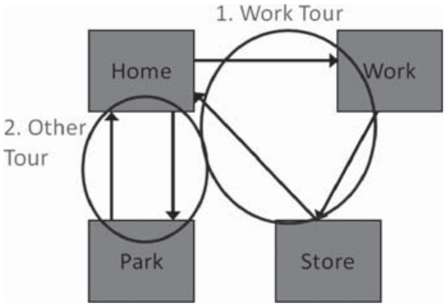


FIGURE 3 Example of tours.

from the desire to participate in activities, rather than the desire to travel for the joy of being in the car. Figure 4 shows the same travel day, but lists the activities in which the person is engaged. The person works at work, shops at the store, and recreates at the park. Further, several activities are listed as occurring in the individual's home. The individual begins her day by sleeping, then eating breakfast. After returning home from work, the individual eats before going to the park to recreate, then returns home to sleep.

Activity-based models recognize that a person is motivated to work (coincidentally another derived demand, associated with the desire to get paid) not to make HBW trips, and that the person is motivated to shop, not to make HBO trips. Therefore, the activity-based models are capable of modeling the tradeoff between participating in a shopping activity as a stop on the work tour versus making an additional tour for the sole purpose of shopping. That tradeoff can be a function of the desirability of shopping locations near the home zone—the data show that persons living in highly accessible locations are more likely to make additional tours, whereas persons in inaccessible locations will seek chain trips into more complex tours.

If an activity-based model were to consider the details of in-home activities, it could explicitly consider the tradeoff between shopping online at home and traveling to a store to shop. Although there has been research on this topic, the models implemented in practice do not go to this level of detail.

The literature is not in agreement as to a precise definition of what constitutes a tour-based model versus an activity-based model. Some would argue that a model is not truly activity-based unless it involves a list of activities and whether they occur in-home or out-of-home. Although there is some intuitive appeal to such a definition, such a distinction is a minor point compared with the large differences with traditional trip-based models. Therefore, in colloquial use, the two terms are often used interchangeably. That practice is continued in this report.

Demand Simulation

Many of the advanced models described in this report depart from traditional deterministic approaches familiar to practitioners of trip-based models. Closed form mathematical equations have been used extensively in trip-based models. An obvious but important property of such deterministic models is that they can be exactly solved obtaining an invariant solution. That is, such a model solved repeatedly will always obtain the exact same solution. Simulation models, on the other hand, are often used when analytical solutions cannot capture the salient characteristics of the system under study. They typically include stochastic (random) effects or variables, such that repeated trials give rise to different outcomes. The degree of difference depends on how much random variation is introduced and at what level the difference is measured. Although most advanced models are constructed using richer behavioral detail and interactions, moving from a deterministic to stochastic framework entails an equally large change in the analytical mindset.

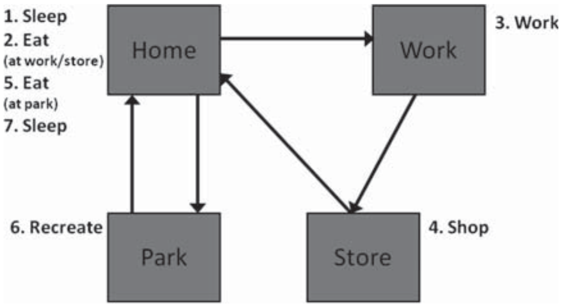


FIGURE 4 Example of activities.

Travel models, both traditional and advanced, are generally built on a core set of probabilistic choice models. A mode choice model, for example, predicts the probability that a user will choose each available mode given the level-of-service for each mode and relevant attributes of the traveler or trip. Traditionally, such models are applied using a fractional probability approach where the probability of each choosing each mode is multiplied by the total number of trips to get the total number of trips on each mode. If the probability of choosing auto is 0.75, the probability of walking is 0.125, and the probability of taking transit is 0.125, and there are 10 total trips, then the model would predict 7.5 auto trips, 1.25 walk trips and 1.25 transit trips.

An alternative way of applying the same model is to simulate the choice made by each trip using a Monte Carlo approach. In this case, a random number between 0 and 1 would be drawn for each of the 10 trips. If the random number is in the range 0 to 0.75 then the trip is assigned a choice of auto, if it is in the range 0.75 to 0.875 it is assigned a choice of walk, and if it is in the range 0.875 to 1, it is assigned a choice of transit. In this example, there might be seven trips choosing auto, one choosing walk, and two choosing transit. Over a large sample the simulation will produce a result equivalent to the fractional probability model, although there will certainly be some variation owing to the simulation. In the travel forecasting practice, this approach is referred to as demand simulation, microsimulation, or pseudo-random sample enumeration. This method usually feeds into a standard user equilibrium highway assignment and should not be confused with traffic microsimulation, where individual vehicles are simulated traversing highways.

Both approaches are based on the same core probabilistic models; therefore, they would produce the same outcome in the aggregate. However, there are several practical reasons for demand simulation (Vovsha et al. 2002). The first main motivating factor is that there are significant computational and data storage benefits for large problem sizes. Second, explicitly tracking the choices of individual agents allows for the downstream choices to be constrained to be logically consistent with the choices that have already been made. Put together, these allow for the formulation and implementation of more complex model systems. These differences are discussed as each method is described in further detail.

Note that it is possible to apply a trip-based model using demand simulation, and it is possible to apply an activity-based model using fractional probabilities. This is not commonly done in current practice, however, with the existing trip-based models usually using a fractional probability approach and the existing activity-based models all using a microsimulation approach. This is primarily because demand simulation makes it easier to manage the added complexity in activity-based models.

Consider a traditional fractional probabilities model with 3,000 traffic analysis zones (TAZs), as outlined in Figure 5. The model begins with a list of households in each TAZ in each of three auto ownership levels. Trip generation rates are applied to each set of households for three trip purposes, resulting in 9 vectors of trips. When those trips are distributed to 3,000 possible destinations, there are 9 matrices. When a mode choice model is applied, those 9 matrices are divided into 27. Thus, for this simple model the software must store and process 27 matrices (3 auto levels × 3 purposes × 3 modes) with 9 million (3,000 TAZs × 3,000 TAZs) elements each, for a total of 243 million elements. Each element is a fractional number, many of which are very small. If each is stored as a 4-byte floating point number, this amounts to about 900 megabytes (MB) of data, a manageable amount for today's hardware.

In the fractional probabilities approach, the problem size increases quickly as the complexity of the model increases. Consider instead a model with 5 purposes and 10 modes, which is not uncommon. Here the model would require 150 matrices (3 auto levels × 5 purposes × 10 modes) and 5 gigabytes (GB) of data. If the model were also segmented by 3 income levels, the problem size would triple to 450 matrices and 15 GB of data. Segmenting fully by 4 times-of-day would quadruple the problem size, for a total of 1,800 matrices and 60 GB of data. Of course, this does not account for other terms such as age, gender, and household composition that may be useful descriptive variables in a travel model. As the complexity increases, the application becomes both computationally intensive and cumbersome to manage.

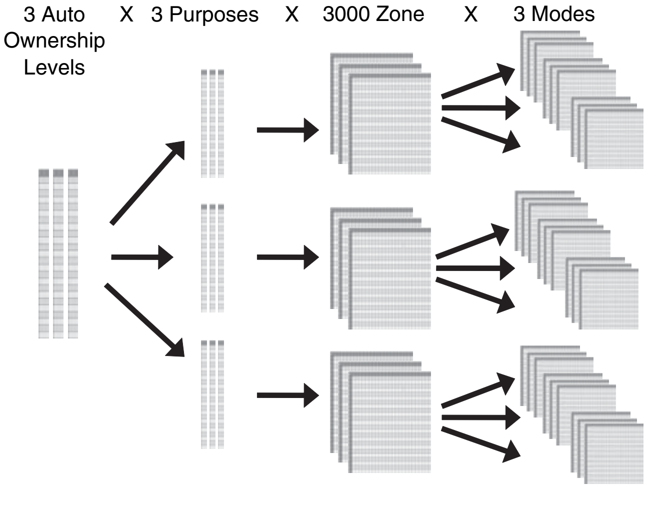


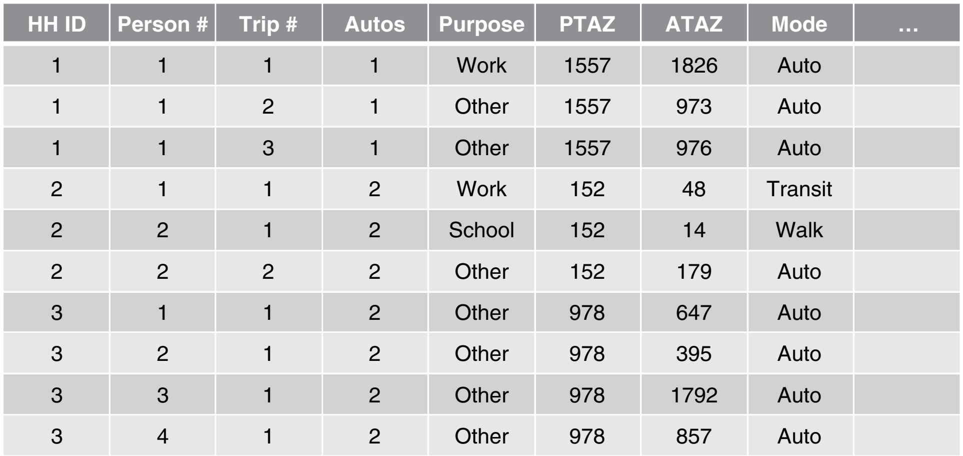
FIGURE 5 Example of traditional model application.

Next, consider the same model implemented using microsimulation. Here the software is relieved of the need to store every possible combination of outcomes for every zone pair and instead only the chosen outcomes are stored. Rather than storing vectors or matrices of data at the zonal level, the model stores a table of data with one record for each trip and a column for each field of interest. In the example shown in Figure 6, if there are 10 million trips and 8 columns of data, the model would need to process and store 80 million elements. If each is stored as a 4-byte-long integer, this would amount to about 300 MB of data. Adding modes or purposes would not increase the amount of data that needs to be stored. Adding income level and time of day would each require an additional column, increasing the problem size to 100 million elements and 380 MB of data. It becomes apparent that as the complexity of the problem increases microsimulation allows for the necessary data to be efficiently stored.

The true advantage to demand simulation is that it allows modelers to develop more sophisticated core probabilistic models without devoting undue resources to managing the complexity. It is less of a burden to include additional variables, such as household composition, age, or additional purposes and modes that may be useful to the model formulation. Further, because the outcomes from the upstream models are stored as discrete values, it is easy to make downstream models dependent on those choices. In the previous section it was noted that in a traditional model the scope of knowledge for a trip is its two endpoints, meaning that the model cannot consider the context of the trip within a more complex chain. Tour-based models can overcome this by extending the scope to the entire tour. Demand simulation allows the scope of knowledge to extend even further, because the decisions are tracked explicitly. For example, time-of-day models can know when other tours have already been scheduled, and avoid overlapping. Also, the model can know what other members of the same household are doing, allowing for joint-travel and intra-household interactions to be modeled. The bottom line is that with less information loss the models can be more powerful.

Typical Model Flow

To illustrate the major components of activity-based models an example model structure is described here and contrasted with the structure of an example trip-based model. The activity-based model is assumed to be implemented in a microsimulation framework and the trip-based model uses the traditional fractional probabilities approach. In both cases a representative



HH ID	Person #	Trip #	Autos	Purpose	PTAZ	ATAZ	Mode	...
1	1	1	1	Work	1557	1826	Auto	
1	1	2	1	Other	1557	973	Auto	
1	1	3	1	Other	1557	976	Auto	
2	1	1	2	Work	152	48	Transit	
2	2	1	2	School	152	14	Walk	
2	2	2	2	Other	152	179	Auto	
3	1	1	2	Other	978	647	Auto	
3	2	1	2	Other	978	395	Auto	
3	3	1	2	Other	978	1792	Auto	
3	4	1	2	Other	978	857	Auto	

FIGURE 6 Example of microsimulation model application.

"good practice" model is described, rather than a specific model system in existence. The individual components are tabulated in a way to illustrate the parallels and differences between the systems.

The basic structure of a good practice trip-based model is summarized in Table 2. Often such models are referred to as 4-step models, referring to the steps of trip generation, trip distribution, mode choice, and assignment. It is common, however, for such models to have more than four steps when components such as time of day, household submodels, and auto ownership are included. The left (stub) column of Table 2 indicates the main stage of the model, the center column lists the individual outcomes associated with those stages, and the right column shows how the data are stored.

The main inputs to the model system include highway networks, transit networks, and a list of households and employment by TAZ. The networks are used to create level-of-service skim matrices representing the travel time and cost between each TAZ pair, and the household and employment data are stored as a list of the total in each TAZ.

Often, trip-based models include a set of household submodels that are used to disaggregate household characteristics from averages to groups. This might include a submodel to convert from the average household size in each zone to the number of households in each zone of size 1, 2, 3, or 4+. Similarly, a submodel commonly converts from the average household income in a zone to the number of low, medium, and high income households. At this point, the model would be storing for each zone the number of households (usually a fractional number) in each size and income group.

Next, the model would forecast any long-term choices, which would typically only include auto ownership. Auto ownership is a function of the household size, income, and usually some accessibility terms at the zonal level. Auto ownership is included because it is such an important predictor of mode choice.

Trip generation rates are applied to these vectors of households by category, resulting in the number of trips generated in and attracted to each TAZ. The trip lists for each purpose here would be segmented by auto ownership and income for home-based trips, with no segmentation of non-home-based trips.

Next the core trip-level models are applied. The first is destination, where trips are typically distributed using a gravity model. Mode choice is then applied using a logit choice model.

TABLE 2
STRUCTURE OF GOOD PRACTICE TRIP-BASED MODELS

Model Stage	Data and Outcomes	Data Representation
Inputs	Highway network Transit network Households and employment by TAZ	Lists of total by TAZ
Household Submodels	Number of households by income group and size	
Long-term	Auto ownership	
Generation	Number of trips by purpose	
Trip Level	Destination Mode Time of day and peak spreading	Matrices by TAZ
Assignment	Auto volumes on each link Transit volumes on each link Auto and transit travel times	Loaded networks

Finally, the trip tables are factored by time of day, usually using fixed factors. Through each of these three steps, trips are stored in zone-to-zone matrices.

The final step is to assign the trip tables to the networks, resulting in highway volumes on each link, transit volumes on each line, and congested travel times.

Table 3 illustrates the structure of a good practice activity-based model. Again, the left column shows the main stages, the middle shows individual outcomes, and the right shows the format in which the data are stored. The inputs to the tour-based model are identical to those of a trip-based model, including the highway and transit networks and a list of households and employment by TAZ.

The first step of the model is to create a synthetic population of households in the region. This can be done by selecting representative households from the Public Use Microdata Sample (PUMS) to correspond to the aggregate characteristics of households in each zone. For example, if the zonal data show that TAZ 1 contains two middle-income, two-person households, then two households meeting those criteria will be randomly selected from the PUMS and associated with that TAZ 1. When this is done, all the other uncontrolled attributes of the household are included as well. Therefore, the first household might include two working adults age 45 and 50 with their associated occupations, whereas the second household might include a single mother and her teenage son. Additional dimensions can be controlled, such as number of workers, number of children, or age of householder, but if they are uncontrolled, the synthetic population will simply match what is found in the PUMS. The end result is a table with one record for each household and person in the region, with attributes representative of the regions' actual population. Population synthesis is somewhat analogous to household submodels converting aggregate household data to something more disaggregate. Although both involve disaggregation, the difference is that population synthesis results in a fully disaggregate population that will be used with microsimulation methods, whereas household submodels still maintain fractional probabilities.

As with the traditional model structure, long-term models are applied next. This includes auto ownership, as was done before, but adds a model of usual workplace location. The usual workplace location model predicts for each worker the zone in which their workplace is located. It is a bit different from a HBW trip distribution model in that the usual workplace location model predicts the work location even if the person does not go to work on the travel day, and even if the person chains trips such that there are no HBW trips. Thus, the result is directly comparable to the U.S. Census journey-to-work data. Workplace is included as a long-term decision based on the concept that it does not tend to change from day to day.

Next, a set of generation models is applied to predict the number of activities by purpose, how those activities are formed into tours, and any joint travel. These models encompass trip generation, but provide significantly more information because they include the entire day's pattern of activity and travel results. It is within this generation stage that the biggest structural differences between activity-based model systems exist. In the San Francisco model and its derivatives each person is given a choice of a daily activity pattern, and thus each person chooses the full package of what he/she will do during the day. In the Columbus model and its derivatives, tours are scheduled one at a time, with each building on the available time windows, and with consideration of intra-household joint travel. Although the workings differ the end result is the same—the set of activities and their composition into tours for each person. Coming out of this model there is now a list of tours in addition to a list of households and a list of persons.

TABLE 3
STRUCTURE OF A GOOD PRACTICE ACTIVITY-BASED MODEL

Model stage	Data and outcomes	Data representation
Inputs	Highway network Transit network Households and employment by TAZ	Lists of totals by TAZ
Population Synthesis	List of representative households with associated income, size, and other attributes	List of each household, person, tour, or trip
Long-term	Usual workplace location Auto ownership	
Generation	Number of activities by purpose Formation of activities into tours Joint travel	
Tour Level	Destination Time of day Mode	
Trip Level	Stop location Time of day Mode	
Assignment	Auto volumes on each link Transit volumes on each link Auto and transit travel times	Matrices by TAZ Loaded networks

The tour-level models are then applied to this list of tours. A primary destination is chosen for each tour. A hierarchy of activity importance is defined, with work or school at the top and serving as the primary destination if it is included in the tour. If the tour is a work tour, the primary destination is predetermined by the result of the usual workplace location model. For non-work tours, the destination is chosen. A time-of-day model is applied to predict the departure and return time for each tour. The tour mode choice model predicts the primary mode of each tour based on the roundtrip level-of-service for each mode between the home location and the primary destination. These three models are parallel to the trip-level models in a trip-based model, but applied to tours instead of trips.

The list of tours is converted into a list of trips, and for each trip the trip-level models are applied. An important detail is that the trip-level models are constrained to be consistent with the tour-level models. For destination choice, the location of any intermediate stops is chosen taking into consideration the deviation from the path between home and the primary destination. For time of day, the timing of individual trips must be consistent with the timing of the tour as a whole and, in mode choice, the trip modes must be consistent with the tour modes. In mode choice, for example, if a traveler takes transit to work, he/she cannot drive home from work. The end result here is a full list of trips with destination, time-of-day, and mode details.

This final list of trips is aggregated into zone-to-zone trip tables, which are assigned to the highway and transit networks. The assignment steps are the same as in a trip-based model.

Models with Coordinated Travel

The initial efforts at activity-based models in San Francisco and New York treated each individual as completely independent, with no knowledge of what the other members of their households do. In reality, however, it is very common for household members to jointly participate in travel and to coordinate their travel. The Columbus model made an important advancement in that it explicitly accounts for these intra-household interactions. Although the individual-traveler models can include variables such as household size, they cannot capture the behavior in a consistent way across household members. Modeling a person without the context of a household is like modeling a trip without the context of the tour.

Accounting for joint travel is important, because members of the same household account for a significant majority of carpools, and understanding joint travel improves the ability of the model to forecast travelers' willingness or lack thereof to carpool outside the home, and the effectiveness of high-occupancy vehicle lanes and regional carpool promotion policies. The difference between the two families of models is largely in the structure of the generation step seen in Table 3. It is worth noting, however, that regardless of the approach used in generation, either model structure is a major advance over trip-based models.

Research Models

Several advanced activity-based models have been developed in the academic world. These include CEMDAP, developed at the University of Texas; FAMOS, developed at the University of South Florida; TASHA; developed at the University of Toronto; and ALBATROSS, developed at Eindhoven University of Technology in the Netherlands. Each of these models is an activity-based travel demand model that offers something of interest beyond what has been implemented in practice. CEMDAP, for example, simulates activities and travel in a continuous time domain. It has been implemented in the Dallas–Fort Worth region, and is being deployed by the Southern California Association of Governments. FAMOS uses the notion of time-space prisms to constrain the available travel and activities. TASHA is a 24-h activity and travel simulation. ALBATROSS uses a decision tree method to implement a series of if-then rules for making decisions. A detailed review of each of these models is beyond the scope of this document. From the standpoint of advanced practice, however, there is room for some of the lessons learned from these academic models to be incorporated into practice.

DYNAMIC NETWORK MODELS

Static traffic assignment models route fixed specifications of demand through a network representation of the transportation system of the modeled area. In the past the demand has typically been specified as daily flows, or the same divided into three or more periods of the day. The resulting link flows and travel times are important performance measures and model outputs, as well as serving as inputs to other components in the modeling chain. The topic of static user equilibrium assignment has been extensively covered in the literature, although much of it focuses on theoretical issues such as problem formulation and increasingly more efficient solution methods. With the possible exception of on-going vendor efforts to parallelize such methods it appears that from a pragmatic standpoint there have not been widespread breakthroughs in static assignment methods over the past decade.

The static methods are often criticized on several grounds. Traffic signals are not represented in the models, such that their major influence on system performance and delay must be captured through link capacity functions. Static models cannot represent queue formation and dissipation. Moreover, static assignment routes all of the demand through the network, regardless of whether there is enough capacity to accommodate it. As a consequence, it is not uncommon to see large numbers of links in forecast years with a volume-to-capacity ratio in excess of 1.0. Although mathematically simple to handle, such flows cannot be accommodated on the roadway, leading to severe congestion, long delays, and possible cancellation or postponement of travel. Even when splitting demand into several periods of the day it is difficult to capture time-varying traffic properties or control strategies and behavioral response to them. As a result, it is difficult to adequately model Intelligent Transportation System (ITS) strategies or other operational scenarios.

The alternative is to relax the assumptions of invariant demand, abstract control representation, and effects of congestion. Traffic simulation models have been in use almost as long as travel forecasting models (Gerlough 1964; Brown and Scott 1970), with current models being capable of modeling large urban systems. However, such models are commonly referred to in practice and in the literature as traffic simulation models. The same convention is adopted here to retain consistency and avoid confusion.] However, few attempts to model large urban areas have been completed, and none by practitioners seeking to use it as an adjunct to or replacement for traffic assignment. However, two somewhat related technologies—TRANSIMS and dynamic traffic assignment—have emerged as viable alternatives. The term "dynamic network model" will be used where any of these three approaches can be described or used interchangeably, and by their specific terms otherwise.

The expanding roles played by dynamic network models in transportation planning were illuminated in a recent workshop on Integrated Corridor Systems Management Plans held in Irvine, California. Co-sponsored by the California DOT (Caltrans) and TRB, the workshop focused on best practices, which typically involve the analysis of urban freeway corridors 20 to 40 miles in length. The size of these corridors makes them regional in significance, yet their analyses require operational details typically obtained using only microsimulation models. The policies examined often include relatively low-cost improvements such as ramp metering, improved incidence response times, spot widening at chokepoints, and arterial signal timing optimization at or near exit and entry ramps. Case studies from Minneapolis and Monterey were presented. Although many studies still solely make use of traffic simulation models a small but growing interest in using dynamic traffic simulation was evident, especially for larger study areas. However, it was equally clear that such thinking is just now occurring, and opportunities for using newer approaches will become more common in the next decade.

TRANSIMS

Dissatisfaction with the four-step modeling paradigm led David Albright, then director of research at the New Mexico DOT, to approach experts in the field of large-scale simulation at Los Alamos National Laboratory (LANL) in 1991. His challenge to them was to start from the requirements of the newly enacted ISTEA and Clean Air Act Amendments and to design, from first principles and without recourse to practices in use, a systems dynamics approach to modeling urban transportation systems. The resulting white paper, long since lost, formed the basis for a proposal to the DOE that eventually funded the TRANSIMS initiative. The resulting broad design is shown in Figure 7.

The Los Alamos team made significant strides in the development of the population synthesizer (Beckman et al. 1996) and began work on the route planner and traffic microsimulator. This was in contrast to the work of others, such as Kitamura et al. (1996) and other early researchers in activity-based modeling, who focused on the demand side of the equation (depicted as the activity generator in Figure 7) and largely ignored the supply side of the model. Regrettably, the two camps never collaborated to their strengths, largely as a result of the differences in opinion over how the overall framework would be structured or developed.

By early 1995, the LANL team implemented a cellular automata microsimulator and the distributed computer infrastructure (hardware and software) necessary to implement it. Tests on small prototype networks revealed promising emergent traffic flow properties (Nagel et al. 1997). The first TRANSIMS case study was carried out in partnership with the North Central Texas Council of Governments in 1996–1998. Because the activity generator had not been attempted, static demand from the Council's regional travel model was sliced into small time intervals, from which trips and tour were synthesized. The entire Dallas–Fort Worth region was included in the model at a coarse level, with North Dallas being modeled

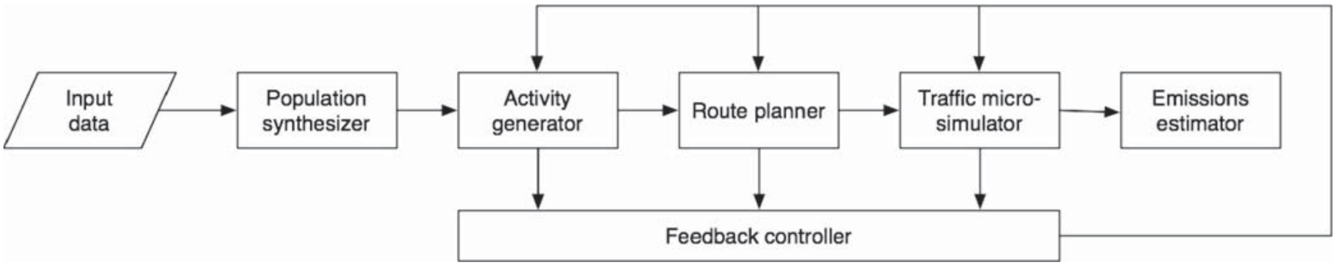


FIGURE 7 TRANSIMS architecture.

in great detail. The case study sought to prove the concept was viable, and the test was widely viewed as successful (Federal Highway Administration 1999).

A second case study was launched in Portland, Oregon, in the spring of 2001. The goal was much more ambitious, including plans to model the entire region using the router and microsimulator and to commence work on the demand side (activity generator) of the model. Achieving the latter would result in operational modules for each part of the system. Extensive network development and testing was undertaken, with two network configurations compared. The development team had long thought that an "all roads" representation of the region was necessary, whereas others believed that the network used for traffic assignment from Portland Metro's regional model would prove adequate. By late 2004, tests of both approaches led to the conclusion that the latter could effectively represent network conditions, although continued refinement of the network and testing of transit networks continued afterwards.

In 2005, the TRANSIMS team at LANL disbanded, having completed the work on the initial framework funded by internal sources, DOE funds, and limited U.S.DOT support. The software was licensed as open source software a year later. During the same time AECOM undertook an extensive overhaul of several parts of the system to include porting the system to Microsoft Windows™ and improving the graphical user interface (GUI) and other user interaction components. Several more tests of the emerging system, carried out by academics in several locations, continued to add to the knowledge base about the model.

The open source implementation of TRANSIMS is the largest and perhaps the most successful such undertaking to date in transportation planning. FHWA decided on the desired outcomes, to include at the outset their long-term strategy for TRANSIMS and gradual transition to a user-supported community. The team made the decision to use an existing widely used open source license rather than writing one themselves. They also adopted common distribution strategies, making significant use of Internet technologies such as web pages, wiki pages, and accessible version control systems. The result is a vibrant, online, user community that is supporting several initiatives and projects. The website for the current version of the software can be found at http://transims-opensource.net.

FHWA established an early deployment program in 2000 and continued to seek case study locations for the system. In contrast to the Dallas–Fort Worth and Portland case studies, most of the current deployments are for smaller studies. A listing of current TRANSIMS research and applications are included in Appendix C. FHWA is also sponsoring research into the integration of TRANSIMS with activity-based travel demand models in Sacramento and Columbus. This work was beginning as this report was finalized.

Dynamic Traffic Assignment

Dynamic traffic assignment (DTA) models occupy the middle ground between macroscopic traffic assignment and microscale traffic simulation models. They employ the familiar network and demand specifications of traffic simulation models, but operate at a much finer level of temporal detail. Because they typically employ link-based simulation models they produce more robust estimates of link travel times and costs. Research in DTA techniques began before the TRANSIMS project got underway, but was largely limited to academics working on its formulation and theoretical aspects. DTA overcomes the limitations of static models noted earlier, although at the cost of increased data requirements and computational burden. Moreover, software platforms capable of solving the DTA problem for large urban systems are just now becoming available. Unlike the activity-based travel and land use models, all known operational DTA packages capable of handling large networks are proprietary or have closed code.

DTA models can generally be classified by how they model intersection delay. Analytical DTA models treat it in the same manner as static equilibrium assignment models, with no explicit representation of signals. Link capacity functions, often similar or identical to those used in static assignment, are used to calculate link travel times. Analytical models have been widely used in research and for real-time control system applications, but not in practice. Simulation-based DTA models include explicit representation of traffic control devices. Such models require detailed signal parameters to include phasing, cycle length, and offsets for each signal in the network. Delay is calculated for each approach, with vehicles moving from one link to the next only if available downstream capacity is available. The underlying traffic model is often different, but at the network level they behave in a similar fashion.

Demand is specified in the form of origin–destination matrices for short time intervals, typically 15 min each. Trips are randomly loaded onto the network during each time interval. As with traffic microsimulation models, adequate downstream capacity must be present to load the trips onto the network. The shortest paths through time and space are found for each origin–destination pair, and flows loaded to these paths. A generalized flowchart of the process is shown in Figure 8. As with static models, the process shown in the figure is iteratively solved until a stable solution is reached. The memory and computing requirements of DTA, however, are orders of magnitude larger than for static assignment, reducing the number of iterations and paths that can be kept in memory. Instead of a single time period, as with static assignment, DTA models must store data for each time interval as well. A 3-h static assignment would involve only one time interval. A DTA model of the same period, however, would require 12 intervals (assuming 15 min each). These are all in addition to the memory requirements imposed by the number of user classes and zones.

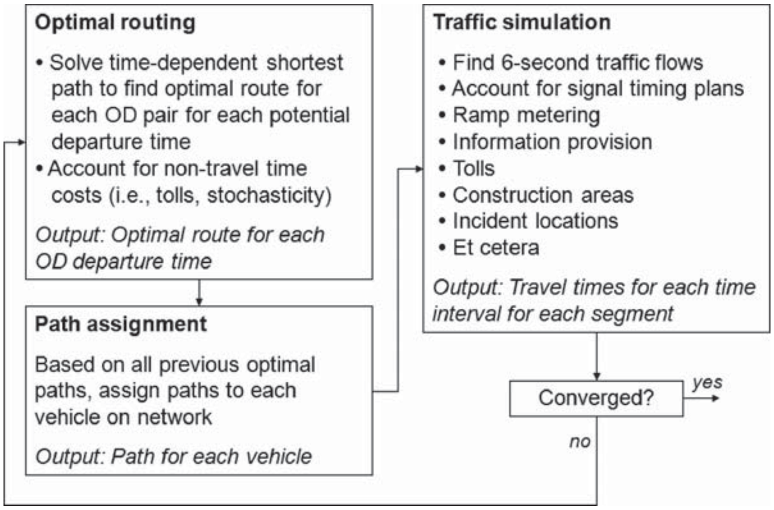


FIGURE 8 Typical DTA solution methodology.

Although its use in planning studies was perhaps always intended (Peeta and Ziliaskopoulos 2001), most of the early investigations focused on freeway control and ITS applications (Van Aerde and Yagar 1988; Mahmassani et al. 1993). Only a few large-scale applications of the model in tandem with regional travel demand models have been attempted. Dynameq has been successfully applied to a large subarea of Calgary and to analyses of the Rue Notre-Dame in Montréal. Although user group presentations of both applications have been made, and reported very encouraging results, the work is currently unpublished and inaccessible except through contact with the developers.

The largest known DTA application to date is described by Hicks (2008). The network from the Atlanta Regional Commission's (ARC's) travel model formed the starting point for the DTA network. Intersections were coded, centroid connectors were re-defined, and network coding errors were corrected. A signal synthesizer derived locally optimal timing parameters for more than 2,200 signalized intersections in the network. Trip matrices from the ARC model were divided into 15-min intervals for the specification of demand. Approximately 40 runs of the model were required to diagnose coding and software errors. Unfortunately, the execution time for the model was approximately one week per run. The resulting model eventually validated very well to observed conditions; however, the length of time required to render it operational and the run time required prevented it from being used in studies as originally intended. Subsequent work by the developer has resulted in substantial reductions in run time, but this remains a significant issue that must be overcome before such models can be more widely used.

A number of cities are currently testing DTA models, but are not far enough along in their work to share even preliminary results. At least a dozen such cases are known to be in varying stages of planning or execution, suggesting that the use of DTA models in planning applications is about to expand dramatically. However, in addition to the issue of long run times, a number of other issues must be addressed before such models are likely to be widely adopted.

- The integration of DTA and travel demand models has only been attempted on an ad hoc basis, although the topic has received considerable research interest (Boyce 1986; Lin et al. 2008). Operational models formally incorporating feedback between the two modeling realms will be attempted as part of the SHRP 2 C10 project which will run from 2010 to 2012. Parallel work in two cities—Sacramento and Jacksonville (Florida)—will be pursued as part of that project.
- Transit has not been credibly tackled in DTA models, and considerable work will likely be required before it catches up with the existing capabilities for handling auto trips. It might be possible to combine static transit assignment methods with DTA models of auto and truck flows on an interim basis, feeding link travel times from the latter to the former.
- Traffic signal timings have a significant effect on network performance. However, most of the research on DTA models has been on node-abstract analytical solutions. Practical and scalable methods for developing signal timing inputs to regional DTA models have yet to emerge despite considerable evidence of its influence on capacity and operations (Berg and Do 1981; Boyce et al. 1989; Rakha and Van Aerde 1996).
- Criteria for the validation of such models have not been widely accepted. The paucity of traffic counts in most urban areas, and especially at 15-, 30-, or 60-min intervals, is a significant barrier to definitive assessment of these models.

It can be noted that these shortcomings apply equally to TRANSIMS and traffic simulation models, although the path to overcoming them may vary by platform.

Traffic Simulation Models

Traffic simulation models have been used for several decades to conduct detailed analyses of roadway designs and operational plans. Individual vehicles traverse detailed networks in very short time steps (typically 0.5 to 5 s intervals) in these models, and they explicitly model driver behavior such as lane changing and car following. Initially developed about the same time as the first four-step models, they likewise were initially executed on mainframe computers. However, whereas four-step models went on to become institutionalized in the urban planning process under strong federal leadership, traffic simulation models progressed at a slower rate. Over the past several decades traffic simulation models have caught up with travel demand models in terms of sophistication, quality of software, experience in practice, and to some extent, suitability for large-scale planning studies. They excel at visualization. Once in the domain of different specialists (traffic engineers and transportation modelers) that seldom collaborated, the two streams are converging as they are being used more in combination.

As with the other types of dynamic network models discussed, traffic simulation models typically use the familiar concepts of roadway networks and trip matrices. The former are typically far more detailed in geometric representation and lane configurations, and the latter are not only spatially more detailed but also more detailed in temporal respects as well. Such models also require explicit coding of traffic detectors and control systems to include traffic signal timing plans. Unlike DTA models, some traffic simulation packages can also optimize signal timings, reducing the amount of input data required to deploy them.

Owing to the amount of data required to develop them and their heavy computational requirements traffic simulation models have traditionally been restricted to small area studies, often encompassing no more than a few dozen traffic signals and the detailed land use patterns and networks accompanying them. Other simulation models were developed specifically for the study of freeway corridors. In recent years the advent of GIS, remote sensing capabilities, online traffic data, and signal timing optimization programs has enabled these models to be used for successively larger study areas. GUIs have significantly eased the coding and checking of input data, and some packages have interfaces to macroscopic traffic assignment models.

Aside from TRANSIMS there have been few attempts to replace traffic assignment models in urban areas with traffic simulation models. Rickert and Wagner (1996) built a model of the German Autobahn network, and Rakha et al. (1998) described the application of the INTEGRATION model in Salt Lake City. Both were prototypical applications that did not lead to their use by public agencies, although further work was anticipated in both instances that would have resulted in calibrated and useful models. There are no known on-going attempts in North America to microsimulate traffic flows for entire urban networks outside of the TRANSIMS program.

At the corridor and subarea level, traffic simulation models are much more widely used in urban areas, with varying degrees of integration with travel demand models. In many instances, traffic count data and origin–destination matrices are used to develop demand estimates for the traffic simulation model. The former are usually directly transferable if in small enough units of time (15-, 30-, or 60-min intervals). The latter are generally too coarse for direct use in such models. Intermediate steps to divide the data into the finer temporal intervals needed by the model, often based on observed diurnal patterns, are required. Most TAZs in travel demand models are too large to serve analogous roles in traffic simulation models, requiring an additional step to divide the origin–destination flows into sinks and sources within zones. Getting traffic dynamics right in traffic simulation models entails coding traffic entering and leaving the network where they do in real life, which is often small feeder streets, parking lots, etc. These are known as sinks and sources. Several, and perhaps dozens, of them might be coded in the same area as a single TAZ. Such allocations are typically based on counts, field observation, or aerial or satellite photography.

The tour- and activity-based models described earlier can mesh with traffic simulation models in several ways. Most tours and their constituent trips are assigned a discrete starting time, or grouped into finer intervals than possible with trip-based models, obviating the need to slice peak periods into the finer intervals required by traffic simulation models. Because synthetic population generators create individual households it is possible to geocode them as point locations, although further research is required to ensure realistic outcomes. Agencies with land use models will find it easier to get such micro-positioning correct. However, these synthetic households will only rarely match the characteristics of a real household at that location. The aggregate characteristics of the population at the level at which the synthesis was constrained (typically census tract or public use microdata area) will match, but individual observations within them will not necessarily do so.

The manner in which such models can work together can be illustrated through several examples. One is the aforementioned implementation in Atlanta. However, the major focus was on the traffic simulation models, which were used to evaluate a wide variety of operational and design issues relating to I-285, a 64-mile circumferential freeway. Traffic simulation models were the only ones sensitive enough to capture the effects of some of the contemplated changes. However, it was also recognized that a number of factors well beyond the freeway affected the demand, such as broad demographic shifts and changing travel behavior, particularly with respect to growing congestion in the region.

After consultation with experts in the field, it was decided to construct a three-tier model to study the I-285 freeway, as shown in Figure 9. Demand data and networks from the regional model were linked to a DTA model of the entire region, with emphasis (in detail as well as calibration) on the study area. As noted earlier, a matrix variegator was developed to divide the peak period regional trip matrices into the 15-min intervals required by the model, using observed peaking characteristics and travel survey data (Simons 2006). Synthetic matrix estimation could have been used to enforce consistency between the demand data and traffic counts, but was not required. Some regional strategies, particularly those related to ITS, were evaluated at the DTA level. Finally, demand data from the DTA model was mapped to the traffic simulation model, the level at which most scenarios were tested. Performance measures were compiled at that level as well. Because the corridor was already congested and most signals operated on pre-timed plans during the peak periods the existing timings and parameters were used in the traffic simulation (VISSIM) models, although provision for using the Synchro model for timing optimization was built in. Opportunities for feedback to the DTA model handled cases where excess demand was supplied to the traffic simulation models.

Microsimulation was also used in tandem with the activity-based travel model maintained by San Francisco County Transportation Authority (SFCTA) to study alternatives for the reconstruction and seismic retrofit of the major roadway providing access from the city to the Golden Gate Bridge. As with the I-285 study, demand matrices from the regional model were adapted for use in the traffic simulation model (Paramics) used in the study. Both spatial and temporal disaggregation was required; however, as in Atlanta, this process obtained reasonable travel patterns without recourse to further preprocessing (e.g., synthetic matrix estimation). Once developed and validated the model was used to study a number of scenarios, to include sensitivity testing of electronic toll collection impacts on the bridge toll plaza, various roadway design alternatives, incident simulation, and construction staging. None of these scenarios could be addressed using the static traffic assignment model used with the SFCTA model. Moreover, the measures of effectiveness—which included estimates of delay at each intersection, incidence and severity of bottlenecks, and other operational metrics—are below the level of resolution of regional models. The animated display of traffic flows, now a standard feature in traffic simulation packages, proved invaluable for conveying model outcomes to the public.

AIR QUALITY MODELING

The output of traffic assignment in regional travel demand models is routinely transformed into the inputs required for emissions models used for air quality conformity analyses. In the recent past the MOBILE6 package (Vehicle Emissions Testing Software) developed by the EPA has been used for such analyses, with California using a variant known as EMFAC (EMission FACtors). Both models produce estimates of tailpipe emissions by vehicle type of various pollutants to include nitrous oxide, carbon monoxide and dioxide, particulate matter, and other toxins. The programs have evolved over time to incorporate changes in fuel composition, typical driving behavior, and improvements in the test data used to develop the various exhaust and evaporative emission rates under varying driving cycles. Additional toxins have been added as well. These models can be applied at varying levels of geography, allowing them to be used for national-, regional-, and project-level analyses. The processing of travel model outputs required to use these models includes an exogenous estimate of average vehicle speeds based on link flows and capacity and analysis of the detailed peaking characteristics of travel within the study area, such that estimates of vehicle miles of travel by vehicle class and speed can be generated from the assignment results.

Aside from continued improvements to the models themselves there has been little change in how they are used in the transportation planning process. Their inputs are specified in exactly the same manner whether a sketch planning aggregate travel model or highly detailed dynamic network model is used to generate them. In the latter case, the preservation

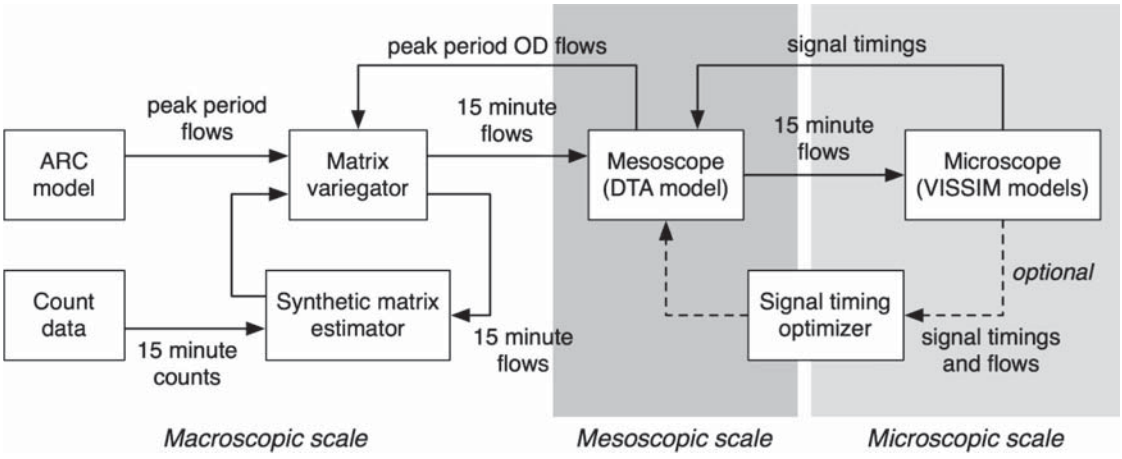


FIGURE 9 Multi-tiered modeling approach for the I-285 study.

of detailed microdata about the vehicle's drive cycle and the underlying travel plans giving rise to it can be mined, allowing for higher granularity in the inputs. That is, a larger number of traveler–vehicle categories can be used to permit more detailed levels of analyses. Insomuch as a dynamic network model provides more accurate depictions of microscale driving dynamics, the resulting estimates of travel time and delay will obviate the current requirement for post-processing static assignment results to obtain more realistic travel speeds.

The EPA has recently developed the MOVES (Motor Vehicle Emissions Simulator) model to replace the MOBILE family of models. Information about the MOVES model, as well as the software, can be found at http://www.epa.gov/otaq/models/moves. As with its predecessors, it is built from a vast amount of vehicle testing data. However, MOVES is more than simply an update of the previous models. The underlying software has been largely rewritten, and now includes a GUI. MOVES is capable of modeling emissions from the national level down to that of individual projects. Although not yet formally approved for air quality conformity analyses at the time of this writing, the software is expected to replace MOBILE6 in the near future. In some respects it remains a work in progress, with some issues relating to compatibility between the various beta versions that have been made available. However, it represents a major advancement over previous emissions models, especially in how it estimates greenhouse gas emissions. Similar efforts are underway to update the EMFAC model in California. MOVES2010 and EMFAC2009 are the current versions of these packages.

The MOVES model will continue as a standalone program, requiring data in its unique format. The situation has been improved somewhat by its ability to read required inputs from relational databases, which will ease the translation from network models. One logical progression is the convergence of emissions and dynamic network models, where the former becomes a standard metric calculated by the latter. Such could be achieved by tightly coupling the two packages so that they share a common database, exchange data dynamically using shared libraries or application program interfaces, or are fully integrated pieces of software. The TRANSIMS emissions estimator is an example of such integration. Although it cannot be used as a substitute for MOBILE or MOVES for conformity analyses, it can be used seamlessly to assess the environmental impacts of the scenarios tested with TRANSIMS. Whether other dynamic network models provide comparable functionality or tight linkages to the MOVES model remains to be seen. Similarly, tools or procedures for incorporating emissions into pricing analyses, which implies a feedback from emissions to travel demand model, have yet to emerge.

Separate tools designed to evaluate carbon emissions have begun to appear, in part because the MOBILE package was not thought to deal with them satisfactorily. The GreenSTEP model developed by Gregor (2009) is perhaps one of the most developed to date. It goes beyond being an emissions calculator by instituting a framework for the codification of the effects expected from and rapid testing of a large number of emission reduction strategies. In Oregon it is designed for application at the statewide level, although nothing in its design precludes it from being used for metropolitan areas. As with MOVES, it contains a variety of user-defined inputs for vehicle fleet composition and their changes over time, fuel characteristics, and prices. However, it also generates a synthetic population and assigns travel characteristics to it, as well as capturing some aspects of land use. The resulting estimates of greenhouse gas emissions and fuel consumption can be used to screen a number of strategies, alone or in combination. The structure of the model is shown in Figure 10.

GreenSTEP and similar tools complement, rather than substitute for, more detailed urban and statewide travel demand models and emissions calculators such as MOVES. Its strength lies in its statewide focus, straightforward interface, ability to test a large number of scenarios or combinations thereof, and ability to define travel characteristics and other inputs that are consistent with other models used by the agency. The need for a tool like GreenSTEP may be reduced over time as more of its features are incorporated into mainstream travel models; however, in the near term it fills a niche not currently filled by other tools.

LAND USE MODELS

Simulating land use improves the outcome of the transportation model. By explicitly simulating the land use and transport interactions, observed behavior of traveling, household relocation, job change, shopping location choice, etc., may be modeled more realistically. It also creates a logical consistency between land use and transportation forecasts, and the performance measures derived from them.

The transportation and land use systems closely interact, as illustrated in Figure 11, by the land use/transport feedback cycle (Wegener 2004, p. 130). Starting at the bottom of the cycle (Land Use), the locations of population and employment determine the origins and destinations of most trips simulated by travel models (Activities). The simulation of the Transport System allows calculating Accessibilities, which describe how accessible one zone is to all other zones. This accessibility shapes land use. Both households and businesses search for locations that are—among other location factors—readily accessible. This closes the land use transport feedback cycle.

Traditionally, changes in the distribution of households and employment are given exogenously based on a consensus forecast. Simulating land use allows for generating logically consistent forecasts that are independent of stakeholder interests, which commonly affect consensus forecasts. Further-

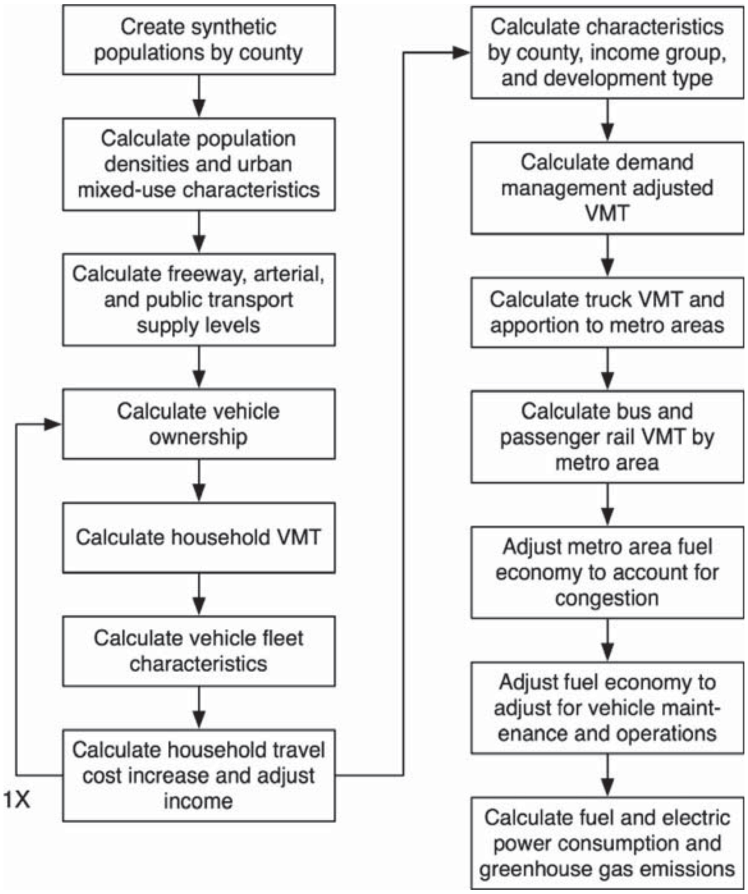


FIGURE 10 GreenSTEP model structure.

more, consensus forecasts commonly forecast land use at the municipal and in some cases at urban district levels. A land use model, in contrast, generated land use forecasts at any geographical level of interest.

Ever since personal computers became available for academic research, land use simulation models have been developed. The pioneering work of Herbert and Stevens (1960) and Harris (1966) was fundamental in exploring how computer models may be applied for urban analysis. Though aspatial in design, the theory of urban interaction developed by Forrester (1969) was a milestone in explicitly simulating businesses, dwellings, and households. The Lowry Model (Lowry 1964) acquired even more popularity. Its relatively simple model structure allowed for the development of many applications, some of which are still in use or undergoing even further development today.

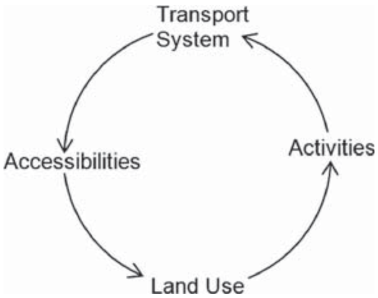


FIGURE 11 Land use–transport feedback cycle (*Source:* Wegener 2004).

A large variety of different land use model approaches currently is in operation. Comprehensive overviews on existing land use models may be found in Kain (1987), Wegener (1994, 1998, 2004), Wegener and Fuerst (1999, p. 42 ff), the U.S. Environmental Protection Agency (2000, p. 27 ff), Kanaroglou and Scott (2002), Timmermans (2003), or Hunt et al. (2005). Although the motivation of many land use models are land use-related analyses, most of these models are integrated with travel models. Therefore, the majority of these models support analyzing how land use models may improve travel models.

Design Principles of Land Use Models

At the detailed level, most land use models work differently; however, many land use models are designed based on a similar rationale as shown in Figure 12. A common design principle is the distinction of three major players on the land use

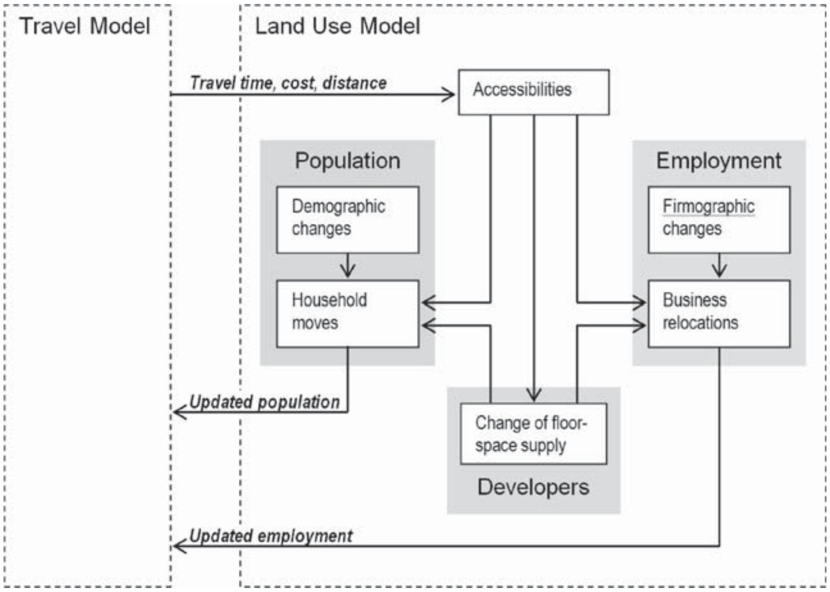


FIGURE 12 Common design of urban land use models.

market: population, employment, and developers. Whereas population and employment are using dwellings or floorspace to locate, developers build additional dwellings or floorspace based on demand and available developable land. Accessibilities influence location decisions of population, employment, and developers. The updated locations of population and employment are then fed back into the travel model. Commonly, the simulation of households is done in two steps. Demographic changes are aspatial changes, such as ageing, marriage, birth of a child, divorce, death, change of educational level, receiving a driver's license, etc. Household moves are the spatially explicit relocation of households. Many demographic changes trigger household moves. For example, a daughter who leaves the parental household needs to find a dwelling to establish her own household. The same distinction is commonly made for the simulation of employment.

Firmography, a contraction of *firm* and *demography,* is the study of the structure and evolution of businesses. Such changes are simulated in the firmographic module including nonspatial events such as business establishment, growth, decline, or closure. Business relocation is the move of the entire firm or of a part of the firm. Again, some firmographic events, namely business establishment and growth, may trigger a business move. Commonly, nonspatial and spatial events are distinguished because they are simulated differently. Often, aspatial events are steered by an economic model simulating employment and population growth or decline. Another distinction is that land use policies may be tested that aim at influencing location behavior; however, policies are seldom tested that influence demographic changes. Hence, spatial modules are designed to be sensitive to a large variety of policy changes, whereas nonspatial modules simulate events that happen to population or employment.

Although the basic design structure is similar for most land use models, there are at least three fundamental design features handled differently in several land use models:

1. Behavioral or structure-explaining approach,
2. Bid-rent or discrete choice approach, and
3. Aggregate or microscopic simulation.

Behavioral approaches aim at simulating the explicit behavior (such as marriage, birth, or relocation), whereas structure-explaining approaches attempt to simulate the outcome (such as population distribution) directly without dealing with the motivation that led population to be distributed in a certain way. Certainly, this distinction is vague and many models are somewhere between these two approaches. The model design in the example in Figure 12 shows a behavioral approach, as the behavior that leads to a certain distribution of population and employment is simulated explicitly. A common example for a structure-explaining model is a Cellular Automata that simulates the state of a single raster cell based on the state of the surrounding raster cells. Raster cells are equally sized quadratic or hexagonal zones that cover the entire study area. Being equal in size the zonal system simplifies simulating spatial interaction between neighboring cells. Cellular Automata models do not explain the change of a raster cell, but rather simulate the outcome. Structure-explaining models tend to be less sensitive to policy scenarios because behavior is not represented in the model. However, Cellular Automata allow for building a land use model even if few data are available. As a consequence, many Cellular Automata models are implemented in developing countries where data availability is limited.

A classic distinction in land use models is the bid-rent approach and the discrete-choice approach. The bid-rent theory was first developed by Alonso (1960). According to this theory, every actor on the land use market is making bids for a piece of land, and the bidder with the highest offer gets the land. Because of transportation costs, everybody is willing to bid more for a location in the city center than for a location on the outskirts. Because most office firms value transportation costs more highly than most households, the office employment makes the higher bid in the city center, whereas the household bids higher in the suburbs. This explains why office buildings are located downtown while most residential areas are in the suburbs. The discrete-choice theory was developed by Domencich and McFadden (1975). Frequently, logit models are used to implement the discrete-choice approach. Households, firms, and developers make choices among a finite set of alternatives. The utility of every choice is used to select one alternative; the higher the utility of a given alternative, the greater the probability this alternative will be selected. Not everyone chooses the perfect solution, but some deviation from the optimum distribution is implemented.

An advantage of the bid-rent approach is that prices are simulated endogenously in the bidding process. A well-calibrated model generates realistic prices that equal the highest bid made for every location. To reach the equilibrium price, the model needs to iterate a few times until prices are found and no one is willing to make a higher bid for any location. The bid-rent approach assumes market transparency and users who maximize their profit. The discrete-choice approach requires an additional land-price model, as prices are not updated automatically. Limited information is introduced explicitly in the discrete-choice approach by logit models: owing to a lack of time and money to analyze all alternatives as well as the result of personal preferences, habits, and prejudices, some users make seemingly nonoptimal choices. Overall, actors in the discrete-choice approach aim to satisfy their needs and not to maximize their profits. Martinez (1992) has shown that the two approaches lead to similar model results. As a rule of thumb, bid-rent approaches work best in markets that are highly competitive and transparent. Discrete-choice approaches work better in markets that react with some time lag and in which users have to make decisions at a certain level of uncertainty.

The third characteristic analyzed in this context is the distinction between aggregate and microsimulation land use models. Aggregate models cluster actors into certain groups, such as households by household type or firms by industry type. All actors in each group are assumed to have homogenous preferences. With a smaller number of groups, aggregate models store data efficiently and tend to have shorter run times. If more detail is added to the model, the handling of many groups may become cumbersome, and a disaggregated approach may become more appropriate (see the earlier discussion of activity-based models). Ever since Orcutt (1960) introduced microsimulation, both land use and transportation models have been developed that simulate every actor individually. The great advantage of microsimulation is the explicit simulation of the interaction between individuals. Hägerstrand (1967) proved in his theory of spatial diffusion how innovations are spread from a single actor to other actors who live in spatial proximity. Individuals who received the innovation become a sender themselves, further spreading this innovation at the microscopic level. Nobel Prize laureate Schelling (1978, p. 147 ff) showed with the self-forming neighborhood model how microscopically simulated households choose more segregated locations than the aggregate segregation desire would suggest.

As discussed in the earlier section on activity-based models, microsimulation models allows for storing complex data sets more efficiently. Often, microscopic approaches are easier to communicate, as describing the behavior of single actors is less abstract than describing the homogenous behavior of groups. Because microscopic models simulate individual interaction explicitly, model results tend to be more coherent with urban theory.

However, model developments obsessed with adding ever more detail do not lead to the best models. By adding detail, model run times may suffer, and in some cases the complexity of the model may exceed time and budget allocated to the model development. Microsimulation models require a random number generator to simulate choices. With different random numbers in each model run, the results in every run are slightly different owing to the stochastic variation. This difference is insignificant if a very large number of actors are simulated (such as a location choice of 1 million households). Stochastic variation makes model output invalid if the output is analyzed at a detailed level (such as location behavior of a hundred households of household type 1 in neighborhood A). If microsimulation is applied, analyses of model results may only be done at a fairly aggregated level.

Examples of Land Use Models in Practice

After a wave of urban model developments in the 1960s, increasing deregulation and a shift from the synoptic planning paradigm to incremental planning decreased the interest in urban models outside academia. Whereas the synoptic planning paradigm sought to take into account many planning aspects simultaneously and hence favored comprehensive modeling, an incremental planning approach aims at addressing single issues one at a time, which requires less understanding of the big picture. In the 1990s, the interest in urban models as a planning support tool was revived as a result of federal regulations by the EPA and a general disappointment with the success of market-driven incremental planning approaches. Ever since, several models have been developed that are applied in practice. To provide an overview of the most common land use models, seven have been selected that have been applied to more than one study area and as such been in practice outside of academic research projects. The models discussed here are, in alphabetical order, DELTA, LUSDR, MEPLAN, MUSSA, PECAS, TRANUS, and UrbanSim. Though LUSDR has been applied so far to only one study area, it has been included here as an operational model with multifaceted policy applications.

The DELTA model has been developed by Simmonds (1999, 2001; Simmonds and Feldman 2007). The acronym DELTA was derived from the five major sub-modules: Development, Employment status and commuting, Location and property market, Transition and growth, and Area quality. This aggregate model simulating economic growth and land use changes may be applied at the regional or urban level. At the urban level, DELTA simulates developers, household location, demographic changes, auto ownership, and employment location. At the regional level, DELTA adds modules that simulate long-distance migration and an economic model. All location decisions are based on the discrete-choice approach using logit models. DELTA has been applied to several cities and regions in the United Kingdom, as well as the Auckland region in New Zealand.

The Land Use Scenario DevelopeR (LUSDR) was designed and implemented by Gregor (2007) for the Rogue Valley MPO in Oregon. A guiding principle was to build a policy-sensitive land use model that limits data requirements to a minimum. LUSDR creates a synthetic population with households and employment establishments. An iterative process allocates households and firms to development types. Subsequently, development types are allocated to zones based on their land availability, plan compatibility, prices, and accessibility using Monte Carlo sampling. The bid-rent approach is used to adjust floorspace supply based on the demand by households and firms. The model was developed using the R statistical programming language. Currently, an application of the LUSDR model is under development for the Salem–Keizer MPO in Oregon. Another Oregon land use model, MetroScope, has been used by Portland Metro for almost two decades (Conder and Lawton 2002). Originally developed as a land consumption model, it includes both residential and nonresidential supply and demand components that include elaborate and sophisticated econometric models. Pivoting off of externally specified amounts of land supply and zoning the model estimates land consumption by tenure, type, and location. In recent years it has been integrated with Portland Metro's regional travel model.

MEPLAN was developed by Echenique et al. (1969, 1990). This aggregate land use model initially was based on the Lowry Model for distinguishing basic (exporting) and non-basic (supplying the local market) employment. MEPLAN is integrated with an aggregate transportation model, and both land use and transportation models iterate until equilibrium is reached. Land use is simulated as economic activities by households that live in housing units and employment that is located on floorspace. An economic input–output model simulates the flows of goods and the required labor to feed the economy. MEPLAN has been applied to many regions worldwide.

MUSSA (Modelo de Uso de Suelo de SAntiago) was developed by Martinez at the University of Chile in Santiago (Martinez 1996; Martinez and Donoso 2007). MUSSA contains a microeconomic approach to simulate demand and supply of real estate. By developing new floorspace, equilibrium between demand and supply is reached. A logit model is used to simulate bids of users that are constrained by the available budget. Developers add real estate based on expected rents and construction costs, while land use regulations are used as a constraint. The model has been developed with a GUI that allows running the model and visualizing the output. In cooperation with Citilabs, Cube Land, which integrates MUSSA with a transportation software, was released recently.

PECAS (Production, Exchange and Consumption Allocation System) was developed at the University of Calgary by Hunt and Abraham (2003). A land developer module simulates the behavior of real estate developers. An aggregate system simulates the exchange of goods, services, and labor. Prices are defined in an equilibrium process. Flows from production to consumption are allocated by nested logit models using prices and transport disutilities as impedance. A large number of PECAS applications are under development in the United States, including those for the state of Oregon, state of California, Montgomery MPO in Alabama, and the Baltimore Metropolitan Council in Maryland. PECAS is one of the few land use models that has been applied both at the urban and the statewide levels.

TRANUS (Transporte y Uso del Suelo) was been developed) in Venezuela by de la Barra and colleagues (de la Barra and Rickaby 1982; Barra et al. 1984, 1989). As an integrated land use transport model, TRANUS simulates location of activities, the real-estate sector, and a multimodal transportation system. Based on the Lowry Model and similar to the MEPLAN model, TRANUS distinguishes basic and non-basic employment. Change of employment in the basic sector is allocated first, and non-basic employment is treated as induced demand. An equilibrium approach iterates between changes in demand and supply to simulate land rents. TRANUS has been applied to cities and regions in America, Europe, and Asia.

UrbanSim was developed at the University of Washington by a team led by Waddell (Waddell 2002; Waddell et al. 2003). This microscopic model simulates households, employees, developers, and real estate prices. Location decisions are simulated based on multinomial logit models. To select a location, a uniform distribution is used to randomly sample a set of nine alternatives in addition to the site with the highest utility. The final location is selected from these ten alternatives. Land values are updated by hedonic regression.

Hedonic models are common in real estate analyses and estimate how much the individual characteristics of the land contribute to its value. Recently, the spatial resolution was increased from raster cells to parcels. UrbanSim applications are under development in many urban regions worldwide.

Today, PECAS, UrbanSim, and TRANUS are common land use models in the United States. As different as the design concepts of the three models are, all allow for expanding pure transportation models to integrated land use/transportation models. The two Latin American and the two English models described previously also have been shown to successfully integrate land use and transportation simulations. Furthermore, several academic land use models have proven to be operational and are promising to provide useful tools for land use analyses (Wegener 2004). There is no one model that fits all purposes; the best selection for an agency must be based on its requirements, capabilities, and resources, with particular emphasis on the scale and type of land use questions that will be studied. If time and funding permit, a custom-made model can even allow for tailoring a land use model to the specific local needs.

FREIGHT AND COMMERCIAL MOVEMENT MODELS

The state of practice in urban freight modeling remains far behind that of person-travel modeling, especially with respect to advanced modeling concepts. Although there has been two decades of intensive research and development of activity-based models, there is virtually no comparable activity in freight or commercial travel modeling. Historically, this has been the result of a lack of emphasis on freight, owing to its predominately private-sector nature and the relatively low percentage of trucks on most urban roadways. Data are difficult and expensive to collect compared with person travel, and the underlying behavior is more complex. Multiple decision makers, some with conflicting goals, influence the transportation choices made in the distribution of freight. As a consequence, little has been accomplished in this field over the same period of time that other advanced models have flourished. However, there are encouraging signs of increased progress and momentum in this area, ranging from improvements in existing techniques to emerging advanced models.

Trip-Based Urban Truck Models

In some respects having an explicit freight or commercial vehicle model at all might be considered an advanced modeling practice, as most urban areas have relatively simplistic representations of commercial vehicle flows. In many cases, they amount to little more than growth factoring of long-ago observed or imputed truck trip matrices. In other cases, a partially or completely synthetic four-step sequential modeling process is employed:

1. Trip generation (typically carried out for specific truck classes rather than by trip purpose)
2. Trip distribution
3. Time-of-day factoring
4. Traffic assignment.

Mode choice is not modeled explicitly, because the mode (truck type) is implicit in trip generation. Moreover, virtually all commercial flows within urban areas are by truck, offering little opportunity for mode choice. Freight mode choice is typically a function of the existence of carrier contracts, price differentials between competing carriers and modes, reliability concerns, and other factors not represented in typical urban transportation models or networks (Donnelly 2007). However, there is increasing evidence that pricing strategies may also influence mode choice (as well as other decisions) within urban areas (Zamparini and Reggiani 2007).

Traffic assignment is typically carried out in conjunction with person-travel flows using a multi-class equilibrium assignment. Uncommon only a decade ago, multi-class assignments now appear to be the norm in most instances; not only do they permit the concurrent assignment of different truck classes, but they also permit partitioning of person-travel demand by vehicle occupancy or toll use.

A number of such models have been successfully implemented. An important NCHRP synthesis of freight modeling was prepared by Kuzmyak (2008). It contains a comprehensive review of recent models including case studies of practice-leading models in Ohio, Oregon, Los Angeles, and Calgary. Profiles of other urban freight models in an additional eight cities are included. Most reported using surveys to build the traditional four-step model described earlier. Most are freight models, although two model only trucks and some attempt to incorporate flows through trans-shipment points. The work in Los Angeles is noteworthy in that they have recently invested in the development of a new heavy-duty truck model and linkages with air quality models. As with some of the others, it also includes explicit handling of trans-shipment centers.

A recently completed revision of the *Quick Response Freight Manual* (Beagan et al. 2007) is another important tool for modeling urban freight. As its name implies, it does not include nonfreight commercial movements. However, it does represent a tremendous improvement in content and organization over the previous 1996 version, making it a valuable resource that will lower the barriers for agencies lacking the resources to complete surveys and model development activities of their own. A second valuable resource is a collection of sketch planning and aggregate modeling techniques used to account for all commercial vehicles (both freight and non-freight) in urban areas developed by Cambridge Systematics et al. (2004). As with most other such models practitioners are familiar with them. Their work is significant not necessarily from a methodological standpoint, although it does nicely bring together several traditional methods in a cohesive framework, but rather because it is almost singular in its ability to address the full range of commercial vehicle travel occurring in urban areas.

Synthetic Matrix Estimation Models

Synthetic matrix estimation (SME) techniques have been employed by some researchers and practitioners to help overcome the paucity of spatially indexed behavioral data. Despite some differences in solution method, all of these models attempt to adjust an estimated, obsolete, or partially observed trip matrix to match observed traffic counts. Earlier methods typically employed maximum likelihood estimates of maximum entropy to arrive at a solution. Such models often suffered from unexpectedly large differences in outcomes owing to small changes in inputs (Van Aerde et al. 2003), as well as their inability to reconcile inconsistent or erroneous traffic counts (Yang and Zhou 1998; Hazelton 2003). A substantial amount of literature exists on this topic, although almost all relates to person-trip modeling and estimation of origin–destination flows for traffic control systems. Munuzuri et al. (2004) developed an SME model for truck movements in Seville that included five different retail markets and one for home deliveries. The demand was consolidated into a single seed matrix and adjusted using a gradient descent method developed by Spiess (1987, 1990).

More recent formulations have permitted multiple sources of data with reliability estimates attached to each, the ability to handle multiple classes of vehicles, and the use of linear programming techniques to reduce untoward responses to small changes in input (Logie and Hynd 1990; List and Turnquist 1994; List et al. 2001).

Synthetic models are relatively easy to construct and have straightforward data requirements. However, they are not suitable for many types of analyses, owing largely to their lack of behavioral basis. Ríos et al. (2002) noted that the link counts themselves have the greatest impact on model accuracy, which is hardly surprising in that the models use them as the constraint against which to work. However, the resulting process is more geared toward replicating observed flows than explaining why they are there in the first place. These techniques are appropriate for evaluating network responses to changes in supply or operation, but cannot be used to address many of the issues facing policymakers and analysts in transportation planning agencies.

An interesting variant on the approaches described here is one developed by Tardif (2003) in the Canadian province of Ontario. Using a database of approximately 78,000 roadside interviews at 240 locations, he built a database of truck trip records that included origin, destination, vehicle type, commodity, and weight. Using truck counts at the survey locations as targets he employed sample enumeration to characterize total daily demand in Ontario, which could then be summarized or segmented as needed for the analysis at hand. Although sample enumeration has been proposed for activity-based person-travel models (Kitamura et al. 1996; Shiftan and Suhrbier 2002), this application in freight modeling is unique. However, it suffers from the same limitations described earlier for other synthetic estimation methods.

Criticisms of Current Practice

Although arguably appropriate for modeling person-travel, the four-step sequential modeling process is inappropriate for analyzing freight flows. The motivation for and characteristics of person-travel are well informed by an extensive body of survey research and can be efficiently represented by relatively few market segments, homogeneous household and travel characteristics, and similar travel budgets. Most person-travel is characterized by roundtrips from home to principal destination, and back again. Stops are sometimes made along the way for secondary purposes, which the traveler does to simultaneously increase their utility while minimizing travel cost. As noted earlier, recent advances in person-travel modeling have focused on the explicit representation of person tours or activity chains to better represent observed travel behavior.

Unfortunately, freight does not emanate from or move according to the same principles as person flows. Freight flows are “the economy in motion,” the trade between producers and consumers that underpins modern economies. The factors driving the economy are more diverse and complex than those motivating personal travel, involve multiple entities (such as producers, carriers, distributors, regulators, and consumers), and are optimized to reduce the cost and uncertainty associated with their conveyance. Trucks are far less likely to make roundtrips serving only a single customer per day, because the lower productivity compared with trip chaining would be prohibitive for most firms. Indeed, within urban areas truck tours with several pickups and destinations comprise a significant share of observed truck flows. Moreover, the widespread adoption of just-in-time and supply chain logistics has increased the use of distribution centers and trans-shipment terminals. A recent study of freight movements within and between Ontario, Canada, found that more than half of all truck trips involve such facilities (Donnelly et al. 2002; Tardif 2003).

Network assignment processes that simply route freight between each origin and destination miss these important dynamics of freight. Not surprisingly, the resulting models do not accurately replicate observed conditions (Taylor and Button 1999; Wigan and Southworth 2005). Even if the origin–destination patterns were correct, the practice of routing each origin–destination interchange separately will still result in flow patterns that do not match observed conditions.

Slavin (1979) developed a model that accounted for truck tours in Boston that is still elegant by today’s standards, and found that it significantly improved the accuracy of the model. Russo and Carteni (2005) formulated a tour-based urban freight distribution model as a series of nested logit models, proceeding from distribution strategy through first-stop choice to subsequent stop choices. The demand is specified exogenously. The model was successfully applied in Italy. Holguín-Veras and Thorson (2003) implemented a tour-based model of empty commercial vehicles in Guatemala City that was linked to previous trips in the tour. Their contribution is significant in that it is one of only a few that addresses empty vehicle movements, although such movements account for between 20% and 30% of urban truck trips (Holguín-Veras and Thorson 2003; Raothanachonkun et al. 2007). Several others have also proposed tour-based models (Oppenheim 1993; Boerkamps et al. 2000); however, there is no evidence they were implemented.

Tour-Based Microsimulation Models

The desire to incorporate the important unique characteristics of urban commercial travel, such as trip chaining (tours), increasing use of distribution centers, and optimization of routing, has spurred the development of models that share many of the characteristics noted earlier for activity-based and land use models.

Hunt and Stefan (2007) describe the development of tour-based microsimulation for Calgary. In 2000, they used a commodity flow survey of 3,454 business establishments in Calgary to build a tour-based commercial vehicle model. It focused on all trips made using commercial vehicles, of which freight movements constituted only one-third. The remaining trips were made for service delivery, business travel, etc. The resulting model is an adaptation of the person-tour-based modeling approaches described earlier, with some elements unique to modeling freight. They attempted to model all commercial travel in the region, which encompasses nonfreight movements as well.

The structure of the model is shown in Figure 13. Three classes of trucks are modeled based on relationships derived from their earlier commodity flow survey (Hunt et al. 2006). The model uses a nested set of logit models at the level of individual tours, which are generated as a function of land use rather than economic activity. Their contribution is unique in that the tours are not defined or optimized beforehand; rather, a decision is made at each stop whether to continue on to another destination or return to the origin. The probability of making another stop is calculated in part by the angle formed by the truck's current location, its origin, and the location of the next stop chosen from a list of all available stops. Stops significantly out-of-direction are rejected in favor of those that move the tour back toward the origin. The resulting tours are sub-optimal from a routing standpoint.

The model has been calibrated to the targets defined in the data, and early validation work appears to show that it matches observed commercial vehicle counts well. The model is being used in the regional modeling system in the city of Calgary.

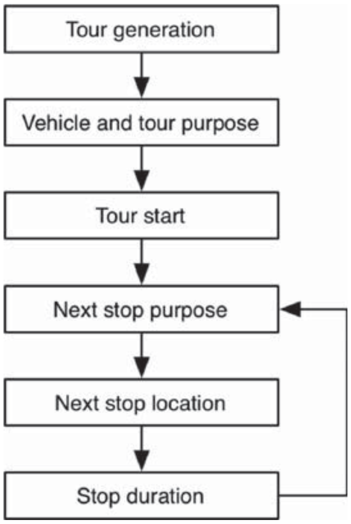


FIGURE 13 Structure of the Calgary commercial vehicle model.

Donnelly (2007) describes the development of a tour-based freight model used as part of Oregon's statewide model. It attempts to overcome the lack of holistic data on freight flows and characteristics by fusing a wide array of disparate and heterogeneous data using a microsimulation approach where different actions are modeled using data most appropriate for that decision. The overall model structure is shown in Figure 14. The model transforms production–consumption flows modeled by the first generation PECAS model embedded in the Oregon statewide model measured in annual dollar terms into daily flows by tonnage, commodity, and mode of transport. The resulting flows are expressed in weekly origin–destination matrices.

For any given origin–destination flow the model calculates the probability of the goods flowing through a distribution center or transportation terminal. If so, the origin–destination flow is split into two, with opportunities for a different mode (generally smaller trucks) for the local portion of the overall movement. The rates were obtained from Canadian surveys, as comparable data are not available in the United States. Once this trans-shipment is accounted for, sampling from observed distributions of shipment sizes, carrier type, and vehicle type are used to transform the weekly flows into discrete daily shipments. These are assigned to specific vehicles, whose itineraries are optimized (if two or more stops are required) using a traveling salesman algorithm. The resulting flows are assigned to a multimodal network along with auto flows using a multiclass traffic assignment.

Both models would appear to be portable. The Calgary model is being tested as part of the statewide modeling system in Ohio. Results from these and other research efforts are

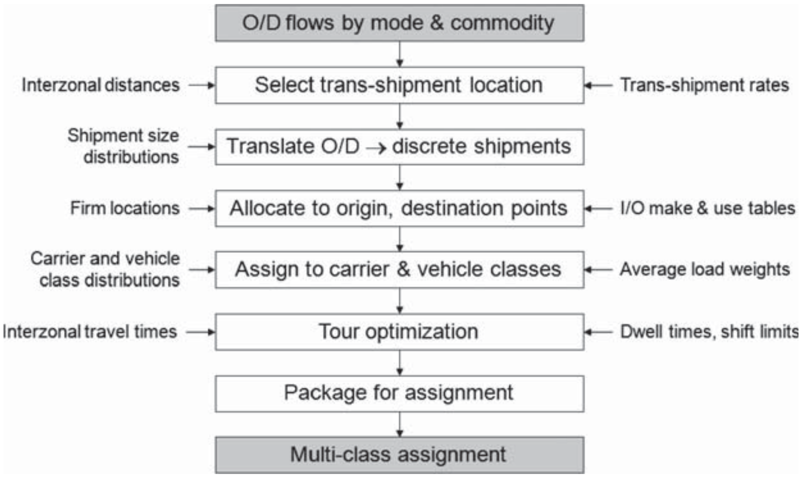


FIGURE 14 Structure of the Oregon commercial transport module.

expected to dramatically change the way commercial vehicles are modeled in urban areas.

Statewide Models

Many of the models and approaches already described have been at the metropolitan level. In most cases these models are not limited by scale, and could be used at the regional or statewide level as well. However, doing so might be impractical owing to the data requirements and lack of need for data at such a high level of detail. Thus, statewide models often sacrifice spatial detail to gain wider coverage. With improvements in GIS and computer technology such limitations are in some places disappearing, prompting increasingly more ambitious statewide models.

At the present time, approximately two-thirds of all U.S. states are known to have a statewide model of some type (Horowitz and Farmer n.d.). Most use a sequential modeling paradigm, either based on travel surveys completed across the state or models borrowed from elsewhere. Michigan, Ohio, and Oregon have all made substantial investments in the collection of short- and long-distance travel surveys, with enough observations by different divisions of geography to model the unique characteristics of each area.

Ohio and Oregon are unique in that their statewide models employ all of the advanced modeling approaches listed previously except for dynamic network modeling. The two models are conceptually similar, incorporating several components that are each fairly sophisticated models in their own right.

1. A macroeconomic model provides statewide forecasts of growth by economic sector and aggregate demographic changes.
2. A synthetic population generator allocates households to TAZs, and updates the population in response to changes in the macroeconomic forecast.
3. A production allocation process is used to allocate employment to zones, balancing floorspace consumption with demand by sector.
4. An activity-based person-travel model is used to model both short- and long-distance travel.
5. A commercial vehicle model also estimates short- and long-distance travel.
6. A traffic assignment model allocates the person and commercial trips to least cost paths on a multimodal network.

The second and third components correspond to the land use models described earlier, whereas the final three focus on the transportation side of the system. Collectively they comprise an integrated land use–transportation modeling system. In both cases, the production allocation model decides where to obtain its workers. Thus, the linkage between workplace and residence is defined, obviating the need for a destination choice model for NHW trips in the transport models. Indeed, tours involving work locations are anchored to these locations, such that intermediate stops are influenced by the workplace choice made before the activity-based component of the model even begins.

The land use and transport components are integrated in other ways as well. Transportation costs and disutilities are directly used by the choice models in the land use components. This permits accessibility to various modes of transportation to be considered in the location choice decisions. The relationships between producing and consuming industries, expressed as input–output make and use coefficients, are also used by the commercial vehicle models to define the linkage between industries and the commodities they produce and consume.

These linkages across different models, as well as the behavioral assumptions included within each component, complicate considerably the task of calibrating and validating such models. Many of the techniques commonly used in travel modeling, such as automatic calibration of destination choice models, certainly cannot be used in this situation. Anomalies in the modeled trip length frequency distributions for the home-to-work portion of the tours, for example, must be resolved in the production allocation model, which in turn affects the calibration of other parts of the model. Therefore, effective strategies and appropriate targets for calibrating such models are only now being learned.

Both models operate at two levels of geography. A coarser zone system (500 to 800 zones) is used for the production allocation process, whereas a finer level of resolution (3,500 to 4,500 zones) is used for the transportation modeling components. The Ohio model also includes a focusing utility that will allow for a more detailed analysis of specific corridors or subareas. The Ohio model is nearing completion, although the Oregon model has been more widely tested to date.

In Maryland, a somewhat different approach has been used in the recent development of a statewide model. It was designed as a multi-level model, allowing different types of travel choices to be represented at the most appropriate level. The model levels are shown in Figure 15, and include the following modules at each level:

- The regional level covers North America with 132 zones, with more detail near Maryland and less farther away. Economic forecasts are generated at this level. Sample enumeration from the long-distance element of the 2000–2001 National Household Travel Survey was used to model long-distance person-travel by residents (those who reside within statewide-level zones) and visitor trips. FHWA Freight Analysis Framework 2 was used to define internal–external and through freight trips.
- The statewide level covers 1,607 zones in Maryland and parts of the surrounding states and the District of Columbia. A more detailed network is used at this level as well. Short distance person and freight trips are modeled at this level using traditional sequential modeling approaches. An important difference is that internal–external and through trips are not modeled at all—they are defined by the models at the regional level. Traffic assignment is also carried out at this level.
- The urban level provides data from the metropolitan models. No statewide modeling is done at this level, but information from the MPO models is retrieved from this level, and comparisons of the statewide model outcomes are made to comparable MPO outputs.

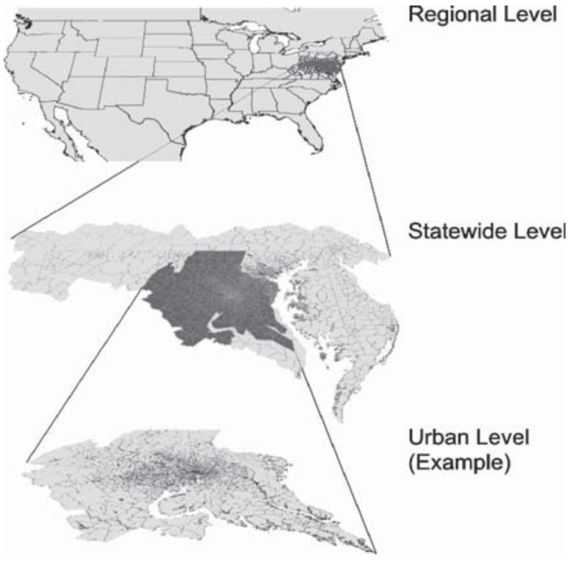


FIGURE 15 Multi-level modeling architecture of the Maryland statewide model.

In many respects the travel models used at the statewide level are simple extensions of traditional sequential models and therefore not noteworthy in a review of advanced models. The long-distance person and visitors models, however, are microsimulation models that directly mine National Household Travel Survey data, which are unique. The first generation of this model was recently completed, with a primary emphasis on being able to accurately portray multimodal travel in the Baltimore–Washington corridor.

INTEGRATION ISSUES

Whenever a model consists of two or more modules, integration of different modules demands attention. Integration in this context simply means the blending or creation of links between otherwise separate models or modeling platforms. The goal is generally to create a more holistic model that performs better than the sum of the parts. However, integration can occur in several different ways within the context of modeling. A common example is passing travel time data from a travel model for calculating accessibilities and disutilities in a land use model. A particular challenge has to be addressed when models work at different levels of resolution. For instance, if a local travel model is designed as a DTA while a regional model is a traditional aggregate transport model, regional aggregate flows that enter the local study need to be translated into single vehicles to be added to the DTA, while local flows leaving the study area need to be aggregated to the vehicle representation at the regional level. The aggregation of local flows into regional flows commonly is a simple addition. The disaggregation of regional flows into local flows, however, requires some procedure that reasonably splits aggregate vehicles into logical vehicle classes and the time-of-day of the local DTA model. Where no data exist, acceptable assumptions must be made.

This integration may have two dimensions (see Figure 16). First, models of otherwise comparable phenomena may work at different geographical levels, such as integrating a travel

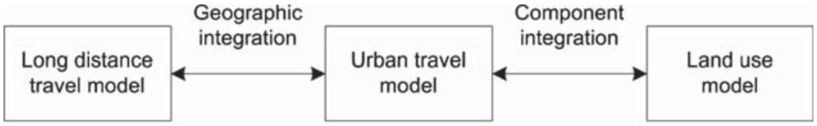


FIGURE 16 Example of two dimensions of model integration.

model for a metropolitan area with a long-distance travel model for internal–external trips (geographical integration). At a minimum, the output of the two models needs to be combined, and often output from a model at one geographic layer directly influences the model behavior at another geographic layer. Second, a model could consist of several modules with different modeling tasks for the same geography, such as a transportation model and a land use model covering the same study area (component integration). The two modules are likely to improve by exchanging information. Each level is discussed separately in the following sections.

Geographic Integration

Models at different geographies allow for simulating the same task (such as a person trip) with different approaches catered to each level. As a benefit, the models may be designed differently, and the spatial resolution of different modules may differ to fit each model's purpose. Although a gravity model may work well to distribute person-trips at the local level, this model becomes difficult to calibrate in a way that it works both for short- and long-distance trips. Thus, the same task of a person-trip may be simulated with different methods at the local and the regional levels. The spatial resolution may be finer at the local level and much coarser at the regional level. For a trip that stays within the study area, the detailed locations of origin and destination are of interest. For a trip that leaves the study area for a destination 100 miles away, the precise location of the destination most likely is irrelevant. A geographic distinction in different model layers may be less relevant for urban models, but offers value to models that cover regional study areas. A common example is a statewide model that feeds into a metropolitan model and vice versa.

If trips are simulated at two geographic layers, special attention has to be given to minimize inconsistencies at the border between the two layers. Figure 17 shows an example of the borderline between two layers. The local travel model on the left side has small zones, such as TAZs, whereas the regional model on the right side could have counties as spatial representation. The trip length distribution shown with the gamma function and the resulting circle on the zone system would capture a larger number of zone centroids of the local geographical level, but would miss most zone centroids at the regional geographical level. If such a model system is implemented, it is important that this border effect be addressed. One way to handle this issue is to simulate internal–internal trips by the local travel model, and to handle internal–external trips by the regional model.

Component Integration

It is common to build several different models that work at the same geographical level. The list could include a person-travel demand model, a truck model, a land use model, and an emissions model, as well as others. Every model is likely to benefit from (if not require) an integration with some or all other models. For example, the person-travel model may require the location of population and employment from the land use model and may provide travel times to the land use model and traffic volumes to the emissions model. The land use model may require travel times from the person and truck travel models and noise emissions (as a location factor) from the emissions model. The land use model may provide the location of population and employment to all other models (compare also land use/transportation feedback cycle in the earlier section on land use models). Such integration may become fairly complex and requires a close communication between the developers of the different models.

Both geographic and component integration have been implemented in many transportation models. The vast majority of transportation models have some same-level integration implemented, most commonly consisting of a personal transport, a freight transport, and/or a land use model. Geographic integration is not as widespread, although multi-level models that require geographic integration are becom-

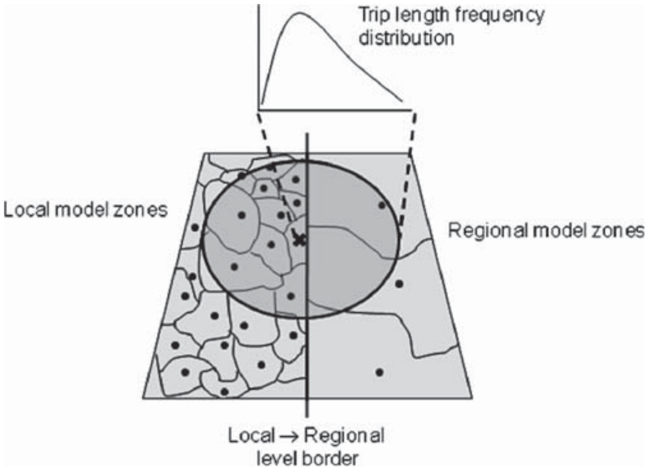


FIGURE 17 Reconciliation for geographic resolution.

ing more common in the transportation modeling world. Examples for geographic and component integration in practice are the statewide models of Ohio and Oregon. In terms of geographic integration, both integrate long-distance personal travel models with a statewide person-travel model and long-distance goods flows with statewide freight models. In terms of component integration, both Ohio and Oregon integrate personal travel, freight travel, and land use models.

Levels of Model Integration

There are different levels of how closely models are integrated technically (see Figure 18 for three examples). The most common is Integration Level 1. Every model runs independently. After a model has started, it reads the output data of several other models, does its own simulation, writes new output data, and is closed. After one model has finished another model can start. Building one single piece of modular software (Integration Level 2) that contains all modules may be advantageous. Having all modules in one piece of software saves run time because a large amount of data can be kept in working memory. Keeping data in memory saves the time one module needs to write data plus the time another module needs to read these data. The integration into one piece of software that is likely to improve the run time requires, on the other hand, a very close interaction between the developers of all modules. The third level of integration runs all modules at the same time. This close integration is only feasible in a microsimulation. Events of each module are run in random order, such as a person makes a trip to work, another household moves, a truck delivers groceries, a child is born, a person goes to the cinema, etc. This very close integration resembles how events happen in reality. So far, however, this level of integration rarely has been achieved in applied models.

A somewhat different approach to multi-level integration is evident in several of the dynamic network models. A few commercial packages, allow for different levels of analyses on different links or in different subareas within the same simulation. Freeways might be modeled using a microsimulation approach, whereas arterials are modeled using a mesoscopic or macroscopic formulation. Alternatively, microsimulation might be used within a subarea of interest, while distant parts of the study area unlikely to be affected by the scenarios tested are modeled using a macroscopic approach. Such approaches can dramatically reduce the amount of data and computer run times required to execute the model, while retaining the flexibility to expand the resolution and fidelity of the model without losing the investment already made in data, interfaces with demand models, and proficiency with the software.

RISK AND UNCERTAINTY

In addition to the models themselves, ample room exists in the industry for advanced applications of both traditional and advanced models. Historically, the practice of travel forecasting has focused on obtaining a single "right" answer that both modelers and decision makers are comfortable with. However, we are operating in a world with many uncertainties, as evidenced by recent radical swings in both fuel prices and the economy. Uncertainties in these dimensions are compounded by what may happen with major policy decisions such as greenhouse gas policy. With such challenges it may be unrealistic to expect any model estimated from and calibrated to past behavior to correctly predict the future 30 years out.

In a world of such uncertainty, it is still incumbent on the modeler to provide useful information to decisions makers. To the extent advanced models can overcome some of these uncertainties they could certainly be implemented. However, in some cases, the model itself may matter less than how it is used. Specifically, an explicit acknowledgment of uncertainty and a strong focus on scenario testing may be beneficial. Ultimately, the strongest project is not necessarily the one that performs best under the base conditions, but may be one that is robust across a range of scenarios.

Some of the recent focus in FTA New Starts projects on scenario testing provides a good example of the form that such analysis may take. Projects are analyzed not just for base conditions, but also a series of "what if" analyses. What if the central business grows half as much as projected? What if the rail travel times are slower than anticipated? What if congestion is lower than expected? These are the sort of tests that can reveal much about the robustness of a project; they are well within our existing capabilities to perform with either traditional or advanced models, requiring only the additional time and effort.

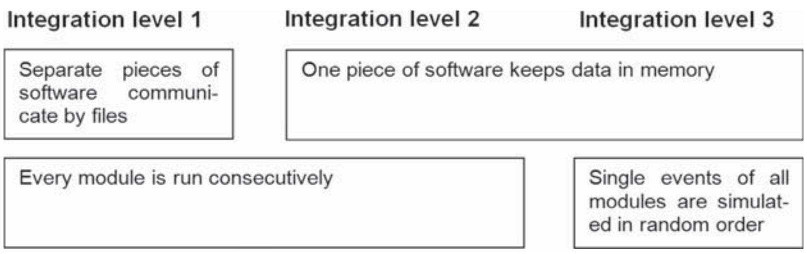


FIGURE 18 Three degrees of integration.

CHAPTER THREE

BENEFITS OF ADVANCED MODELS

During the interview process, each agency was asked about the motivation for moving to advanced models and the benefits of doing so. The responses were specific to the context and stage of development of each agency: those agencies at the beginning of model development projects could only speak to the expected benefits that motivated them to implement advanced models, whereas those agencies that have used the models extensively in application could speak directly to those benefits that they have actually achieved. More weight is given to the latter in the discussion of those benefits that follows.

The notion of benefits is best considered in the context of what an ideal model must do. A good model must do three things:

1. Replicate base year conditions,
2. Be sensitive to the policies being tested, and
3. Respond logically to changes in input.

Model calibration and validation efforts in practice tend to focus on the first objective, which is a legitimate objective as a measure of the model's ability to replicate observed behavior. Thus, it is fair to argue that an advanced model could validate at least as well as a traditional model against base year conditions, and one area of benefits identified focuses on an advanced model's ability to do so.

The most significant advantage of advanced models noted in validation is simply the ability to validate against a much broader range of criteria. That is, if an activity-based model has 12 core models (population synthesis, usual workplace location, auto ownership, tour generation, joint travel, tour destination, tour time-of-day, tour mode, stop location, trip time-of-day, trip mode choice, and assignment), each of those models can be individually calibrated. Furthermore, microsimulation allows for model results to be tabulated in any number of ways, just as with a household interview survey, allowing the analyst to compare the model and the survey in any number of ways. Ultimately, advanced models allow the analyst to dig much deeper into the model system to understand what is transpiring, and what aspects of the real world the model does or does not capture. In contrast, aggregate, trip-based models can be very good at hiding mistakes. It is easy for such model systems to contain compensating errors, and difficult to detect—just ask any modeler who has been involved in a New Starts forecast, and realized that they need to significantly adjust the mode choice model to overcome problems in trip distribution. Activity-based models allow for a much more detailed validation of the system, but also allow for much more targeted calibration.

However, a model that achieves the validation objective while ignoring the other two objectives will be limited in application. There is far more to building a quality model than achieving the lowest possible root-mean-squared error compared with traffic counts, especially if achieving that goodness-of-fit involves sacrificing logical responsiveness in the model system. The ultimate goal of most model developments is to test alternative policies and to forecast future conditions, and not to recreate reality. Although agencies did acknowledge the quality of validation as important, the motivations for moving to advanced models, and the benefits achieved by doing so, overwhelmingly involved the ability to evaluate more sophisticated policies than existing models could be used for.

The remainder of the chapter discusses specific benefits cited by the agencies. It is not a comprehensive list, but seeks to identify those common themes mentioned multiple times. Clearly the benefits of different types of models differ; therefore, the benefits are segmented by the class of model. A section is then presented that discusses the types of policies an agency might consider and the benefits of advanced models for evaluating those policies.

ACTIVITY-BASED MODELS

The enhanced framework of an activity-based model system is to be sensitive to policy changes in a consistent way across more dimensions. In other words, when the time or cost of travel changes, an activity-based model would consider travelers responding by changing route, mode, time-of-day, destination, frequency of travel, or auto ownership. A traditional model would only consider changes to route, mode, or destination, often with route and destination sensitive only to highway travel time and not to changes in cost.

In certain applications, the added sensitivity is of particular importance. For example, in the San Francisco Mobility, Access and Pricing Study (MAPS), peak period tolls were considered for a cordon surrounding downtown San Francisco, with the goal of providing an incentive for travelers to shift out of the peak periods or to switch to transit. In this application it was important that the time-of-day models be sensitive to cost, and the choice of destinations consider cost so that the study team could understand how many people would shop or recreate elsewhere, rather than switching to transit or traveling in the off peak. Also, because the application linked trips into tours, and simulated individual travelers, it was able to model area pricing scenarios in which travelers would pay a single daily fee to bring their vehicle downtown and then could travel as much as they wanted for the rest of the day.

In either case, the models are calibrated to match base-year conditions, so it is not clear that activity-based models are any better at replicating base-year traffic counts or transit volumes than traditional models. *The true advantage is that they are sensitive to a broader range of policies and can answer more complicated questions.* If planners and decision makers ask the same questions of the new models as the old, their value will be limited. However, if the planning and modeling processes evolve together, their value can be much greater.

Beyond the additional dimensions of sensitivity, five primary advantages of activity-based models were identified: (1) eliminating NHB trips, (2) allowing for a more detailed analysis of outputs, (3) improved ability to model pricing, (4) more detailed representation of time, and (5) a greater ease of extensibility. These are discussed in further detail here.

Eliminating Non-Home-Based Trips

As discussed in chapter two, traditional trip-based models commonly include a category of trips called non-home-based (NHB), which neither begin nor end at home. This could be a trip from work to a doctor's appointment or from the gym to a grocery store. NHB trips are difficult to model because the information available to simulate them is limited in scope to the two endpoints of the trip. This limitation has two implications. First, because neither end is at home, the model cannot include any demographic or socioeconomic characteristics of the traveler when modeling NHB trips. For example, although we know that auto ownership is a highly important predictor of transit use, NHB trips cannot be segmented by auto ownership, and the explanatory power of that variable is lost. Second, it is impossible to know the context of the trips—whether it is a stop for coffee as part of a longer work commute, a trip to get lunch, or a trip on a multi-part shopping tour. It would be logical to assume that a stop on a work commute would occur somewhere between home and work; however, a trip-based model does not have that context and cannot account for that. Therefore, in the words of Gordon Schultz, an early pioneer in travel modeling, "you just sort of smear them around."

Activity-based models overcome this limitation by chaining trips into tours that both start and end at home. In this way, NHB trips are connected to the home location and detailed attributes of the traveler, such as auto ownership and income, can be considered when modeling those trips. Furthermore, the locations and modes of those trips are constrained to be consistent with the surrounding trips. Therefore, in the example of stopping for coffee on the way to work, the NHB trip will have one end at work and one end between home and work. Further, with the knowledge that the trip is really part of a larger work commute, specific preferences (propensity toward transit, time-of-day characteristics) associated with work commutes can be considered.

Thus, the chaining of NHB trips is about making the models more accurate, and making them respond more logically to changes. The SFCTA specifically reported that they have been pleasantly surprised with the way their model responds logically to the wide range of policy alternatives they tested.

In addition, agencies mentioned several ancillary benefits to eliminate NHB as a category of trips. For one thing, agencies noted that the model is actually easier to explain when the model more closely replicates reality. Anyone who has tried to explain what a HBW trip or NHB trip is at a public meeting can attest to this. In an activity-based model, it is much easier to show the results for work tours and have it align with everyone's intuitive understanding of what a work commute is.

A related benefit noted is the ability to trace all of a household's travel back to the household itself. This issue is of particular importance to MPOs in California who are subject to the planning requirements outlined in Senate Bill 375, which seeks to reduce greenhouse gasses. Both the Metropolitan Transportation Commission (MTC) and the Sacramento Area Council of Governments (SACOG) cited the ability to trace vehicle miles traveled (VMT) back to individual households as important when evaluating the effects of the location of new households in established urban areas versus in suburban locations. With this detailed information, the analyst is much better able to do a thorough accounting of transportation affordability, an issue of growing importance to many agencies. By eliminating NHB trips, all costs can be traced back to the household, and with the simulated population it is possible to know which households are incurring which costs. Therefore, it is easy to know how many low-income versus high-income households are paying for a toll increase.

Detailed Analysis of Outputs

Another benefit to activity-based models that was cited several times is the ability to do a much more detailed analysis of the outputs. In a trip-based model, the results of the demand models are sets of trip tables segmented by purpose and mode. In an activity-based model, the decisions of individual travelers are simulated, so the results of the demand models are a list of individual households, persons, tours, and trips that look just like what you get from a household travel survey. Therefore, the results can be reported across any number of dimensions. For example, it is possible to tabulate commuter rail riders by income, by age, by gender, by the number of trips on a tour, or by any other category included in the synthetic population or in the results.

The ability to tabulate the results in this way truly enhances the analyst's ability to do environmental justice analysis and understand how projects affect different categories of people. Moreover, the structure of these models appears to be more amenable to the modeling of nonmotorized transportation. This is partially because of the increased level of spatial resolution typically built into these models, which enables analyses at the same scale at which such travel often takes place. They can also incorporate more variables that directly influence the choice of nonmotorized travel, as well as focusing on the subset of the population most likely to engage in it. However, it should be noted that explicit representation of nonmotorized transportation is not inherent in activity-based models. As with traditional models their inclusion must be explicitly accounted for in data and model design and development.

Pricing

Another commonly mentioned benefit to activity-based models is an enhanced ability to model pricing. Traditional models either assume that all travelers have the same value of time, or segment the value of time by three (or so) income groups. Research has shown that even at the same income level, travelers can have widely different values of time. Ignoring this reality leads to aggregation error, particularly at higher price points, where a relatively small, but still significant, number of travelers may be willing to pay. At the Innovations in Travel Modeling 2008 conference in Portland, Oregon, one of the core topics was pricing, and many speakers emphasized the importance of accounting for this distribution in values of time.

Because activity-based models simulate individual travelers instead of aggregate matrices of trips, they provide the ability to assign each traveler their individual value of time, thus simulating this continuous distribution.

In addition to value of time, their disaggregate nature allows for a more coherent accounting of cost itself. In many downtown areas, for example, individual travelers pay vastly different parking costs depending on any subsidies or free parking provided by employers. Usually the high-income workers pay the least to park, because they are more likely to receive parking as an employee benefit. Typically, models use an average parking cost in modeling mode choice, but activity-based models allow for an explicit modeling of who pays what, enhancing both the model's accuracy and the accounting of transportation affordability.

Furthermore, a new type of pricing policy currently being implemented in London, Singapore, and Stockholm; previously considered in New York; and currently under consideration in San Francisco, is area pricing. In such a scenario, travelers would pay to enter a downtown area, and once they have paid for that day, they can drive around as much as they want. A trip-based model would struggle with such a scenario, because there is no way to know whether a traveler has already paid or not; however, with the chaining of trips and traceability back to the traveler it is explicit in an activity-based model.

The types of pricing policies that can be tested are numerous—it is possible to exempt low-income households from paying tolls, give seniors and youth transit pass discounts, test the effect of eliminated employer-paid parking, or vary prices by time-of-day. With their enhanced ability to model variation in the population and the wide range of policies that can be tested, activity-based models offer a superior platform for evaluating pricing alternatives.

Time-of-Day

A situation where specific enhancements are warranted is not unusual in an advanced model. The ability to deal with complex policies, such as congestion pricing, in a meaningful way is not something obtained "out of the box" in an activity-based model. However, starting from the framework of an activity-based model opens the door to a credible and robust treatment of time, whereas the options are much more restricted with a trip-based model. For example, it is possible to build a time-of-day model in an activity-based model that does not consider travel time; however, the model will then be completely insensitive to congestion. Adequate attention must be paid to that detail to obtain reasonable sensitivity in the model, although the same would be required in a trip-based model as well.

The difference is that there is more that can be done in an activity-based modeling framework. In such models the context of the trip is known in terms of what other activities happen before or after it. These other activities serve as constraints, making travelers less sensitive to congestion than would be apparent in an unconstrained (trip-based) approach. Also, the disaggregate framework allows for the consideration of individual preferences. This is useful in the San Francisco peak spreading models, where for each trip a "preferred" departure time is selected. This then determines how much the traveler is willing to shift away from their preferred time to avoid congestion. Similarly, for an agency interested in peak period pricing, the disaggregate approach allows each simulated traveler to be assigned his or her own value of time. This heterogeneity reflects that some people are much more sensitive to pricing than others, which a trip-based model simply cannot account for.

Extensibility

One additional and unanticipated benefit has been realized by those agencies that have the longest history in applying and maintaining activity-based models—that of extensibility. Because of the disaggregate nature of these models, it is actually quite easy to add a new descriptive variable to the model system. In an activity-based model it is as simple as adding a column to a table, whereas in a trip-based model it involves further segmentation of trip matrices, which can quickly become unwieldy. Furthermore, the ability to simulate individual travelers greatly enhances the types of policies that can be tested.

One example is the New York Metropolitan Transportation Council model, which was successfully applied to test license plate rationing in Manhattan. The premise is that on any given day, only autos with license plate numbers ending in certain digits could enter lower Manhattan. License plate numbers were randomly assigned to each vehicle in the simulated households and, depending on which vehicles were available for use, modal alternatives were made available or unavailable. Such a policy could not have been tested using a traditional model.

Further, model enhancements undertaken as part of the San Francisco MAPS showed that extending the existing model system to account for distributed values of time, track area pricing, and enhanced peak spreading models were a relatively moderate effort compared with the contortions that would have to be made to a trip-based model system to achieve a similar result.

Simply stated, disaggregate activity-based models offer a platform that is readily adaptable to evaluating a broad range of policy alternatives. The ability to model complex policies does not come without a cost—the modelers must still pay attention to the details to make sure that each individual model component is sensitive to the right variables; however, the platform provides the ability to do this. This attribute is extremely appealing in agencies where the next big policy issue may remain unknown.

DYNAMIC NETWORK MODELS

Traditional user equilibrium highway assignment models predict the effects of congestion and the routing changes of traffic as a result of that congestion. They neglect, however, many of the details of real-world traffic operations, such as queuing, shock waves, and signalization. Such operational details are important both to reflect reality and to evaluate policies associated with improving traffic operations. Examples of such policies might include ramp metering, signal coordination, or targeted improvements at choke points.

Currently, it is common practice to feed the results of user equilibrium traffic assignments into dynamic network models as a mechanism for evaluating these policies. The simulation models themselves, however, do not predict the routing of traffic, and therefore are unable to account for re-routing owing to changes in congestion levels or policy, and can be inconsistent with the routes determined by the assignment. Dynamic network models overcome this dichotomy by combining a time-dependent shortest path algorithm with some type of simulation (often meso- or macroscopic) of link travel times and delay. In doing so it allows added reality and consistency in the assignment step, as well as the ability to evaluate policies designed to improve traffic operations.

The nonlinear and chaotic nature of congestion at the micro scale and its effect on vehicular flow characteristics is well documented (May 1990; Newell 1995; Boyles et al. 2008). The benefits of modeling individual vehicle interactions and how they collectively give rise to level of service and congestion have long been captured in traffic simulation models. Such models have traditionally been tractable for small study areas, owing to their data requirements and heavy computational demands. Other than a few isolated attempts to simulate large networks, such models were not considered practical at the urban or metropolitan level irrespective of what benefits they might have offered. TRANSIMS arguably changed that, demonstrating proof of concept from its inaugural case study in Dallas–Fort Worth to early deployments today.

During the same timeframe that TRANSIMS has evolved, separate progress has been made in the use of DTA models in planning studies, an application not widely anticipated a decade ago. Given their successes and the growing interest in fusing activity-based travel demand models with dynamic network models it is likely that such models will become more widely used in practice over the coming decade. As with activity-based models in general, practitioners are eager to learn what practical advantages such models have over traditional static traffic assignment models. There is arguably insufficient evidence at this writing to conclusively show their superiority. Regardless of the level of network resolution, such models have already provided indispensible benefits that cannot be obtained using traditional static network models:

- Dynamic network models are capable of capturing the time-dependent effects of congestion, something that static models are not capable of doing. The incidence, location, and duration of congestion, often evidenced as bottlenecks in the roadway system, lead to highly unstable flows, high variabilities in travel times, and unreliable system states. These effects can only be represented in an aggregate sense—in both time and space—in macroscopic models, which assume invariant flows and travel times over the entire analysis period. Even when modeling peak periods the variability in travel times and their effect on departure time, mode, destination, and route choice varies considerably within that time. Static models are simply unresponsive to such variation, and to the extent that they can approximate the macroscopic outcomes, do so in a manner inconsistent with current traffic flow theory.
- Macroscopic models represent traffic control in an abstract manner, such that improvements in that realm go unnoticed. Traffic signals are the most abundant control strategy in place at the present time, although areawide control schemes, ITS, and traveler informa-

tion systems are rapidly increasing in importance. With management and operation of the transportation system playing an ever-increasingly important role, the need for tools appropriately sensitive to such actions is critical. Dynamic network models fill this gap.

- Dynamic tolling and congestion pricing schemes rely heavily on accurate and detailed information about temporal patterns of demand and their response to changes in levels of service. To the extent that such schemes become more commonplace in the future investors in and operators of such systems will require more robust estimates of network performance and response than can be obtained from static models. Dynamic network models are ideally suited for such analyses.
- Global climate change is renewing the focus on mobile source emissions. California has adopted statewide policies to dramatically reduce mobile source emissions (California Air Resources Board 2009). The recent proposed federal "cap and trade" legislation includes regulatory powers for the EPA over emissions estimation methods and standards. These changes will require more accurate estimation of link and network travel times, which in turn will require a more robust representation of the time-dependent effects of congestion and traffic control systems. By contrast, most static models resort to using post-processing of macroscopic assignment results to derive credible estimates of link travel times.

It is expected that the various types of dynamic network models will converge at some point. Some commercial packages offer the capability to seamlessly move between varying levels of detail and, depending on the flow levels, between different models (macroscopic, mesoscopic, and microscopic). If DTA models fulfill expectations, it is possible they will be capable of providing most of the performance measures required, and at an acceptable level of resolution and accuracy, without resort to traffic simulation models.

LAND USE MODELS

Adding a land use model to a travel demand model adds a large set of land use-related policy scenarios that can be tested and improves traffic forecasts through better travel demand input data. If emissions are of interest, a land use model allows adding emissions from dwellings and firms to traffic emissions. Such models can be used to analyze land use policies as well, ranging from the implementation of growth boundaries to tax incentives for transit-oriented development. Implementing a land use model may also improve the functioning of travel demand models, be they traditional or advanced formulations. For example, if an additional highway reduces congestion at the beginning, subsequent relocation of households may dampen the congestion relief. If changes in land use are simulated explicitly, rather than using fixed exogenous forecasts, the quality of a base forecast as well as the responsiveness of the travel model to alternative policies may be significant.

Extended Scenario Analysis

For many agencies the driving motivation for using a land use model has been the capability to analyze a wider variety of scenarios. Agencies seeking to reduce urban sprawl by zoning or an urban growth boundary have used land use models to better understand the impact of development restrictions. Concerns about rising land prices owing to zoning can be analyzed with a land use model before the urban growth boundary is established. Impacts on land use patterns and the demographic distribution of households by, for instance income, help to better understand if zoning policies may have unexpected side effects. After Cervero and Kockelman (1997) published a paper on how the three Ds (density, diversity, and design) affect travel demand, several agencies across the country have used land use models to simulate the impact of an alternative urban design. Land use models also allow for simulating the effect of subsidies. If an agency attempts to vitalize a depressed region by subsidizing the development of an industrial business park, land use models may be used to analyze the likely demand for such kind of development.

Transportation–Land Use Feedback Cycle

In chapter two, the transportation/land use feedback cycle was described, explaining how transportation influences land use and how, in turn, land use creates transportation demand. Integrating a transportation model with a land use model implements the entire feedback cycle, which helps account for induced travel demand.

New transportation infrastructure affects land use patterns. Today, large-scale infrastructure developments are fairly uncommon. Kreibich (1978) proved that the extension of the commuter rail system in Munich for the Olympic summer games significantly fostered urban sprawl within the catchment areas of the train stations. Likewise, high-speed rail or highway developments may encourage people to increase the distance between home and workplace. Conversely, a changing demography may alter travel demand substantially. If over time a neighborhood develops to become a retirement area the daily travel demand may be reduced significantly. A change in average income within a neighborhood has an effect on auto ownership and, hence, mode choice of people living in this area. Land use models allow accounting for these land use–transportation interactions.

Emissions from Non-Transportation Sources

Several states are beginning to analyze carbon dioxide (CO_2) emissions as part of climate change and greenhouse gas emission reduction strategies. As this point, most efforts concentrate on estimating the emissions from mobile sources. Given that less than half of the CO_2 emissions in most areas originate from the transportation sector, a reasonable next step will be to estimate emissions from land uses. Oregon's

GreenSTEP model (Gregor 2009) is an example of an emerging methodology for estimating emissions from fixed-point sources.

FREIGHT AND COMMERCIAL MOVEMENT MODELS

Freight and commercial movement models offer the ability to analyze the effects of transportation improvements on freight. Furthermore, where they contribute a significant portion of traffic volumes, they enhance a model's ability to properly forecast traffic congestion. Hunt and Stefan (2007) estimated that commercial traffic—of which freight is but one aspect—comprised roughly 20% of all VMT in Calgary in 2002. The percentage of VMT attributed to commercial vehicles appears to be increasing in most urban areas; growing faster than either the economy or auto flows in recent years (Transportation Research Board 2003b; Downs 2004). Moreover, the impact of trucks on air quality has become a major issue in many metropolitan areas.

Although nonfreight commercial vehicle flows, such as service and sales travel, might arguably be better captured in tour- or activity-based travel models because of their ability to model multi-stop itineraries, it is likely that these unique travel patterns are poorly represented by current models. Attempting to account for them in trip-based models is typically accomplished by expanding NHB trips to account for the missing trips. Such misses affect the dynamics of such flows as well as their spatial characteristics. The approach adopted in Calgary is one approach to explicitly modeling such behavior. However, further advances in tour- and activity-based models are likely to give rise to progressively more sophisticated models of firms and their contribution to travel demand. Although employment (as a surrogate for firms) is still modeled in aggregate in most advanced models, opportunities exist to better account for work-related person travel. This is a fertile area of research that is expected to expand in the next few years.

The separate modeling of urban freight has been carried out for several decades. As noted in chapter two, most such models are analogues of traditional trip-based person-travel models. Although they perform acceptably in most cases, it is well known that some important dynamics of freight are missed. Tours are even more prevalent and more important than in-person travel. Moreover, the use of urban distribution centers has greatly increased over the past two decades. As a consequence, a large volume of goods that formerly was delivered directly to firms and households by long-distance trucks now unload at a single distribution center. Deliveries to local customers are consolidated and made as needed from these distribution centers. Donnelly et al. (2002), analyzing data from Canada, found that one-half of all intercity truck flows were destined to or from a distribution center, a number that has likely increased since then. Thus, the dynamics of distribution centers and their effects are so important they can no longer be ignored in freight models. Models capable of capturing their dynamics will provide a much more credible basis for representing urban freight.

An advanced freight model will be capable of capturing such dynamics. It will also be capable of explicitly representing other important factors influencing the demand for freight and its impact on the transportation system. Freight movements are influenced by several different actors (e.g., shippers, consumers, carriers, and intermediaries) that often do not share the same goals or information. Almost all person trips begin and end within an urban area; however, freight movements often have one or both trip ends outside of the place under study. Thus, linkages to statewide and regional truck models, a likely trend in the near future, will continue to grow in importance.

The freight industry has undergone tremendous change in recent years. These changes include the deregulation of the trucking industry, the birth and expansion of supply chain logistics and just-in-time deliveries, the advent of third-party logistics companies, the widespread adoption and tremendous growth in container traffic, the early adoption of ITS in freight, the birth and rapid growth of shippers such as United Parcel Service and Federal Express and retailers such as Wal-Mart, globalization of trade, e-commerce, and the rise of regional and urban distribution centers—to name but a few. More changes are on the horizon, such as the increasing sophistication of containers that enable logging, remote tracking, and integrity monitoring. Radio frequency identification tagging and other digital short-range communications technology will heavily influence the freight industry in the coming years as well.

It is unlikely that any urban freight model will capture all of these factors in the near future. However, the gulf between practice and need can be usefully bridged in two ways. The first is the adoption of a framework that allows for a flexible but holistic representation of all actors, resources, and constraints in the system. It is important that each actor or market segment be represented in the physical and behavioral structures most appropriate to it, rather than forcing it to fit within a certain modeling framework. Moreover, response to policies or exogenous constraints could be exerted in a realistic manner recognizable to end users of the model. The effect of differential pricing, for example, could be realized in the mode choice decisions made by those actors affected by the costs.

It is also apparent that a system of models can be constructed that will capitalize on the strengths of different modeling approaches at each level of the problem. Xu et al. (2003) describes a three-level modeling framework that uses price and commodity signals between them. The design is compelling and clearly demonstrates the utility and validity of multi-scale approaches to freight modeling. Taken together, a hybrid of both approaches offers advantages that cannot be obtained through either alone.

The emerging crop of microsimulation-based freight models be they based on rule systems, behavioral constructs, or a combination thereof, are capable of incorporating these many unique facets of freight and nonfreight commercial travel patterns. To the extent that policymakers and interest groups are interested in better understanding and forecasting them, the various advanced options for modeling this market segment will prove invaluable.

STATEWIDE MODELS

Statewide travel models have been used over the past several decades to examine long-distance and intercity travel, review linkages between urban areas, focus on freight, and standardize modeling throughout a state. They are not a separate class of models per se, but rather are characterized by the scale at which they operate. Tour- and activity-based statewide travel models enjoy the same benefits described previously. However, an increasing number of statewide models also have explicit economic and freight components, and several recent ones (including Maryland, Ohio, and Oregon) include formal land use models, with their attendant benefits, as well. A compilation of the benefits of statewide models is not reported in the literature, but was gleaned from interviews, review of peer reviews (Transportation Research Board 2005, 2006), and case studies cited by Horowitz (2006). Some of the major benefits cited follow.

- Statewide models are capable of estimating intercity travel, which can be a significant share of statewide VMT in eastern states and in states with several metropolitan areas. Most urban models represent such trips as information-poor external trips. Statewide models can make explicit external tripmaker characteristics, origins, destination, and other attributes.
- Most statewide models do not end at the state border, but provide successively more aggregate spatial representation as distance outside the state increases. Such models can be used to study specific intercity markets, such as high-speed rail, corridors of national significance, the effect of major highway closures, and similar scenarios where the influential factors are far larger than or far from an given urban area.
- In several states statewide modeling is not only a single model at the statewide level, but a set of standard models and methods applied consistently across the state. Michigan and Oregon have used such an approach for several years. In both cases the major metropolitan area uses its own approach, but interfaces loosely with the statewide model. In the case of Oregon, a standard four-step model is used by all urban areas (including Portland). As a result, all agencies are able to share in the development costs, data collection, and knowledge transfer.
- Statewide models are also used to ensure consistency in demand estimation and impact measurement between urban areas within a state. Statewide transportation plans and programming is seen as more consistent in such cases. Florida and Iowa have cited this benefit as a significant motivating factor for investing in statewide models.
- Owing to their inclusion of or linkage to macroeconomic models, some statewide models are capable of generating fairly detailed estimates of direct and indirect user benefits. Indiana and Ohio have both developed formal economic impact components of their statewide models. Oregon uses its statewide model to estimate the impact of transportation decisions on job retention and local economic impacts. In most states these analyses can be reported at the local, corridor, and statewide levels.
- Freight flows are much more likely to cross the urban cordon than person travel. In some instances the emphasis at the statewide level is as much on freight as it is for person travel. Even more so than for auto traffic, the delineation of origin–destination patterns and truck and cargo characteristics are important data for policy studies.

The benefits and utility of statewide models can be extended even further through the adoption of multi-level modeling, as described in the previous chapter. In such cases information can flow between models at varying scales, such as between regional, statewide, and urban models. Data can be transformed as it passes between levels or simply used at the spatial and temporal scale at which it is provided. An excellent discussion of the benefits of multi-scale modeling can be found in Nagurney et al. (2002), with an innovative application to regional freight modeling described by Xu et al. (2003).

SELECTING A MODEL APPROPRIATE TO POLICY QUESTIONS OF INTEREST

The modelers at agencies that have moved or are moving to advanced models noted that they are motivated by the more complex policy questions that their boards and planners are asking. As this report has come together, it has become increasingly clear that the right model is the one that best meets the policy needs of the agency. Depending on the agency's specific needs, the selection of a model system and the appropriate allocation of resources will vary. As a tool to assist in selecting which advanced models may be most appropriate to evaluating specific policies and the benefits that such models may offer, Table 4 shows types of policy questions, whether they can be answered with traditional models, what type of advanced model would be most beneficial, and what that benefit would be.

TABLE 4
ADVANCED MODEL ADVANTAGES FOR SPECIFIC POLICY QUESTIONS

Theme	My Policy Issues Include	Can a Traditional Model Answer These Questions?	Advanced Modeling Should Focus on	Advanced Models Would Offer These Benefits
Highway	Highway capacity projects	Yes	Activity-based models	Eliminate NHB trips
	HOV lanes and carpooling	Yes, if it includes a mode choice model that includes a choice of drive alone, shared ride (2 persons), or shared ride (3+ persons)	Activity-based models with joint intra-household travel	The bulk of shared ride trips are composed of members of the same household. A model that does not account for this behavior risks overstating travelers willingness to form inter-household carpools.
	Time-of-day and peak spreading	Yes, if it includes a peak spreading model	Activity-based models with time-of-day choice sensitive to level-of-service	Trip-based models cannot account for the constraints of adjacent activities or travel, and therefore risk overstating travelers' willingness to shift times of day in response to congestion or pricing.
	Traffic operations analysis (queuing, choke points, etc.)	No	Dynamic network models	Standard user-equilibrium traffic assignments do not account for the dynamics of traffic progression. Dynamic network models can overcome this limitation.
Transit	Major transit investments	Yes	Activity-based models	Trip-chaining allows mode choice to consider the context of the trips. For example, transit must be available in both the departure and return period for it to be available, so there is an advantage to having a tour-based model that considers the level-of-service in both directions.
	New Starts analysis	Yes, with careful attention to detail	Activity-based models, with careful attention to detail	Same as above, but also note that the microsimulation framework would allow a more detailed analysis of the forecast markets using transit because it allows the results to be sliced and diced in more ways. Note in both cases that the fundamentals, such as transit path building, logical mode choice coefficients, and an understanding of the markets, are crucial. This part is the same in either case.
Emissions and Greenhouse Gases	Air quality conformity	Yes		End output is the same, but may offer better sensitivity to specific policies.
	Tracing greenhouse gas emissions to households and tours	No, can calculate the total emissions, but not which households are responsible.	Activity-based model	Activity-based models eliminate the problem of NHB trips, allowing all travel to be traced back to the household. This allows for a better analysis of VMT per household when households are located in different zones.
	Tracing greenhouse gas emissions to vehicles	No	Dynamic network models	Most dynamic network models can trace emissions of individual vehicles, as well as their disaggregate acceleration and deceleration profiles. This meshes well with the MOVES approach.
	Reducing greenhouse gas in region by a given percent	Yes, with an emissions model	Comprehensive emissions models	With motor vehicles accounting for about half of greenhouse gas emissions transportation models can provide important insight into the effectiveness of strategies for reducing greenhouse gas emissions, when connected with an emissions model such as MOBILE6 or MOVES. Specifically, any strategies that reduce motor vehicle travel, such as transit investment or land use changes can be evaluated. However, there is a whole range of strategies for which a transport model is irrelevant, such as point source and area source emissions. For these, a more comprehensive set of tools is necessary.
Pricing	Tolling and pricing	Yes	Activity-based model with distributed value of time	The microsimulation structure allows each traveler to be assigned an individual value of time, drawn from a continuous distribution. In a trip-based model, the variation in value of time is constrained to the number of market segments in the model, leading to aggregation error.

(*continued on the following page*)

TABLE 4
(*continued*)

				Further, an activity-based model allows for a wide range of pricing policies that can be tested. It is possible to exempt people from households earning under XX dollars per year, model senior transit fare discounts, or understand how eliminating employer parking subsidies might affect transit use.
	HOT lanes	Yes	Activity-based model with distributed value of time and intra-household interactions	See comments on Tolling and Pricing and on HOV lanes.
	Transportation affordability	Partially	Activity-based model	Allows all costs to be traced back to households, including the cost of owning and operating vehicles, gas, tolls, transit fares, etc. Also allows the results to be sliced and diced in any way imaginable, to understand the implications for different subsets of the population.
Land Use	Effects of land use on travel	Yes	Activity-based model with sensitivity to land use characteristics	Either model could be built with sensitivity to small-scale land use characteristics. Both are already sensitive to the households and employment in each zone.
	Effects of transportation investments on land use	No	Land use model	Assuming the land use model is sensitive to accessibility measures from the transportation model it will be able to evaluate the effects of improvements on land use.
	Evaluating “reality” of land use plans	No	Land use model	Land use model can serve as a reality check on plans to understand if they are supported by the market.
	Urban growth boundaries or infill development incentives	No	Land use model	A land use model with the appropriate policy sensitivity will allow for the evaluation of land use specific policies, such as urban growth boundaries, or infill development incentives.
Validation	Matching base-year traffic counts	Yes		Can potentially do a better job of matching traffic counts, but the real measure of a model is how it responds to change.
	Detailed validation and understanding of markets	Partially	Activity-based models	Because the advanced models can be summarized in so many different ways, it opens up a whole range of additional validation checks, and evaluation of travel markets that can be done, in addition to those traditional checks done for a trip-based model. This has the potential to raise the bar, because for many analyses in a trip-based model we would never have the option of know that we’re wrong.
Interaction with Population	Effect of changing demographics	Partially	Activity-based models	Microsimulation structure allows for the inclusion of a much greater range of demographic variables, and thus sensitivity to changing demographic conditions, such as an aging population.
	Environmental justice	Partially	Activity-based models	Model results can be sliced and diced in many different ways, allowing for better analysis of effects on different sub-populations.
Other	Truck lanes	No	Commercial and freight model	Commercial and freight models are designed to forecast truck volumes, in addition to other modes.
	Economic impacts	No	Integrated economic model	An economic model sensitive to accessibility measures from the transportation model is needed to evaluate economic impacts of transportation investments.
	Intercity transportation infrastructure	No	Statewide model	A model with a larger geographic scope than single urban area is needed to evaluate intercity transportation infrastructure investments as well as for understanding intercity commodity flows.

HOV = high-occupancy vehicle; HOT = high-occupancy toll.

CHAPTER FOUR

IMPLEMENTATION AND INSTITUTIONAL ISSUES

Adopters of advanced models have had to overcome a number of obstacles and develop new techniques to reach their goals. Facing such challenges is hardly unique to advanced models, because most dramatic changes from the status quo require taking risks and thinking about old problems in new ways. It is interesting to note that many of the pioneers of advanced models saw them as gradual improvements following many years of research and development. Those not so involved tended to view the changes as far more radical and sudden. The magnitude and variety of issues that have been identified and addressed is encouraging, for it attests that much has already been accomplished. Some of the key implementation and institutional issues facing developers and users of advanced models are described in this chapter. Although most of the issues discussed were recurrent themes, several less common issues were unique and insightful enough to warrant mention.

METHODOLOGICAL ISSUES

A number of barriers were overcome to implement the roughly 40 advanced models listed in Table 1. Many of them related to the challenges of implementing a fundamentally new modeling paradigm. Some were anticipated based on the weaknesses of the previous generation of models, whereas others were unique. Most of the advanced models in use today are based on the microsimulation of the interaction of individuals, households, and firms, whereas the four-step paradigm was based on aggregate representations of them. As households and firms were progressively divided into finer categories this approach became known as disaggregate modeling. However, it did not reach the level of spatial and temporal resolution and fidelity that characterize advanced models. The issues profiled here were faced by those who made the transition to advanced modeling.

Complexity and Perceived Complexity

The added sensitivity associated with advanced models does come at the cost of added complexity. With more moving parts, more knobs are available to turn in calibration and sensitivity testing. This means that there are more individual steps to calibrate, but it also provides the opportunity for the models to capture the right behavior for the right reasons, resulting in a sounder model. An example of the added complexity is a peak-spreading model versus fixed time-of-day factors. The fixed factors are easy to calibrate, because they can be derived directly from a survey, but offer no behavioral response to increased pricing or congestion in the peak periods, and so are limiting. There is no doubt that a peak-spreading model is more complex than a fixed factor; however, if that is an important policy consideration, then it is necessary.

There does, however, appear to be some disconnect between the actual complexity of advanced models and the perceived complexity, with those on the outside tending to perceive the complexity as greater than it is. The perceived complexity of advanced models is an issue that has not been examined deeply, or at least not in the literature. The topic comes up at conferences on advanced modeling and appears prominently in the ensuing discussions. Many of those "on the fence" about moving to advanced models note it as a drawback of such models. However, no objective measure of the additional complexity of such models is apparent despite widespread acknowledgement of such from even in early literature on the topic (Kitamura 1988; Bowman and Ben-Akiva 2001). However, it has also been pointed out that the increased complexity is not of the model itself, but rather the behavior being represented. Many proponents of advanced models cite the ability to capture such behavioral complexity as a key advantage (Transportation Research Board 2007; Ye et al. 2007; Outwater and Charlton 2008). The structural and algorithmic complexity of such models reflects those same qualities in the population under study.

A paradox was evident from talking to practitioners, who believed that activity-based models were easier to explain conceptually to decision makers and the public, and more readily acceptable because of their closer correspondence with how people make travel choices. However, the conceptual clarity comes at the price of increased data requirements, model complexity, and computational burden. It appears clear from the responses that until the perceived benefits outweigh the cost, opportunities to move forward in advanced modeling will fall short of their potential, irrespective of how impressive the research achievements and experiences from those on the cutting edge are. Quite simply, the proponents and early adopters of advanced models and the mainstream of the profession are too far apart in their capabilities and resources to achieve the cohesion required to move advanced modeling into the mainstream.

Some of this divide will be bridged when the experience base in advanced models deepens. As these models are proven in practice, their benefits—or lack thereof—will become more widely understood and published. For the time being their added complexity can only be acknowledged and traded off against the increase in utility gained from their adoption.

Modeling Versus Forecasting

An interesting philosophical issue was raised in several interviews about the relationship between modeling and forecasting. Although the two cannot be fully separated, there is a subtle but important difference. Modeling is about building and applying tools that are sensitive to the policies of interest and respond logically to change, and the success of modeling is a function of its ability to provide useful and timely information during the decision-making process, even if there may be certain caveats or limitations for that information. For example, when ranking candidate projects for inclusion in a regional transportation plan it is important that the model produce consistent results for all projects such that they can be ranked fairly, even if the correspondence to what is on the ground today is not perfect.

Forecasting is an attempt to envision or visualize future conditions. In the current context it usually involves predicting future travel demand and the resulting multimodal flows or changes in land use patterns over time. Forecasting usually, but not always, involves applying formal models, but can also incorporate other analyses and assumptions. Given the uncertainty about the future, several approaches might be used in forecasting. For example, a sketch planning or pivot point analysis might be compared with a regional travel or land use model. Direct and indirect comparisons can be made of the two forecasts. The differences in outcomes must be interpreted in light of the experience of the forecaster, reasonability of the results, confidence in the model and underlying data, and the assumptions about the stability of the behavior and trends implicit in the model. The success of the forecast can only be objectively measured through before and after studies.

It is important to understand the distinction between these two activities, as they heavily influence the mindset of modelers in general and how they perceive the benefits of advanced modeling in particular. If the goal is forecasting, it is best to identify the factors most likely to affect the forecast and focus on getting those right. If the policy under consideration is to extend the existing transit system, for example, this often involves starting with an extensive onboard transit survey to understand the full use of the system as it stands today. It may further focus on ensuring that reasonable parking cost and land use inputs are going into the model, and involve evaluating the forecasts extensively to identify anomalies.

The more the policies under consideration diverge from what is on the ground today, the more a model-centric approach may be needed. For example, when introducing a mode not currently in existence, the best that can be done is often to develop a model based on stated preference data, information from other regions, or rational theory. The same is true when evaluating any sort of behavior incentives not currently in existence, or when considering gas price, land use, or congestion conditions radically different than they exist today. This is where the modeling process can truly shine in helping planners and decision makers grapple with issues not fully understood. This is especially true of scenarios that have not been encountered before, such as traveler responses to much higher fuel prices than have been experienced over the past several decades.

It is important to note that neither viewpoint is “correct” in any sense. They simply reflect the priorities and needs of the modeler and their clients. Given the wide diversity in how models and their outputs are used across the country it is hardly surprising that similarly wide differences in opinions exist about how (or whether) to best further the practice of travel modeling. As a consequence, some agencies will find the case for advanced modeling far more compelling than a neighboring agency with different priorities and mission.

Model Estimation, Calibration, and Validation

Three related steps are important to the model development process:

1. Estimation: Using statistical methods to determine the model coefficients that best fit observed data.
2. Calibration: Tweaking model coefficients to better match aggregate targets.
3. Validation: Comparing model results to observed data independent of what was used for estimation or calibration.

Estimation can play a more important role in advanced models than in traditional models simply because there is less industry experience with the new models. Experience only exists with a handful of daily-activity pattern models, whereas practitioners have been developing mode choice models for three decades and have a good sense, for example, that the in-vehicle time coefficient for work trips should be between –0.02 and –0.03. At the same time, however, as models are being asked to respond to questions, such as the response to very high fuel prices, that pose a world very different from today, the value of models estimated solely from existing conditions and designed to replicate existing conditions becomes limited. In such cases, a strong theoretical foundation may be as important as the estimated values.

Calibration involves applying the model and adjusting the coefficients to better match existing conditions. Calibration is specific to a locale and involves first calibrating each individual model component, and then evaluating the system as a whole.

Advanced models, to the extent that they have more degrees of freedom, have more steps to calibrate and more knobs to turn during calibration. This does make calibration more challenging, but it also provides an opportunity to get the right result for the right reason, with the potential for less reliance on simple factoring without a relationship to behavior.

Model validation is applying a model and comparing the results with a data source independent of what was used to estimate and calibrate the model. Most often, in a travel model, this is a comparison with traffic counts and transit boardings by route. In practice, calibration and validation are usually iterative, with model validation revealing issues that require further calibration to overcome.

Questions of how well such models validate to observed conditions, as well as to existing traditional models, remain a topic of high interest among practitioners. The appropriate criteria and tests for determining model validity have been questioned, with some proposing that the long-standing focus on comparing observed with estimated link flows is inadequate for more advanced travel demand forecasting models. It is not clear why this bias remains, given the equally long-standing published advice on the topic (Barton-Aschman Associates and Cambridge Systematics 1997). Although standard validation tests such as this are a good first measure of a model's performance, there is much in the validity of a model that cannot be fully understood without sensitivity testing or using the model in application. For example, a model with constant time-of-day factors may validate very well against traffic counts by time-of-day, but would not be useful for testing policies designed to move travelers out of the peak periods.

The TRB Innovations in Travel Modeling 2006 conference (Austin, Texas) ended with many attendees asking for better evidence that such models perform acceptably in practice before they would consider moving toward them. A series of eight presentations on operational activity-based models from around the world were highlighted in the Innovations in Travel Modeling 2008 conference in Portland, with the express goal of answering that challenge. It was clear from the presentations that the models performed very well in this regard, although a single definitive evaluation of such models has yet to be compiled.

The best mechanism to measure a model's validity is through comparisons to before-and-after studies. Use the model to forecast the volume on a facility, build the facility, and evaluate how well the model did at predicting the volume on that facility. Naturally, building infrastructure is an expensive proposition and not something typically done for the purpose of evaluating a model. Therefore this measure of performance works well when forecasting the effects of policies or facilities similar to what has been done in the past; however, when the policies are different from what has been done previously (such as rail or pricing where it does not currently exist), one must properly rely on the predictive ability of models. This attribute highlights a key advantage noted for advanced models—a model that is able to test the policy of interest is clearly superior to one that is not, even if the validity of that model cannot yet be proven with a before-and-after study.

Appropriate model acceptance criteria for statewide travel models have likewise been oft-discussed to no resolution (Horowitz and Farmer n.d.). It has been acknowledged that such models are unlikely to validate at the same level as urban models. NCHRP has recently initiated a study to examine this topic, with results expected in 2012.

There are few examples of operational freight or commercial vehicle advanced models in existence. Hunt and Stefan (2007) describe the development of a tour-based microsimulation model of commercial movements for the Calgary region. The calibration of the model is discussed in detail, but its validation is not. Donnelly (2007) describes the development of a microsimulation model of freight flows in Oregon, which incorporates validation criteria that have a variety of measures, to include modal shares by commodity, trip length frequency distributions, incidence of trans-shipments, and trip chaining behavior. Both models are also discussed as case studies in Kuzmyak (2008).

The subject of validation of dynamic network models has been discussed in the literature, but generally on prototypical networks. Most authors compare link flows by time period with target data, often treating each instance (link flow from small time increments, typically 15 min) on a link as separate observations while pooling all observations. There are two general categories of DTA models in use. Analytical solutions use node–abstract representations with classical volume–delay functions, much like static macroscopic models. Simulation-based models include explicit representation of traffic signals (phases, cycle length, offsets, etc.) to calculate delays at intersections. The former are used almost exclusively in academic research, whereas the latter are used in practice. Because most of the literature focuses on the former the results shown are difficult to generalize. Most of the work in validation of large-scale DTA implementations has focused on comparing zone-to-zone or point-to-point travel times with travel time surveys collected by MPOs. Only one application—an implementation of Dynameq in Calgary (Mahut et al. 2004)—had traffic counts at a level of resolution adequate enough to permit validation. To date, two other large applications—Atlanta and San Francisco—are works in progress that have not been published. In both instances, however, only daily traffic counts were available for the majority of the network, precluding a detailed comparison of link flows.

A primer for DTA is under preparation by TRB's Network Modeling Committee (ADB30), and will include a chapter on validation. Because it is oriented toward practitioners and end users it is expected to contain validation procedures familiar and relevant to practitioners. Until the current crop of models is validated, using widely accepted criteria such as these definitive conclusions about the performance of these models relative to static models cannot be drawn.

Transferability and Portability

Transferability is concerned with whether a model developed in one location can be used in another location with substantially the same structure and, often, with little or no change to the parameters and coefficients of the model. Much has been published about the transferability of trip-based modeling approaches, particularly mode choice. Insufficient research has been carried out or experience gained with the advanced models described in this report to reach conclusions about their transferability. Moreover, there are several aspects of transferability that can be considered.

Most of the agencies that have made progress with advanced models seemed relatively unconcerned about how portable or transferable their modeling work was, and placed low value on being able to import work done elsewhere. This may be because most of the early adopters have engaged developers to build custom models. This in turn is the result of the lack of existing proven platforms that could have been adopted easily to meet their requirements. Thus, transferability is a topic about which much must still be learned.

The view among those considering moving to advanced models, however, is much different. Many are highly interested in this topic, and have deferred plans to move toward advanced models until more is known about them. It is likely that many agencies are unable to afford the original development of such models, forcing them to rely on adaptation of successful work elsewhere. In closing sessions of the TRB Innovations in Travel Modeling conferences in 2006 and 2008 (in Austin and Portland, respectively) this topic was widely discussed. In addition to the pragmatic desire to build on the work of others, the ability to choose from among several competing models and a strong desire for proof of concept was voiced by attendees.

To date, only one activity-based model has been transferred from one location to another. The Columbus Mid-Ohio Regional Planning Commission (MORPC) model was implemented in Lake Tahoe by transferring the model and coefficients. The majority of the effort was therefore devoted to calibration and validation of the model to local calibration targets (Willison et al. 2007). The results were very encouraging, with the model matching targets better than the locally developed model it replaced, as well as being easier to model the unique population characteristics of the region. The Lake Tahoe project is described more fully as a case study in chapter six.

A second test of transferability is currently underway. An activity-based model was specified and estimated for Atlanta (ARC). Currently, both models are being implemented in Atlanta and the San Francisco Bay Area (MTC). This approach allows both agencies to share software development costs and to progress through model calibration and validation in parallel. When complete, it will serve as an interesting test of the transferability of an activity-based model across large regions with very different characteristics.

The situation in land use–transportation modeling is quite different. Currently, the three most common packages in North America—UrbanSim, PECAS, and TRANUS—have been applied in several locations with varying degrees of success. These models fall into a somewhat different category than the activity-based model applications in that they are purposely designed to be widely deployed in a variety of places with different requirements and data availability. These models are unquestionably the furthest along in terms of the portability of all of the advanced models.

The dynamic network tools have been developed in a similar manner. Although early tests were conducted in a number of cities, the tools were designed to be broadly usable. However, most were envisaged as small area analysis tools and only recently have been investigated as replacements for static traffic assignment for regional travel models. Upcoming research and development associated with the SHRP 2 C10 project will investigate the formal linkage of activity-based travel and dynamic network models. Sacramento and Jacksonville have recently been chosen as the locations for the work under this project.

There are no known cases where an advanced freight model has been transported to another location.

Based on the initial examples the transferability and portability of models can be considered at three levels:

1. Software, if well written and sufficiently generic, can be transferred to a new region with limited changes and no downside. Commercial software packages have proven for years that this is true. More recently, open-source software packages have been developed to facilitate advanced modeling, including the Common Modeling Framework and the Open-Source Platform for Urban Simulation.
2. The second level of transferability is of estimated model parameters, which was done in the Lake Tahoe model, and is currently being done in the MTC models. The case for the legitimacy of transferring estimated parameters is less clear, although both models appear to be behaving rationally so far.
3. The third level of transferability is of the model calibration, which is not transferrable at all. One cannot expect to receive a model delivered in a shrink-wrapped box, unwrap it, and have it behave properly. Instead, the model must always be calibrated to local conditions, as was done with Lake Tahoe and MTC, as well as the land use models that have been transferred to new locations.

Thus, it is best to view model transferability and portability as a mixed bag. It is not a panacea that will instantly grant new users a free lunch, but it does offer the potential to significantly reduce development costs, particularly for the software. There is potential for the modeling community to follow the lead of some highly successful open-source software projects, where new developments are shared with the community in a compatible format, allowing all to take advantage. Such sharing of developments may take off as a critical mass of advanced modelers develops, if there is a champion and framework for such sharing.

Of course, transferability assumes some similarity between the regions being modeled. One could reasonably expect similarity among most American and Canadian cities, but transferability to or from Europe or Asia is likely more limited in its potential.

Software and Platforms

Traditional travel demand models and the current crop of dynamic network models are supported by commercial vendors. They have made considerable investments in the core modeling capabilities, GUI, and documentation. Most also have dynamic linkages to relational databases and GIS, as well as the utilities to import data from their competitors format. These vendors in essence provide the software implementation of the models, which substantially reduces, and in some cases eliminates, the need for the user to write their own software. Moreover, they provide training and support for users, and absorb the costs of updating the software and fixing bugs. Most users of traditional models appear to be satisfied with such an arrangement.

By contrast, almost all of the activity-based models developed to date, as well as the integrated land use–transport models, have been developed from scratch for each specific implementation. A few are entirely original works. DRCOG's activity-based travel model is coded in the C# programming language, whereas LUSDR and Jem-n-R (Oregon DOT) are written in the R statistical language. The CEMDAP model, implemented at NCTCOG, is the only proprietary model among the advanced travel demand models. The rest have been developed using open source software components to reduce development time and cost. Waddell et al. (2005) have developed a model development platform called Opus, which uses a combination of the Python programming language and certain functions coded in C to maximize computational efficiency. The current generation of the UrbanSim model is based on Opus, which is flexible enough to accommodate the design of other types of spatial interaction (including travel demand) models. PB has developed Balsa, a similar library of model building blocks written in the Java programming language. Almost all of the activity-based models they have developed, starting with the MORPC model (Davidson et al. 2007), are based on Balsa. In both cases the finished model is unique to a given client; however, its "lower level" functionality is provided by Opus or Balsa. Both Python and Java are themselves open source projects, are portable across operating systems, and are supported by a broad and active user community. Other open source software commonly used with advanced models includes relational database managers (e.g., PostgreSQL and SQLite) and visualization tools.

The resulting models combine code that is specific to each client and parts from one or more open source packages. The client unquestionably holds all rights to the former, in effect allowing them to keep the overall model as open or closed to others as they desire. The trend to date, irrespective of components used, has been to make the entire model open source, or at least available to others developing similar models. This is both true for fully functional generalized models (e.g., PECAS, TRANUS, and UrbanSim) and models tailored for each client.

Open source software offers some advantages over proprietary software. Developers and users can inspect the code to learn details of its operation and help debug problems. They can modify it for specific applications and experiment with ways to make the code more efficient. The ability to build off of the work of others can reduce development cost, allow others to verify and check the code, use it with different operating systems, and collaborate with others. The cost of entry is low, and a user community can provide help and ideas. However, it is no panacea. Although the code is free, the expertise required to creatively and competently use it is not. Novice users can unwittingly introduce errors that are difficult to trace and that violate the assumptions or integrity of embedded models. Most open source projects are overtaken by inertia and quietly fade away (Fogel 2005; Daffara 2006), often because the underlying software addresses a narrow niche or is complex enough to present a steep learning curve. Both might fairly characterize Opus and Balsa; although they have enjoyed many of the advantages cited for open source software (most notably wide collaboration), part of their success undoubtedly is because there is no commercial alternative available. Moreover, it might be argued that their respective developers have been the only benefactors to date.

Whether the next generation of advanced models continues as "home grown" an open source remains to be seen. In part it will depend on what the commercial vendors bring to market. Equally influential will be whether a small number of models dominate, such that they have a chance of building a critical mass of users and developers. Finally, it will depend on having more than just a handful of model developers with the skills necessary to build and implement sophisticated software.

Hardware and Model Run Times

Most advanced models have much more demanding computational requirements than (dis)aggregate travel models. This is particularly true for land use–transportation and dynamic network models. Such models are often characterized by run times that number in days rather than hours, which place them at a significant disadvantage to the models they seek to replace.

The activity-based model implementations to date have employed sample enumeration or microsimulation approaches. The constituent models of the latter include rule systems, sampling from statistical distributions, deterministic mathematical models, and discrete choice models. The latter, popularized in the traditional mode and destination choice models, are applied at the individual traveler level instead of for groups of them (as with traditional models). Coupled with the higher spatial resolution that newer models operate at, this vastly increases the number of alternatives considered and utility expressions calculated, resulting in much longer run times.

Fortunately, improvements in computer hardware are closing the gap between model run times and user expectations. As more developers find ways to parallelize or distribute their code to take full advantage of multi-core processors run times will continue to improve. The question remains, however, how much must they improve to meet the needs of users? There was near unanimous agreement that 16 h is the gold standard for model runs, as that would allow overnight runs. Some were insistent that 16 h represented an absolute maximum, and that multi-day run times seriously reduce the utility irrespective of how robust or informative the outcomes are. They reported that as policymakers they are accountable to typically require quick responses to their enquiries and that late replies typically do not influence outcomes. As such, they require tools that balance fast models with the desired behavioral, spatial, and temporal resolution desired.

Steady advances in computer hardware and operating systems have provided the solution ingredients. Continually faster microprocessors and memory provide linear reductions in run time, although most agencies reported being unable to update their hardware more frequently than once every three years. Moreover, even when they do they often have a difficult time controlling the purchases that are made on their behalf, putting them at a further disadvantage. Developers are helping them, sometimes unintentionally, by crafting models that only run on 64-bit computers and operating systems, forcing the agency to upgrade the hardware available. However, the transition from 32-bit to 64-bit architectures, like the transition from 16-bit to 32-bit computers in the early 1990s, only rarely happens, such that the effect will be significant now, but diminished in following years.

Most advanced models now in use employ a cluster of computers (typically six to eight) over which execution of their programs is distributed. Each machine typically has several microprocessor cores (i.e., Intel's Core2 Duo and machines built using their new I7 chip) and 4 to 16 GB of memory. The precise configuration depends on the model, but these computers currently range in price from $6,000 to $12,000. Thus, most agencies will spend between $36,000 and $60,000 on a cluster to run advanced models, depending on their needs and required configuration. Machines used for large-scale DTA modeling typically use larger amounts of memory (32 to 64 GB), considerably raising their cost. However, it must be emphasized that the hardware requirements and costs are decreasing as software is becoming more efficient and the performance of computer workstations continues to grow.

Some developers are working hard to distribute or parallelize their code. The two terms are often used synonymously, but are different approaches. Distributed computing spreads the problems across multiple machines, some of which might be remotely located. Message passing is used to communicate between a controller and several workers, with each worker typically holding all of the data it needs. Parallel computing, on the other hand, generally involves multiple processes running on a single computer and sharing the same memory space. Parallelization is particularly attractive, as it will allow programs to take full advantage of multi-core processors. It is easily implemented for tasks that do not have dependencies on other tasks, such as population synthesis or destination choice. However, there are many parts of both traditional and advanced models that do not lend themselves well to either parallel or distributed solutions, limiting the amount of improvement possible. Much of the parallelization of the code is accomplished through simply dividing the number of cases (travelers, households, etc.) among the number of cores. However, vendors such as Caliper Corporation and Citilabs have taken this one step further, using multi-threading of their assignment code to permit it to make maximum use of available processors and memory. Further advances in this area appear to hold the greatest promise for reducing run times without sacrificing model form or structure, and have the potential to further reduce the cost of hardware required to run advanced models.

DATA ISSUES

The issue of data was not identified as a major concern for tour- and activity-based person-travel models. However, questions about data requirements appear to be a major concern to agencies contemplating adopting advanced models. The literature is not clear about data requirements, in part because the data requirements for a model depend heavily on the scale that is applied, scope of issues and behavior it must address, and at what fidelity and resolution. Moreover, most agencies have invested heavily in GIS technology in the past few decades. That, coupled with ever-increasing sources of open source data available on the Internet, has reduced the *perception* that data are more readily available. The reality will of course depend greatly on the specific model, its intended applications, availability of such data from other sources, and resources available to collect and analyze the data.

Typical data requirements are therefore difficult to describe and even harder to estimate the costs of collection for. An attempt has been made to distill the data requirements that appear common to most of the advanced models deployed to date. The typical and optional data used in the various types of models discussed in this report are shown in Table 5.

Most developers of advanced person-travel models reported availability of adequate data for model estimation and calibration, or facing challenges no worse than for the development of traditional data. Indeed, substantially the same surveys are required for collected travel diary data for traditional

TABLE 5
TYPICAL DATA REQUIREMENTS FOR VARIOUS MODEL TYPES

Model Type	Minimum Required Data	Optional Data
Trip, Tour, and Activity-Based Travel Models	Transportation networks	External travel survey
	Geo-located households and employment	Workplace travel survey
	Household travel survey	Stated preference surveys
	Traffic counts by time period	Zonal land use attributes
	Observed transit boardings	School location and catchment areas
	On-board transit survey	Visitor data and surveys
Dynamic Network Models	Transportation networks	Transit routes and schedules
	Traffic control data (signal timings)	Truck counts
	Demand by 15-minute intervals	Truck demand
	Traffic counts by 15-minute intervals	Detailed detection strategies
	Travel time survey data	
Land Use Models	Geo-located households and employment	Land prices
	Current floorspace by type	Neighborhood quality
	Floorspace consumption rates	Input-ouput accounts and coefficients
	Permitted land uses and vacant land inventory	Economic output by sector
	Accessibility measures	Raster cell/parcel land use data
	Knowledge of user preferences	School location and catchment areas
	Future control totals for population and employment	Environmental quality/locational amenities
		Workers by occupation
		Observed trip length distributions by purpose
		Demographic transition probabilities
Truck Models	Transportation networks	Special generator studies
	Geo-located intermodal connections	Truck intercept surveys
	Geo-located households and employment	External travel survey
	Truck counts by period and truck type	Establishment/employer surveys
Commodity-Based Freight Models	Transportation networks	Trans-shipment characteristics
	Geo-located intermodal connections	Special generator studies
	Geo-located households and employment	Truck intercept surveys
	Truck counts by period and truck type	External travel survey
	Commodity flow survey	Establishment/employer surveys
	Foreign Trade Data	Port counts and surveys
	Input-output accounts and coefficients	

trip-based or more recent advanced travel models (Stopher 1992; Sabina et al. 2008). However, the question of whether traditional sampling rates are adequate is an open question. The number of households included in travel diary surveys has declined over time, such that most agencies only obtain data from 2,000 to 3,000 households. This appears to be the minimal number of observations required to capture statistically significant differences between market segments typically used in disaggregate four-step models, although definitive guidance on optimal sample sizes remains controversial (Stopher and Jones 2003). The compromise usually adopted is to collapse dimensions within the data when smaller surveys fail to obtain enough samples to differentiate all desired aspects of travel behavior. Such an approach cannot be used with activity-based models, as the desired levels of resolution and fidelity translate into more detailed representations of households, travelers, and their choices. The resulting variables and coefficients cannot generally be aggregated without reducing the explanatory power of the model, which runs counter to the goal of a richer and more accurate behavioral representation. Thus, the compromises imposed by using smaller sample sizes become readily apparent far more quickly when crafting activity-based models. However, reduced power and sensitivity of the model is obtained irrespective of whether a traditional four-step or cutting-edge activity-based model is crafted from them.

To date, some of the activity-based model development has been accompanied by large household travel diary surveys. Some have included 12,000 households, at a cost much greater than for the aforementioned minimal required sample sizes. The size of these surveys was dictated by the higher level of behavioral resolution and more detailed modeling of choice behavior than found in typical models. (To be fair, it is important to note that surveys approaching this size would be required to develop more detailed and sophisticated trip-based models with a larger number of market segments.) The desire to be able to confidently differentiate the wide variety of tour patterns and estimate statistically significant parameters for them also dictated larger sample sizes. In some cases it was also decided to err on the side of more observations than might be required, given the lack of experience with such models at the time. The developers of such models have posited that perhaps half as many observations (5,000 to 6,000 households) might be sufficient; however, more definitive guidance must await evaluation of several models currently in development. The level of detail desired in the model will dictate the size of the survey required, which in turn should be informed by analytical requirements. A credible and useful activity-based model could be constructed from a small survey, but to obtain the increased sensitivity and detail desired by current adopters of such models larger sample sizes might be required.

The literature also suggests that a greater reliance on stated preference experiments is likely (Petersen and Vovsha 2008), and might be especially relevant for modeling behavioral responses to high fuel prices, new technologies, virtual commerce and meetings, and pricing and tolling schemes. Such conditions have not been encountered before, precluding the use of existing data and models built on them for assessing their impact. Unfortunately, stated preference surveys are more difficult to construct, execute, and interpret than revealed preference surveys. Fewer modelers and travel survey firms have experience with them. The cost associated with them and expertise required makes them ideal candidates for collaborative data collection. To date, no such joint effort has been planned or undertaken; however, several respondents indicated a willingness to do so.

The situation for the other types of advanced models considered is dire by comparison. Land use–transportation models use more data than traditional travel demand models, especially if parcel or comparable small units of geography are involved (Moeckel et al. 2002; Miller et al. 2004; Clay and Johnston 2006). Such additional data include:

- Floor-space consumption and tenure by land use type,
- Population and employment by type at the same level of spatial resolution,
- Permitted zoning or land use(s), and
- Residential and nonresidential land prices.

These data are generally available, although at cost and requiring considerable analysis to become well acquainted with them. Many are available through local government or third-party sources, but there are often substantial amounts of data cleaning and reconciliation required before the model can be made operational. Data on the cost of acquiring these data has proven elusive, in part because the cost has largely been borne by in-house staff or acquired through other governmental agencies. Moreover, the choice of modeling platform will influence the cost and effort required. For example, deploying a land use model such as LUSDR will result in smaller data requirements compared with PECAS and UrbanSim.

The situation is not as fortunate for freight and dynamic network modeling. The paucity of even basic data on urban freight behavior and spatial distribution patterns is a long-standing barrier to progress in understanding and modeling urban freight systems (Transportation Research Board 2003a; Wigan and Southworth 2005). Truck and shipper surveys conducted in most urban areas are very small, with several hundred to a few thousand observations. Given the diversity of commodities, vehicle types, and origin–destination patterns this represents probably too limited a sample from which to develop robust freight or commercial vehicle models. Compounding this problem is that most urban areas do not have extensive reliable trucks counts. No differentiation is made between privately owned trucks and vans and commercial vehicles of the same configuration. This category constitutes the largest share of commercial goods movements in urban areas (Holguin-Veras and Patil 2005). For freight models the problem is compounded by not being able to differentiate commercial vehicles carrying freight, as opposed to other commercial trip purposes.

A similar situation faces users of dynamic network models. To date, in most areas where large-scale DTA has been applied there have been few counts available by hourly or 15-min intervals, and certainly too few from which to calibrate or validate the models. Data on actual versus modeled path choice are likewise not available. It is clear that substantial investments will be required in mining real-time ITS and traffic control data to develop the databases needed to rigorously assess these models. In addition, simulation-based DTA models and TRANSIMS include explicit representation of signals. Data on their operation (phasing, cycle length, offsets, etc.) are required to implement the model, but techniques for generating these data on an urban scale are still lacking. Further research and development in this area will be necessary before these data can be synthetically generated without extensive user intervention. Some researchers, such as Gershenson (2005), advance the idea of self-organizing traffic control systems as an alternative to traditional signal optimization approaches. Mahmassani (personal communication April 2009) also advocates this approach, arguing that setting all phases of fully actuated signals to their minimum length and letting the DTA model find the best solution is preferable to external optimization. Such techniques might hold great potential, but require additional research and verification before their practical application can be assessed.

COST AND SCHEDULING ISSUES

Significant internal staffing and funding resources have been required for most of the development and implementation efforts undertaken to date. Virtually all of the funding has come from MPO or state DOT sources, with the notable exception of federal funding for TRANSIMS. However, the issue of funding was dwarfed by concerns about scheduling issues. Virtually all of the efforts took longer to complete than anticipated, in some cases more than doubling the initial estimate. Overcoming these issues, both for currently underway and future efforts, will be essential if advanced models are to achieve widespread adoption.

Cost Issues

During the interviews, a lack of available funds for model development was cited surprisingly few times as an impediment to moving forward. However, it is acknowledged that most of those interviewed were already involved in advanced modeling, and that otherwise similar agencies might be as involved if they had comparable funds available. Many respondents believed that the current economic downturn, coupled with anticipated austerity measures implemented later on to reduce the debt incurred by stimulus spending, will reduce the funds available for advanced modeling over the next decade. The degree of reduction expected varied widely, as did opinions about how much it will slow down the evolution of advanced models. A few even thought that a reduction in funding would provide the benefit of forcing consolidation of efforts and standardization of models and data collection sooner than might otherwise occur.

Information about the cost of developing and deploying advanced models is eagerly sought by agencies contemplating an investment in them. “How much will it cost me?” is a question often heard when discussing such models. It was surprisingly difficult to answer this question despite a concerted examination of efforts to date. In some cases such information was difficult to obtain or interpret. Some respondents did not know the full cost involved, often because their tenure was shorter than the model development work. A few declined to provide cost information despite repeated requests. However, most objected to generalizing their experiences. Some believed their case was atypical, either because it was a first for that particular type of model or they perceived problems with local data or issues unique to their agency. The majority noted that theirs was “a work in progress,” and that the true cost would only be known after the model was successfully implemented.

Software development has been required in most of the advanced models developed to date. This has influenced the overall cost of implementation in two ways. One was the loss of time and effort when software bugs were uncovered; growth pains that most hope are largely past. The second factor is the assumption of reusability. Once initially developed it is likely that the cost of a specific modeling platform will go down considerably for subsequent adopters. This, in turn, has two potentially misleading interpretations. One is on the part of managers, who mistakenly believe that if the software works elsewhere that their staff will refrain from making necessary changes. In this case the manager assumes the software cost is zero, when in reality it can be high. The other misinterpretation is on the part of the developers, who probably cannot accurately state what portion of the development cost was devoted to software and what went to other development activities.

Finally, it was difficult to obtain complete cost data from most respondents. Almost all knew how much they had paid consultants or developers. However, few could provide information about in-kind or internal expenditures, such as the cost of agency staff devoted to advanced modeling, data collection, peer review, training, or program management. Several agencies reported having two or more staff members dedicated to model development and implementation, suggesting that their total outlay for the overall effort is much larger than the size of consultant contracts. All that said, a few observations can be made:

- The consultant contracts for the first few activity-based person-travel models (in San Francisco, New York City, and Columbus) were $1 to 2 million apiece. In two of these cities no agency staff participated in their development, whereas a single person played a large role in the third.
- The consultant cost of currently ongoing efforts (to include Atlanta, the San Francisco Bay Area, San Diego, and Phoenix) ranged from $750,000 to $1.2 million. All of these agencies have a senior staff member dedicated part-time to directing the effort, and anticipate dedicating more of their time and possibly additional staff as the models draw closer to completion.
- It was difficult to isolate the cost of software versus model development, as many tasks involved both activities.
- The Columbus model was adapted to and validated in Lake Tahoe at a cost of approximately $350,000, which included the cost of developing the network, zonal data, and other aspects of the model.
- The cost of urban freight models was highly variable, ranging from $20,000 to more than $1.2 million. The former only involved the implementation of a sequential model using transferable parameters, whereas the latter involved extensive truck and establishment surveys.
- The range of costs for land use models has been similarly wide. LUSDR, developed internally at the Oregon DOT, cost approximately $50,000 in staff time to develop and apply. By contrast, the more sophisticated models have included several millions of dollars in development cost alone, with the cost of application highly variable depending on the availability and quality of data.
- There are virtually no useful and comparable cost data available for the development of dynamic network models at a regional scale.

Several respondents expressed hope that the cost of future models could be significantly reduced using a combination of standard model forms, transferable parameters, and open source software. Part of the appeal of open source software is that several collaborators share the cost of its development, making possible software that none could produce working alone. Many respondents applied the same rationale to model development, with the hopes that shared funding would reduce the cost of advanced models. A few examples were cited of such collaborative development:

- The ARC and (San Francisco Bay Area) MTC are sharing the cost of implementing their activity-based travel models.
- The Oregon, Ohio, and Florida DOTs have each invested in common data and advanced travel models across the

state. Oregon's LUSDR model is not location-specific and can thus be used elsewhere in the state, although to date it has not.
- The statewide modeling program in Oregon sponsored the early development of both UrbanSim and PECAS.

It was expected that other agencies would be eager to replicate these collaborative successes. Although some agencies expressed an interest in building on work already completed elsewhere, a surprisingly large number appeared uninterested in such partnerships. Many expressed an unwillingness to relinquish control over the final product or choice of developers, or expressed skepticism that an agreement could be reached on important design issues. However, the respondents appeared far more eager to collaborate in the funding of data collection programs, especially for large-scale travel surveys and complicated stated preference experiments. The case for shared funding of specialized model components, such as visitor or special event models, was seen as advantageous by most agencies.

Another topic widely identified as needing funding was education and training. There was consensus on the need for collaborative funding for intensive training programs that are longer and more in-depth than current National Highway Institute or TRB workshops. However, other than an eagerness to see federal leadership in this area, it was apparent that those interviewed did not have a clear vision for how such programs would be structured or by whom.

Phasing and Scheduling Issues

Many of the advanced models deployed to date have taken longer and cost more than originally intended, and in some cases were delivered only through the sheer determination to succeed on the part of the champions and developers. The developers of such models offered a variety of explanations for this:

- Such models are cutting-edge endeavors, with attendant technical uncertainties and lack of experience in cost and schedule estimation.
- Several dead ends were encountered that required reformulation of the modeling approach.
- The time estimated to implement the models in computer code was underestimated.
- The resulting models have long run-times, often measured in days, such that changes took longer to test and assess than with traditional models.
- Only a handful of people were attempting such models until recently, such that just a few projects absorbed all of the available talent.
- The funds available for the effort were not well aligned with the model design.

Not surprisingly, the model recipients had a somewhat different perspective. Although quick to acknowledge the developer's perspectives, they often cited overcommitment of the consultants, as well as overdesign of the model. Given the lack of experience with such models, they viewed it as difficult to know whether the proposed scope of work was achievable or not. The earlier projects appear to have been more affected by these factors than more recent undertakings, although the total number of such models attempted is still small and many are still in progress.

Another characteristic of the earlier development efforts, not reported in the interviews but apparent from looking at the whole, is that they all embarked on large, multi-year development efforts preceded by detailed model specifications. The latter was typically completed within a few months; however, the subsequent development and implementation was undertaken over a period of years. Problems tended to become apparent only when the model became operational, which was most often near the end of the project. Accordingly, the options open to the team were few and mostly involved compromises on the original design or deferral of capabilities. Because many of these large projects were "once in a lifetime" opportunities for the agency to adopt advanced models there was often little ability to expand the budget. The resulting model was either reduced in functionality or resulted in inadvertent cost-sharing by the developers. That none of these projects failed outright is surprising.

In contrast, most of the successful implementations studied—in terms of cost and schedule—were developed in stages. All were driven by the same comprehensive design at the outset, but were structured to provide interim capabilities and milestones. These in turn allowed the agency to gain familiarity with the models, assess them in practice, and permit changes as requirements or desired capabilities changed. More will be said about this in chapter five, as it represents a key lesson learned from the experience gained to date.

INSTITUTIONAL ISSUES

As challenging as the methodological, data, and budgetary issues were, perhaps the most daunting challenge facing most proponents of advanced modeling were institutional issues. Many suggested that otherwise successful advanced models could not succeed without overcoming these issues.

Motivations for Advanced Models

A few respondents noted that they were interested in advanced models based solely on a desire to keep up with the latest trends. However, in most cases, the cost of doing so is high enough that such motivation alone is insufficient to justify the investment. The majority of respondents were able to quickly describe a range of analyses that they have accomplished with advanced models that were difficult or impossible to model using traditional methods. The analytical needs that these models fulfilled are recounted in chapter three.

Most of the agencies that have instituted advanced models—and all but one with land use–transportation models—operate in political climates where issues larger than just transportation are being tackled. Some, such as the Oregon DOT, are also charged with growth management, forcing them to expand their analyses beyond just transportation. In other instances the motivation for modeling a larger realm includes the need for making the case for transportation investments when they compete with other programs, a desire to demonstrate how transportation affects other sectors and land markets, and mandates to contribute to larger analyses such as energy and emissions forecasts. Most believe that these "larger than just transportation" issues will grow in importance in the coming years, and are actively seeking to reorient their modeling capabilities to support such analyses. Some wanted to capitalize on the premise that they were "the only modeling game in town," and saw these larger issues as an opportunity to leverage their considerable existing investment in data and models into new and larger roles for their agency.

Many of the overarching issues affecting all advanced models include pricing and public–private financing, economic growth and job retention, the effect of the economic downturn, energy scarcity and effect of large fuel price increases, impacts of changing vehicular technology, and greenhouse gas emissions and their effect on climate change. These are all in addition to traditional concerns about congestion and transportation system efficiency, which remain as important considerations, but only two among many competing urgent agendas.

There is growing concern that macroscopic traffic assignment models, a fixture of the four-step modeling paradigm, do not accurately portray the location, extent, and duration of congestion, especially in large metropolitan areas. The average travel times over peak periods is faced by few travelers, who generally either encounter shorter times in the shoulders and longer ones in the peak hour, which skews trip distribution and time-of-day models. The desire for more realistic portrayal of network conditions and traveler responses thereto is driving the move toward dynamic network models.

Partnerships with Other Agencies

The move into advanced modeling brought with it the need to develop strategic alliances, and in some cases close working relationships, with other entities. These varied by locale and the type(s) of advanced models used. Many agencies working on tour- or activity-based person-travel models reported that their new partnerships were with outside developers, but that their relationships with other agencies remain unchanged. Their model enhancements represented more of an evolution than expansion of their current mission and capabilities.

Forays into land use–transportation modeling perhaps entailed the largest number of new relationships. In addition to linkages with land use planners, this field of modeling typically requires close collaboration with GIS and business data specialists, as information not commonly used in urban transportation models is required. This includes detailed information about population, households, and firms, as well as floorspace occupancy and tenure, detailed employment data, and zoning and comprehensive planning overlays. Explicit linkages with economic models require collaboration with urban and regional economic forecasters. In some agencies working together on the technical level was simple; however, internal politics and department boundaries made formal collaboration more difficult.

Region-wide dynamic network models typically start from the same network as used in static assignment, but add considerably more operational details. Traffic control devices and their settings must be added to the network, as well as more careful coding of zonal centroid connectors. More detailed traffic count data than typically found in most MPOs are required for validation, as well as travel time information at fine-grained temporal resolution. Relationships with traffic and ITS engineers are required in such cases, as well as traffic control center staff.

Some agencies reported that they expect to develop closer relationships with the EPA as the MOVES emission model comes into use. Modeling for air quality conformity analyses is currently carried out using the EMFAC model in California and MOBILE6 elsewhere. In many cases the output from traffic assignment (link flows and travel time by vehicle type) is provided to air quality agencies that run the emissions models without assistance from the modeling agency. The MOVES model will require more complex data at a higher level of spatial and temporal resolution than MOBILE6, and will require close collaboration between transportation and air quality modelers.

Staffing and Education

By far the most frequent issue cited by those interviewed was a lack of suitably qualified and trained staff. This staff shortage manifested itself in many ways, from agencies being unable to compete with the private sector for the required talent, to conviction that universities were not equipping graduates with the necessary skills, to inadequate funding for additional staff even if they could be recruited. The wide diversity of factors contributing to the lack of staff precludes an easy solution to the problem. The truth of this conclusion could be seen in that none of the agencies surveyed identified a means of overcoming it.

Part of the difficulty is because no guidelines on minimum qualifications have been established for the various types of modeling identified in this report. Even if such guidelines were available, it is unclear whether the modeling community would embrace them. This is especially true if few or no opportunities exist to acquire the required skills. It is also unclear how such guidelines would be enforced absent a strong federal role in monitoring and certification. Finally, several respondents noted that strong skills in software development, beyond the ability to use spreadsheets and write simple database queries, are equally important as modeling skills. Modelers at the Oregon DOT, for example, have become adept at using the R statistical language for analyzing data and building models. It is unlikely that the DRCOG model development would have succeeded without its staff having comparable skills.

Two related issues were often mentioned as well. In several instances it was found that although the agency had "the right people" already, many were drawn away from model development to more pressing applications. This finding appeared to be correlated with those agencies that tended to do all of the modeling work in the region in-house, although some exceptions were apparent. Most agencies are organized around periodic updates to their long-range transportation plan, which is a major undertaking that consumes virtually all of their resources. In the agencies we talked to this cycle ran in three- to five-year intervals, which meant that model development, if it were to occur, had to be accommodated in the "off years" of the cycle.

A second issue often identified by almost all agencies interviewed was the almost complete lack of training resources and opportunities available in advanced modeling. In many cases it was asserted that otherwise capable and interested staff had no practical means of acquiring the knowledge necessary to develop, implement, apply, or evaluate advanced models within their agency. Most believed that this knowledge was tightly concentrated within a relatively small number of academics and consultants. The publications of the former were often viewed as being physically (by virtue of publication in costly academic journals) or mathematically inaccessible. It was widely believed that the work of the consultants was not well-documented and was protected by proprietary interests. In both instances it was noted that the level of detail provided in TRB publications and presentations, while appropriate for making contributions to the literature and sharing general knowledge, was wholly inadequate for conveying the level of detail necessary to replicate the work reported.

There was no consensus about how to overcome this problem. Many believed that this was an area where federal leadership would be most effective. Some pointed to the strides made by the FTA in harmonizing New Starts analysis requirements and its annual travel forecasting workshops as evidence of what could be accomplished in this realm. Others believed that this was an area where the universities might logically take the lead, but have shown no interest in doing so. A few agencies reported that including a task for formal training in their consultant contracts was helpful, although the effectiveness of the resulting training has not been established. One agency advocated for a more coherent approach to talent management, where the spreadsheet modelers, the software developers, and the statisticians each find a role suitable to their abilities.

The most compelling solution suggested was an intensive "advanced modeling boot camp." It was believed that this should be a month-long course that covered the fundamental concepts required to understand advanced models, as well as an in-depth look at one specific model development project in enough detail to understand how to replicate or transfer the model to another location. However, most agencies reported that they would have difficulty affording the cost of such training, and most were openly candid about worries that the participants would afterwards be lured away by consultants after completing the minimum time necessary at the agency. A number of alternatives to a month-long course suggest themselves, but the issues of who will take the lead or how to pay for its delivery just to the largest MPOs remains unresolved.

TRB has recently undertaken an important leadership role in the development of technical resources for travel modeling, some of which will likely include knowledge-sharing networks and collaboration. With financial support from FHWA and FTA, TRB will serve as the coordinator of the Travel Demand Forecasting Technical Resource Initiative. It will provide staff and technical support to the program, which is designed to bring together leaders in the modeling community to help guide the development of a multi-faceted web-based portal. The contents and format of the portal are undefined at this writing, but are expected to include a wide variety of media, to include documentation on best and emerging practices, research reports, links to relevant research in parallel areas, educational and training material, podcasts or other multimedia presentations of top topics and breaking research and development results, and other tools. In so doing, the Initiative will not only introduce a new and widely accessible repository, but also equip modelers and agencies seeking to expand their capabilities. The staff and advisory committee are being invited at this writing, with work expected to begin in earnest early in 2010.

Peer Review

There was diversity of opinion about the value of external peer review panels for advanced modeling work. Some, such as the Oregon DOT, have long maintained a high value obtained from using a panel. The Ohio DOT is working on a similar model (an integrated land use–transport model with an activity-based model component), but reported that peer review was a low priority. Similar paradoxes were found for other types of model development work. In the case of dynamic network modeling no instances of peer review were found except for the TRANSIMS early deployments, which relied heavily on expert panels. Many of their subsequent activities (see Appendix C) have also benefited from peer reviews.

CHAPTER FIVE

LESSONS LEARNED

The lessons learned from the efforts to date were gleaned from the literature, documentation, and interviews with key modelers and members of the topic panel. Each was asked, “If you had it to do over again, what would you do differently?,” a less confrontational manner than asking where they failed. Indeed, many had success stories to tell, lessons from which were as equally valuable as what not to do. Interestingly, most of these lessons relate primarily to institutional issues. It was believed that most of the key lessons from methodological and data standpoints were already adequately addressed in the literature. What was lacking, most believed, was a digest of the practical issues associated with implementing such models in practice. This chapter attempts to fill that void.

ASSESS THE CASE FOR ADVANCED MODELS

The benefits of advanced modeling summarized in chapter three will be realized only if the questions asked by users of the model truly require them. Quite simply, if modelers are not being asked to model the complex issues of equity, pricing, sustainability, and other behavioral changes then most of the benefits of advanced models will not be apparent. In the past, travel demand models were typically used to estimate travel conditions under a variety of large-scale policy and investment options, with levels of congestion and aggregate travel times as the principal outputs. Existing four-step models are arguably well-suited to producing credible and useful estimates of such travel. Although advanced models may improve the quality or accuracy of such forecasts in cases where travel behavior and choices are not expected to change significantly, it is difficult to quantify such improvements. Conversely, in cases where an advanced model is able to evaluate a policy that a traditional model cannot, the benefit is clear. For example, without a freight and commercial vehicle model, an agency could not effectively evaluate the potential benefit of truck-only express lanes serving a marine port.

It quickly boils down to whether assumptions of relatively stable socioeconomic growth and transport policies and infrastructure are tenable to the agency. The agencies that have gotten the most out of advanced models are those for which such assumptions are not valid and those agencies where decision makers are asking more expansive questions and demanding more comprehensive analyses.

One interesting finding is that in addition to responding to the questions posed by decision makers, advanced models can be used as a mechanism to prompt decision makers to ask more sophisticated questions and, if they see value in the information being provided, rely more heavily on the models themselves. In other words, the models in the planning process can be used either proactively or reactively. The success of such endeavors depends on more than just the quality of the models themselves, but also on the role technical information plays in the planning process. Both SACOG and SFCTA, for example, have established cultures where planners and modelers are continually pushing each other to understand what insights can be gained from their suite of technical tools.

VALUE OF A LONG-RANGE MODELING PLAN

Most champions of advanced models began with a formal long-range plan for what they wanted to accomplish. This plan was used to educate decision makers and staff, define staffing and outsourcing requirements, and secure funding. It also set out the criteria for success, which in turn allowed for benchmarking of the various work efforts included within it. In some cases the plan was fairly simple, consisting of a few pages of broad overview and a roadmap, and in other cases it contained detailed work statements and resource scheduling for each step. The degree of detail appeared to be dictated by the requirements of the individual agency.

The plan proved useful well beyond the initial justification and launch of the advanced modeling program. Many respondents used it repeatedly to remind agency executives where they were in the process and to demonstrate acceptable progress. Many believed that its value in retaining funding for advanced model development was more significant than for doing so initially, for it documented the dependencies of other programs on the current work. The plan was also used in the MPO certification process conducted by U.S.DOT, as well as for budgeting purposes within the agency and development of the Unified Planning Work Program. In some instances it was portrayed as a living document, with updates being made each year.

It is notable that to date all of the successful models have been guided by such plans. Most of the champions that employed them were emphatic about their value, both for organizing themselves and their staff and for selling the program. It was the most widely cited lesson learned, suggesting that its importance and value cannot be overstated.

IMPERATIVE OF THE CHAMPION

Each advanced modeling success story examined was found to have one or more champions who spearheaded the adoption of the models within the agency. Moreover, that champion typically received strong support from one or more mentors or key executives within the agencies in order to succeed. A few had to build the relationship, but most benefited from a long-standing existing relationship. There was a surprising commonality among the champions:

- The champions were motivated to expand their modeling capabilities by their perceptions of changing analytical requirements and the needs of decision makers. In most instances they reported that they believed that their existing models were not capable of answering the questions policymakers were likely to pose.
- They shared the conviction that their modeling work would become less relevant to the agency and its sponsors if they could not be informed about current issues and proposals.
- All started with an unwavering and clearly defined vision that required a year or longer to germinate before they could take the next steps.
- Almost all of the champions had to find the money to fund the move toward advanced modeling.
- They personally led the resulting work for several years after it was initiated, as the fledgling efforts often faced technical, funding, and institutional challenges that would have derailed them without the champion's protection.

In many instances the champion was not the technical leader of the advanced modeling effort, particularly in its initial development. In most instances the champion hired consultants to handle many of those details. Rather, they focused on how the advanced models would be used in practice. Many helped policymakers decide "the right questions to ask," and then translated those questions into model inputs and outputs.

In some instances the champion was the consultant, which usually produced a less satisfactory outcome than when the champion was internal. In these cases the consultant persuaded the agency that the move to advanced models would better serve their interests than the status quo or incremental improvements. The consultant fulfilled all of the roles outlined earlier, except that they were the beneficiaries rather than providers of the funding. What was lacking in these instances was the close relationship with executives higher up in the client agency, such that their work was defined by contract rather than a closely shared long-term vision for the agency. In some instances an internal champion emerged to carry on the work of consultant-driven investments; however, in many cases the respondents lacked the same zeal and vision that characterized the agencies with internal champions.

It is thought, but not yet apparent, that the need for the champion will diminish as advanced modeling practices become established. The role of the champion would then blend with that of the leader of modeling at the agency. However, the advanced modeling practices outlined in chapter two are all still evolving, which appears to reinforce the continued need for the champion for many years to come. Indeed, transforming the current generation of leaders in MPOs into such champions with the same vision, determination, and leadership skills is essential if these models are going to move into the mainstream of practice.

ADVANCED MODELING REQUIRES MORE THAN MODELERS

A great deal of emphasis was placed on finding, educating, equipping, and retaining the right people needed to succeed in advanced modeling. It was implied that there was a shortage of individuals entering the profession as well as of those already in it. However, almost all of the discussion focused on modelers without really defining who they are or how they are evolving. It is clear that modelers can be roughly divided into developers and users, with some working in both camps. However, in advanced modeling it is uncommon to find modelers with equal interest or aptitude for leading both activities. Neither the models reviewed nor interviews conducted brought fresh ideas to this important area.

It was clear to most respondents that model development and software development were two quite different but highly complementary activities. Almost all agencies interviewed noted their unfulfilled need for software engineers with skills comparable to those of the model developers. The need for software specialists was apparent whether the model development was being done in-house or by consultants. However, most agencies were unfamiliar with the software industry in general, including effective means for recruiting or career development needs and most productive practices for software engineering. Moreover, the need for software developers with skills relevant to high-performance scientific and engineering computing was viewed as being highly desirable, but even harder to locate. It is conceivable that many advanced modeling efforts will be compromised by the lack of software implementations as sophisticated as the models themselves, making it essential that as much thought and effort goes into incorporating software engineering specialists as for the modelers themselves.

The need for similar linkages with GIS specialists is readily apparent. However, most metropolitan planning agencies have already made substantial investments in GIS technology and staff. Excellent relationships between modelers and GIS specialists were reported in those agencies interviewed. By contrast, there were very few effective partnerships with information technology departments reported. In many instances information technology is viewed as an adversary rather than ally, a situation that can only hinder advanced modeling. Therefore, it is clear that establishing strong relationships that will lay the foundation for the use of appropriate hardware, operating system, and programming practices needed for success in advanced modeling is essential. Without that foundation it is unlikely that advanced models can achieve their potential.

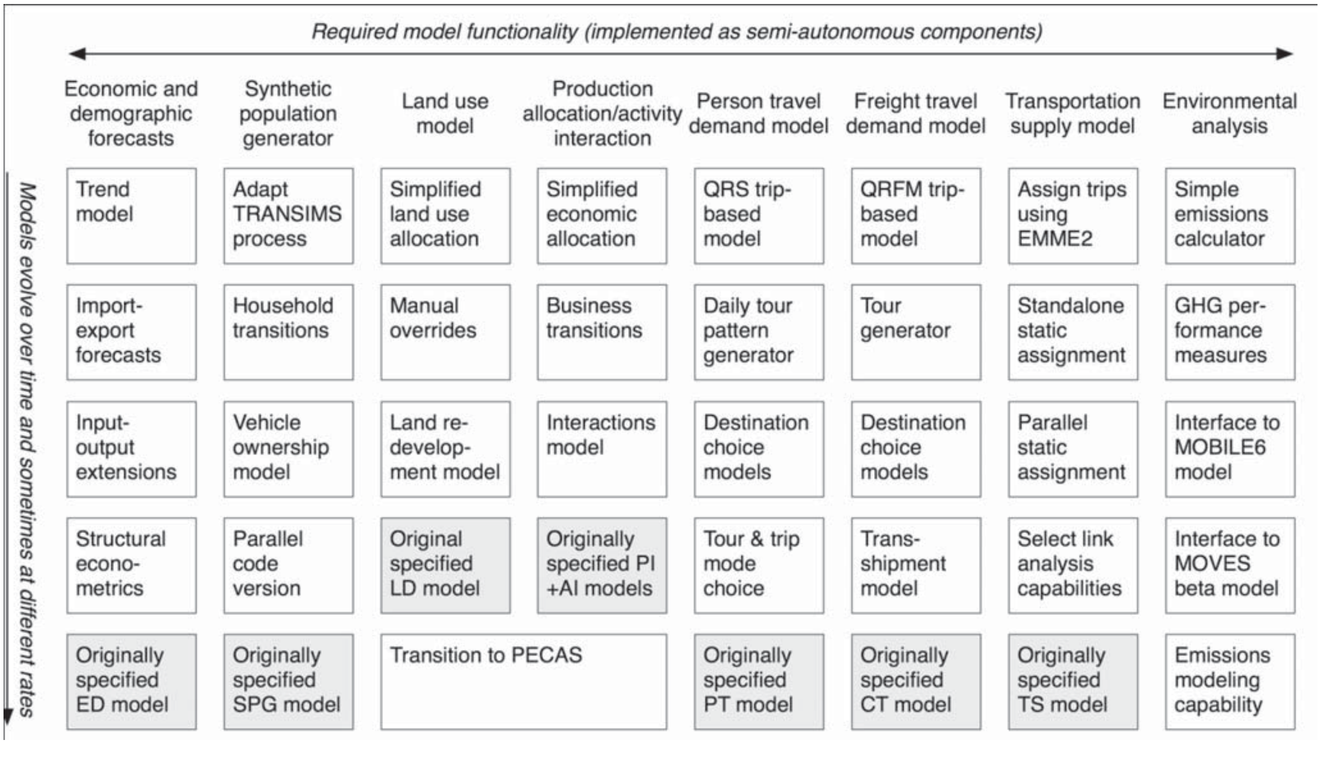
CONTRACTING AND PROJECT MANAGEMENT FOR SUCCESS

The approach used to contract and manage the implementation of advanced models significantly affects its prospects for success, both technical and financial. It was apparent from this study that large, multi-year development projects are usually riskier than spending the same money on a series of smaller, incremental steps. Some of the more recent efforts have benefited from adopting the latter approach, which is becoming more widely used in other fields of engineering, and especially in software development. Agile development (AD) evolved in response to the frustration surrounding the high rate of failure of large software projects.

The traditional approach—in both software engineering and advanced model development—had been multi-year monolithic development efforts where a scope of work drawn up at the outset became rigidly set in contract, and the remainder of the project revolved around implementing this "big design up front." Not surprisingly, this approach did not work well when the domain knowledge was not mature enough and technological change was not slow enough to permit accurate estimation of the time and resources required for model development. Moreover, the definition of success is often fuzzy in research and development efforts such as this, where lessons learned during the research often shaped the work program (or at least could have). Advanced models surely embody these characteristics.

AD seeks to overcome these barriers to successful delivery by emphasizing short, incremental development cycles. As with traditional approaches, sufficient time is devoted at the outset of the project to analyzing the problem and designing solutions. The best and most current ideas are still brought to bear on the problem. However, in a departure from most projects, the user interface and elements of the user documentation are written up front, to focus the team on what is essential and usable from the client's perspective. Understanding how the user expects to interact with the software or model becomes an important part of designing the solution. Equipped with such knowledge, the development team then proceeds to implement the solution in short (typically one week to one month), incremental development cycles. "The simplest thing that can possibly work" (Occam's Razor) becomes the first product, embodying little of the ultimately desired capabilities but having the advantage of placing interim software (and models in this case) in the users' hands.

Because software development is required to make advanced models operational (with the notable exception of the dynamic network models), many tenets of AD are directly applicable to these projects. The experience gained from the Oregon TLUMIP project illustrates the potential of AD. The overall process is shown in Figure 19. Listed across the top are the principal modeling capabilities originally specified for



Economic and demographic forecasts	Synthetic population generator	Land use model	Production allocation/activity interaction	Person travel demand model	Freight travel demand model	Transportation supply model	Environmental analysis
Trend model	Adapt TRANSIMS process	Simplified land use allocation	Simplified economic allocation	QRS trip-based model	QRFM trip-based model	Assign trips using EMME2	Simple emissions calculator
Import-export forecasts	Household transitions	Manual overrides	Business transitions	Daily tour pattern generator	Tour generator	Standalone static assignment	GHG performance measures
Input-output extensions	Vehicle ownership model	Land re-development model	Interactions model	Destination choice models	Destination choice models	Parallel static assignment	Interface to MOBILE6 model
Structural econometrics	Parallel code version	Original specified LD model	Originally specified PI +AI models	Tour & trip mode choice	Trans-shipment model	Select link analysis capabilities	Interface to MOVES beta model
Originally specified ED model	Originally specified SPG model	Transition to PECAS		Originally specified PT model	Originally specified CT model	Originally specified TS model	Emissions modeling capability

FIGURE 19 Example of the agile development process applied to advanced models (*Source:* Donnelly 2009).

the model. The first row shows the simplest implementation that would have worked, with progressively more sophisticated versions below it. Across the bottom are the ultimate desired capabilities. These are what would have been started from the outset using traditional approaches. Indeed, some of the components shown were attempted that way before shifting to an AD mindset. Adopting an AD approach allows each advance to be proven; if it does not lead to a significant increase in functionality it is not carried forward. Moreover, the development process can adapt as requirements change and experience is gained with interim products.

The successes using AD in Oregon, San Francisco, and for the ongoing statewide model development work in Maryland, as well as in other disciplines, suggest that it has great utility for advanced model development. Whether such an approach will prove necessary when more experience with such models is gained, or when established models are being transferred to new locations, remains unclear. It appears reasonable to assume that developers will have better success at estimating the cost, schedule, and potential pitfalls of mature products, making them better candidates for traditional contracting. However, for most development and implementation work without a clear track record of success it would appear that AD is a safer method of contracting. Cohn (2004) and Shore and Warden (2007) are recommended for readers wishing to acquire further insight. The principles of AD, known as the Agile Manifesto, can be found at http://www.agilemanifesto.org.

VALUE OF EDUCATION IS UNDERAPPRECIATED

The need for education in advanced modeling was often mentioned during the interviews. The importance of continuously educating staff members, agency executives, policymakers, and board members about modeling was emphasized several times. It was believed that if they understood the value and potential of modeling they would be more likely support it. Likewise, understanding what questions can be answered by a model would make them more likely to make informed use of it. Finally, it was believed that giving decision makers an understanding of modeling would make them more receptive to requests for funding and support. Much of this education must be carried out at the local level, such that this job becomes the responsibility of the champion. Modeling staff in agencies without a champion are at a disadvantage in this regard and therefore could take advantage of educational materials prepared for this purpose by federal or TRB experts in the field.

As already noted, the educational needs of modelers were brought up several times. These discussions ranged from needing to attract more graduate students into transportation and land use modeling, to improving the modeling skills of graduating planners and engineers, to the need for lifelong education for practicing modelers. These problems are chronic and long-standing, and have been cited many times in the past to no effect (Weiner and Ducca 1996; Ben-Akiva and Bonsall 2004; Donnelly 2008). Absent concerted federal leadership there appear to be few prospects for innovation or advances in this area.

DEBATE OVER OUTSOURCING VERSUS HOME GROWN REMAINS UNRESOLVED

Most agencies believed it was helpful to outsource some development tasks to universities or consultants. Because model development happens only rarely in most cases it is not an efficient use of limited build staff capacity for building advanced models, which requires skills in high demand. Moreover, even if staff with development skills are hired they typically lack the experience developers have gained implementing such models elsewhere. As one luminary in the field noted, “in learning the ropes they repeat most of the mistakes others have already learned from, only to finish with little opportunity to exploit that expensive education.” Without continued development work to keep them challenged, these recipients of heavy investment often look for work elsewhere.

The counter-argument is that outsourcing the development work leaves the MPO overly dependent on the developer. In some cases this might be an acceptable outcome; however, in most instances is it clearly seen as detrimental. There is widespread consensus that all agencies should have staff with enough knowledge of the structure and internal workings of the models to permit their creative and competent use and maintenance. Intimate knowledge of the model is necessary for users to adjust, debug, and extend the model, and to understand its key strengths and limitations. Such knowledge can rarely be imparted through a single or a few courses presented at the end of the model development effort. It cannot be assumed that several years’ worth of familiarity with the model can be distilled into a single week of training. Only a few cases were found where this tension had been adequately resolved:

- The original activity-based model development work in Portland succeeded to the extent it did because of the close working relationship between the champion and the developers. The team met frequently, and the champion made it a priority to be acquainted with the details of the on-going work. It was quickly acknowledged that this was possible only because the champion was shielded from day-to-day application issues by an equally qualified deputy.
- The Oregon DOT dedicated one of its most experienced and capable modelers, at considerable cost in terms of operational capacity, to familiarize himself through testing and applying the model on an almost full-time basis over an extended period of time. However, it was only through this level of investment that the agency was able to usefully apply the models without consultant assistance.

In both instances the investment required from agency staff was considerable, in addition to the cost of outside developers. MPOs seeking to develop and deploy such models are well advised to include allowances for such investment in internal capabilities in addition to expenditures on outside help.

It is argued that the adoption of AD practices will help overcome this tension. The rationale is that if outside but more experienced developers interact frequently with the ultimate users a more gradual and effective knowledge transfer will occur. Such a concept is facilitated by client participation in reviews of the outcomes and the ability to use the interim working products from each cycle (from weeks to months each). This provides the opportunity for the ultimate users to engage in the process far earlier than traditional contracting allows. Although this has proven true in the software industry, its applicability to advanced modeling is only now becoming evident. MPOs face some obstacles that other AD adherents do not, in particular that developers are often located in distant cities, making their availability for frequent meetings questionable.

One obvious solution is to use consultants or academics in a purely advisory and quality oversight role. In such an arrangement they would provide formal training and coaching to agency staff responsible for doing the actual work involved. This would be practical only when the academic or consultant is located nearby, as a high amount of interaction would be required at the outset. No example of this contracting model was found, although the city of Calgary and the University of Calgary have used such arrangements effectively for smaller projects.

CHAPTER SIX

CASE STUDIES

PORTLAND

Portland, Oregon, has a long history of innovation in land use and transportation planning, and has consistently been a leader in the development of advanced models. Portland Metro is the MPO for the region, which had an estimated population of 2.2 million in 2008. In the 1990s, the well-known Land Use, Transportation, and Air Quality Connection (LUTRAQ) program provided the impetus for improved modeling in the region. Still working in a trip-based travel modeling paradigm, Metro developed models based on their 1985 household survey that incorporated land use effects and focused heavily on improving the treatment of non-auto travel. Parallel work on MetroScope, a land use and economic model, began during this time as well. It was expected from the outset that MetroScope and the travel model would eventually converge into a single model, a goal that has not been completely achieved, but in which considerable progress has been made. To date, Metro considers bringing land use explicitly into the regional travel modeling as its greatest contribution. Unique features such as legislated urban growth boundaries and transportation planning rules have also influenced the modeling agenda. These and other sustainability issues have resulted in heightened interest in advanced models.

Metro's next steps in advanced modeling began in late 1993, when an expert panel recommended an investment in activity-based models. Metro embraced this view and began working to collect the necessary travel behavior data. This led to its 1994–1995 household travel survey program, which was expanded statewide in the following two years. These data were used for both updating the trip-based models and development of the activity-based model. In 1996, a perfect opportunity emerged to further the activity-based model development, in the form of an FHWA-funded demonstration project for road pricing. Only small changes to the survey were required to use it for estimating both trip-based and activity-based models. A stated preference survey was conducted in conjunction with it to obtain information about likely traveler responses to pricing.

Keith Lawton, then manager of modeling at Metro, brought in a team consisting of Greig Harvey, Moshe Ben-Akiva, Cambridge Systematics (including John Bowman), and Mark Bradley to build the model. The model was based on Bowman's Master's thesis. A prototype of the model was used to evaluate a variable pricing scenario on OR 217 between I-5 in Wilsonville and US-26 in Portland. Preliminary reports were prepared in 1996–1997, and it was intended to adopt the STEP platform (Bowman et al. 1999) as the foundation for further model development. Unfortunately, Greig Harvey's untimely passing in 1997 slowed progress on this front. The remaining team members built the model into what has since become known as the Bowman–Bradley model.

The resulting model was tested and used; however, difficulties arose with its joint model of destination and mode choice. The resulting elasticities looked excellent; however, the model suffered from a lack of base year calibration. It was slow (computationally heavy) and suffered from edge effects, which further slowed progress in model calibration. Despite these setbacks the team made remarkable progress. Unfortunately, the original funding was exhausted before calibration of the model could be completed, which compounded the conceptual difficulties surrounding the calibration of the joint model. It was decided to use Metro's four-step sequential travel model to constrain the model, and to pivot the joint model off of its results. This approach yielded reasonable time-of-day changes in the model, lending confidence to its results. The joint model was converted into sequential destination and mode choice models to ease the calibration; however, recalibration was not completed before funding ran out.

In 1999, Metro successfully applied to become an early deployment test site for TRANSIMS. Adequate funding and agency support was available for this effort, which allowed Metro to pursue its longstanding interest in network microsimulation and DTA. It also allowed them to catch up on the supply side to where they had already reached on the demand side. In 2000, the testing focused initially on the router and microsimulation of traffic. A substantial amount of time and effort was devoted to testing the network, which expanded the knowledge about its performance in typical applications and helped guide the development of transit modeling capabilities. Its work confirmed that a highly detailed roadway performs no better than more abstract networks typically used with regional models, which makes the approach more tractable for most agencies. Work on the activity-based modeling component was carried out in 2003–2004, which made significant strides in destination choice and integration of the demand and supply sides of the model. This first phase of the project was considered a success; however, in 2004, reductions in TRANSIMS funding and unexpected heavy staff demands to support New Starts and Summit analyses for transit proposals forced Metro to curtail work on the second phase (activity-based model development) before the microsimulation of mode choice was undertaken. Although officially dormant, further work on the project has not been undertaken in the past few years.

Metro is continuing its evolution of activity-based travel models based on its collective experiences to date. An adaptation of a Markov decision process formulation developed by Gliebe (2010) is underway. Known as DASH (for Dynamic Activity Simulator for Households), the model is expected to become operational within the next two years. The model is unique in that it assigns roles to individuals, and considers the interdependence of travel decisions among household members. As with many current formulations it treats time as a continuous variable rather than as periods of the day.

Equally impressive progress has been made in parallel with MetroScope (Conder and Lawton 2002). Its roots date back to the LUTRAQ work, which served as the impetus for Metro to develop the model. It has been extensively used in planning and policy analyses over the past decade, and is a successful example of a locally developed model similar to the aggregate land use modeling approach developed by Alex Anas in New York City around the same time. The model started in spreadsheet form and has improved over time through linkages to the regional travel model and GIS. The current version is written in the R statistical language. It is now an integrated modeling application, and extensions are being added to calculate greenhouse gas emissions. More recently, the model has been ported to Salem, Oregon, which has demonstrated its portability.

SAN FRANCISCO

The SFCTA is in an unusual position as a developer of advanced models in that it is not an MPO organization or state DOT, but a county transportation authority and congestion management agency. The Authority was created in 1989 to administer a local half-cent transportation sales tax.

The Metropolitan Planning Commission (MTC), the metropolitan planning agency serving the nine-county San Francisco Bay Area, has a long history of developing and applying transportation models. MTC's existing model (BAYCAST-90) is a fairly standard trip-based model that served SFCTA's needs throughout the 1990s. When the SFCTA began planning for the Doyle Drive seismic retrofit/replacement, it became clear that the MTC model in place at the time was limited in its ability to evaluate the types of alternatives in consideration for the project. Specifically, there was a strong interest in understanding the travel patterns and congestion effects by time-of-day, and the MTC model at the time was only a peak period/24-h model, and did not assign trips by time-of-day. Further, there was an interest in analyzing the results at a higher level of geographic detail than could be done with the zone system used in the MTC model.

Given the desire for greater temporal and spatial resolution, SFCTA chose to develop its own model and hired a consultant to do so. During the consultant selection process, one team proposed developing an activity-based model to gain all of the expected benefits of advanced models, specifically an enhanced ability to model time-of-day choices. SFCTA started down this path at a time when no activity-based models were being used in practice in the United States. The decision to push the envelope with a more advanced tool, rather than simply perform a subarea analysis with a trip-based model, can be attributed largely to the executive director of the agency, Jose Louis Moscovich, who pushed, and continues to push, to develop the best analytical tools possible.

Having decided to become a pioneer in the modeling world, several factors combined to make the project successful. The first was the presence of an active and able champion within the agency. Joe Castiglione served as the client project manager of the model development project. Although that role was important, the more significant effort was in his shepherding the model through its first few years of successful application. He was able to both learn the details of the model and its implementation and serve as a spokesperson and advocate for advanced modeling within the agency. Having someone successfully play that role permitted the model to be integrated into the institutional flow of the agency, allowing the planners and managers at the agency to understand the benefits of using the advanced techniques and take advantage of it by asking more sophisticated questions. Further, as a champion in that role, he was able to help the end users understand the limitations of the model and know when to invest in further refinements. Joe left the agency several years ago, but was replaced by Billy Charlton, an equally committed and qualified champion.

A second major factor contributing to the success of the project was an intelligent phasing of the work. The approach was to first implement a basic activity-based model for just San Francisco County. Later, the activity-based model was extended to all nine Bay Area counties. As a third phase, functionality was added to better capture the response to pricing and further enhance the time-of-day models.

The original implementation was a multi-tiered approach where there was a high level of geographic detail within San Francisco county and larger zones lining up with MTC's zone system in the other eight Bay Area counties. San Francisco residents were modeled using the newly developed activity-based model. Those resident trips within the county were combined with nonresident trips and inter-county trips from the MTC model before assignment. Keeping the original implementation limited in geographic scope saved significant effort in model calibration and validation, because the effort did not need to be concerned about the full scale of heterogeneity in the region and complexities of inter-county travel including the bridges, tolls, ferry system, and long-distance commutes. Further, the initial implementation considered only a limited number of tour purposes, and did not consider such complexities as intra-household interactions, keeping the process as simple and manageable as possible.

This approach of keeping the initial model simple was successful, as the model was developed, implemented, and calibrated within a timeframe of about two years. The initial development cost approximately $700,000 in consultant fees. The model was completed in 2001, making it the first activity-based model to be used in practice in the United States.

A key aspect to making the project phasing successful, however, is that it resulted in a working product. Because of this, the model could be applied for the Doyle Drive study, and the study could gain the benefits of the model's enhanced time-of-day abilities. This Doyle Drive application is actually a third factor contributing to the long-term success of the model—by achieving an early victory with a model application project, the technical staff was able to build credibility with the management and planning staff at the agency. In turn, this added credibility allowed them the resources to further enhance the model in subsequent phases of work. The SFCTA staff noted that an important corollary lesson here is to make sure that you are spending resources to answer the planners' questions.

Since 2001, the one-county model has been successfully applied to numerous transportation planning studies. Some examples include:

- Congestion Management Program
- Countywide Transportation Plan
- Yerba Buena Island Ramps Improvement Project
- 19th Avenue Transportation Plan
- Central Freeway Replacement/Octavia Boulevard
- Geary Corridor Bus Rapid Transit
- Van Ness Avenue Bus Rapid Transit
- Market Street Study
- Mission–Geneva Neighborhood Transportation Plan
- Mission South of Chavez Neighborhood Transportation Plan
- Tenderloin/Little Saigon Neighborhood Transportation Plan
- Columbus Avenue Neighborhood Transportation Plan
- Bi-County Study Update
- Caltrain Oakdale Ridership Study
- Transbay Terminal Development
- Caltrain Electrification
- Transit Effectiveness Project
- Third Street Light Rail
- Central Subway New Starts Analysis.

Throughout this broad range of applications, the modeling staff noted that the results consistently appeared reasonable. After careers working with four-step models, they have come to expect unusual results from the model at unexpected times, and were pleasantly surprised by how good the activity-based model results appear. With believable model results, staff noted that the results are easy to explain to planners and at public meetings, and the planning staff has become familiar with these responses and come to place more faith in the model results.

Staff further noted that the level of detail is impressive, and that for them time-of-day is important. They are not being asked what the volumes are on new freeways, but are instead being asked about pricing, traffic calming, bus rapid transit, and other non-brick-and-mortar projects, for which the model is ideally suited.

In 2007, SFCTA received a grant from the FHWA to study congestion pricing within the city. The focus of the resulting MAPS was on evaluating the feasibility of charging vehicles a fee to drive in specific portions of the city when conditions are congested. The fees would seek to either dissuade some motorists from driving or instead entice them to drive in the less congested off-peak periods. Either way, peak period congestion would lessen, improving travel times for the remaining motorists and for the buses remaining on those routes. Furthermore, revenue could be generated for investment in improved transit service.

Given these planning needs, it was clear that to model these congestion pricing alternatives well the model needed to do three things:

1. Appropriately capture travelers' responses to pricing,
2. Reasonably model travelers' willingness to shift times-of-day in response to pricing or in response to congestion, and
3. Treat San Francisco residents and nonresidents in a consistent manner given that a large number of nonresidents would be priced.

Although the San Francisco activity-based model provided a good framework to model congestion pricing, several enhancements were needed to do it well. To appropriately capture a traveler's sensitivity to price, stated preference surveys were conducted to observe the sensitivity, and the models were enhanced to use individual values of time within the synthetic population, rather than values specific to aggregate income groups. To capture the time-of-day shifts and peak spreading, the existing time-of-day models were enhanced to include the round-trip mode choice logsum for each time-of-day alternative as a descriptive variable. The mode choice logsum is a composite measure of impedance that weights both the travel time and the cost in a manner consistent with the traveler's value of time. To treat residents and nonresidents in a consistent manner, the activity-based model was expanded to cover all nine Bay Area counties.

The enhancements for the congestion pricing study constituted phase 2 (extend to nine counties) and phase 3 (add functionality) of model development work. Again, the phasing was designed such that each phase resulted in a working product that could be used for planning purposes, such that as the planning study progressed with the initial model results, the modelers were working on the next phase of modeling. These two phases of model development together took about 1.5 years, and cost approximately $250,000. This phasing approach again proved successful and served the needs of the study.

This was a final, important lesson learned from the SFCTA modeling work—that the activity-based model framework is adaptable enough that it can be enhanced to model very complicated and specific policies. All of the policies may not have been anticipated at the initial phase of model development; however, the framework is inherently more flexible than an aggregate trip-based model. It is therefore suitable for modeling things such as congestion pricing and time-of-day shifting that would be very difficult to model in a traditional framework.

Since that initial development, the SFCTA has continued to invest in its model. Over a five-year timeframe, it has spent approximately $300,000 in on-call consulting fees and model application assistance. Although the additional costs were not required, the SFCTA saw the value in further refinement and improvements. In addition, the SFCTA has generally maintained two staff positions that have been responsible for all model development work and all model applications.

SACRAMENTO

Early in this decade, SACOG embarked on an ambitious regional planning effort, which culminated in 2004 with the SACOG Board of Directors adopting the Sacramento Area Blueprint. The Blueprint promotes compact mixed-use development and more transit choices as an alternative to low-density development.

As part of the Blueprint planning process, SACOG took advantage of a number of tools to assist decision makers and stakeholders in understanding the implications of the alternatives under consideration. I-PLACE3S was used as a sketch-planning tool to assist the decision makers in assembling land use scenarios. Those land use scenarios were fed into the existing trip-based travel demand model to evaluate the transportation effects of such scenarios, and those results were fed into emissions models to understand the air quality effects. Other tools such as three-dimensional visual simulations were used to assist in visualizing different levels of density.

The Blueprint process was successfully completed using a relatively simple set of analytic tools. It was however a set of tools that was appropriate to the process and available within a timeframe that could allow the planning process to progress on schedule. An important secondary effect of the Blueprint process was that it further established a culture where decision makers and planners need to provide relevant and insightful information, while still acknowledging the limitations of the existing analytical tools. This process helped to establish a relationship of trust with the technical staff, and assisted in integrating the role of technical information into the planning process.

There is a key lesson to be learned here: because technical staff was focused on serving the planning needs of the agency to the best of its abilities, the process was successful. Rather than conceding or putting the planning process on hold while they developed a model that could, they sought to make the best of the situation, while acknowledging the limitations of their existing tools. By doing so, they both served the planning process and enhanced their own credibility.

Following the completion of Blueprint, SACOG technical staff sought ways to further improve the available tools to better serve the planning process the next time. The model improvements focused on two areas: building an activity-based travel model (SACSIM), and building a land use model. The land use model is still in development; therefore, the remainder of this case study focuses on the activity-based travel model, which is currently being used successfully.

Gordon Garry and Bruce Griesenbeck emerged as champions of the new model. They found a high level of support from management and planning in doing so, largely because the goals of the project were to better serve the planning process of the agency, and the decision makers had come to understand the value of good information. Although the support of management is important, it is also crucial to have onboard a technical champion who can communicate to management the value of the product and take full advantage of the model's abilities in application.

The primary motives for moving to an activity-based travel model were to improve the ability of the model to inform congestion pricing policies, and to improve the ability of the model to inform the planning process for Senate Bill 375 (SB 375) and Assembly Bill 32 (AB 32), the California greenhouse gas reduction bills.

The latest version of the regional transportation plan includes the option of congestion pricing as a mitigation measure. As staff began to consider modeling this issue, it found in Bain and Plantagie (2004) and Bain and Polakovic (2005) that traditional models have done a poor job of pricing analysis for toll roads, even with so-called investment grade forecasts. They explored the possibility of an activity-based model and found that it offered the potential to do a better job of analyzing pricing by modeling individual traveler decisions, and potentially distributed values-of-time and disaggregate costs. Further, it offers the possibility of obtaining a consistent response to price across all components of the model system, including mode choice, destination choice, time-of-day choice, and tour generation.

A second major factor influencing the decision was the presence of SB 375, which is a common concern for all the major California MPOs. SB 375 requires MPOs to consider ways to to achieve greenhouse gas reductions. Therefore, it is important to understand how the built environment affects travel decisions, and how the location of households and jobs affects

VMT and emissions. Activity-based models offer an improved ability to do this analysis by eliminating NHB trips. Without NHB trips, the location choices of destinations can be better understood, and all travel can be traced back to individual households, allowing for an analysis of which households generate how many VMT. Also, SACSIM was specifically designed to understand the effects of urban form on travel, which it does by allocating households and jobs to the parcel level, and modeling parcel-to-parcel travel, while aggregating to zones for assignment. This higher level of geographic resolution allows the model to capture smaller-scale land use differences.

SACOG completed the development of the activity-based model in 2007. It hired consultants to design and estimate the models, as well as develop software to implement the model. SACOG staff took on much of the model calibration and validation work, running the model and tabulating results while continuing to engage the consultant team in resolving issues that arose during that process. Staff found this approach to be a mixed blessing. It noted that it was an excellent way to learn the behavior of the model system and be a part of the development process, while at the same time acknowledging that it was a challenge to be engaged in model development while still keeping up with day-to-day responsibilities. Bruce noted that, “I’ve never worked as much overtime in my life as when we were calibrating those models.” In the end, they are pleased with the division of labor, because it puts them in a position to take advantage of the full power of the model system.

SACSIM was also staged in a way to get a fully operational model up and running in a reasonable amount of time by implementing a model structure that had been used before, and is similar to that used by the SFCTA. The area in which SACOG pushed for new methods was in modeling travel at the parcel level, which was deemed important to understanding the travel implications of different land use scenarios. SACOG chose not to push for advanced pricing methods in the initial version, although they are interested in doing so as a next step. Also, SACOG chose to develop a land use model as a separate project, rather than have the first version closely tied to the activity-based model, and did not implement DTA in the first version, even though they have an interest in doing so. By separating out these other challenging components, SACOG was able to get the activity-based model up and running in a period of about two years. This is another example of intelligent phasing of a model project, where the phase constitutes a large chunk of work, but not everything imaginable or desirable in a model system.

By getting the model up and running in this timeframe, it was available for use in the Placer Vineyards project for an early application. This project involved the review of a large proposed green field development that would incorporate smart-growth concepts into the design. The project was proposed as containing 21,000 new households and 8,000 employees. Owing to concerns about the traffic that would be generated by such a large development, a less dense version was also under consideration that would instead contain 14,000 households and 5,000 jobs.

Because all trips could be traced back to the households in the Pacer Vineyards development, the model could be used to track the amount of VMT generated by those specific households. The analysts considered that if this development were to be built less dense, the remaining 7,000 households and 3,000 jobs would go elsewhere in the region. To model this, 7,000 households were created with the same demographic and socioeconomic characteristics as those that would be located in Placer Vineyards. Those households were instead distributed throughout the region. The same was done with jobs. It was important to control for the demographic and socioeconomic characteristics of the households because if they were instead treated with the characteristics of the zones in which they were moved to, differences in income levels or household size could confuse the differences owing to geography. The model showed that the denser development produced fewer VMT than if the households were located elsewhere, and helped the project gain traction.

It is interesting that this application helped the activity-based model gain favor among one stakeholder group in particular—developers who are trying to show the benefit of infill projects. Although infill developments usually are beneficial from a standpoint of reducing automobile travel and greenhouse gasses, infill projects have neighbors, and thus often run into more community resistance than low-density suburban developments. Having a tool that can clearly quantify those benefits can help ease the political friction encountered by infill development and help the region as a whole achieve a more sustainable future.

A key lesson here for future implementers of advanced models is the value of finding an early success in model application to help build the credibility of the tool. It also reinforces the value of having one or more champions on the staff who can do a thoughtful job of applying the model to a complicated policy scenario, rather than just adding lanes to the highway network and pushing the “run” button.

SACOG continues to maintain its old trip-based model for certain applications, but hopes to move away from it in the future. The trip-based model has been used successfully for New Starts analysis, and SACOG wants to maintain that option until the new model makes it successfully through a New Starts submittal process. Doing so is not expected to be a problem, and will involve adapting the procedures developed by SFCTA and the Mid-Ohio Regional Planning Commission (MORPC) to calculate user benefits for input to SUMMIT. Also, the trip-based model is currently used for air-quality conformity analysis. The emissions budgets were developed using that model; therefore, calculating emissions with the new model would lead to a result that is somewhat inconsistent with the budgets. When the emissions budgets can be updated to be consistent with the new model, the old model will be retired from use. SACOG staff view this approach as a logical way to manage risk with special applications of the new model. They recognize, however, that the new model is capable of handling these tasks, and superior in other ways, and therefore seek to move all applications to the activity-based model in the future.

LAKE TAHOE

Activity-based models have generally been recognized as the most promising direction in the advancement of travel modeling practice. However, at present, almost all activity-based models developed and applied in practice have been associated with large urbanized metropolitan areas with populations of 1 million or more (San Francisco, New York, Columbus, Atlanta, Denver, etc.). The model development process for these regions required significant time, budget, and data collection efforts. There is ongoing discussion about the applicability and transferability of activity-based model structures to smaller and less urbanized areas. Such areas actually constitute the majority of the planning organizations in the United States. For the Lake Tahoe region, it was shown that it is possible to successfully transfer and apply an activity-based resident model originally developed for the MORPC in Columbus Ohio.

The Lake Tahoe Region is located on the California–Nevada border between the Sierra Nevada Crest and the Carson Range. Development and urbanization of the basin occurred during and following the 1960 Squaw Valley Winter Olympics. According to the 2000 U.S. Census, the total year-round resident population in the Lake Tahoe Region was 63,448. More recently however it has been estimated that the year-round population has decreased to approximately 54,793, culminating from increasing home values and increases in second homeownership.

Although the model was being transferred from a large metropolitan area to a comparatively small, non-urban area, the hypothesis was that the travel behavior of the region was similar enough that the explanatory variables and coefficients would capture the overall behavior. This was found to be true for most of the model components and therefore the transferability of those components, such as tour generation, destination choice, time-of-day choice, etc., was straightforward. Only minor parameter adjustments (i.e., distance coefficients and alternative specific constants) were made owing to regional characteristics and available data. Some of the other unique factors affecting travel in the region such as seasonal residents, the relatively large worker flows into and out of the region, and the seasonal variation of travel were not addressed and had to be added.

The advantages to transferring a model are many. First, because the models were based on the MORPC structure time was not spent analyzing the household survey data and figuring out the model structure. Second, setting up estimation file sets and doing the estimation, which is a significant part of the model budget, was eliminated. Finally, the limited funds could be spent on other important tasks such as the user interface, the visitor model, and scenario development.

The successful development and application of the prototype model structure developed for MORPC in the Lake Tahoe Region leads to the important conclusion that an activity-based modeling approach can be extended to smaller and less urbanized regions.

CHAPTER SEVEN

CONCLUSION

This report was designed to assess the benefits and challenges associated with moving beyond the traditional four-step travel demand modeling practice. A great deal of innovation in transportation and land use modeling has occurred over the past two decades, both in volume and its departure from their traditional roots. However, a great number of the advances and lessons learned from them are readily accessible only to the relatively few who have been actively engaged in their pursuit. Therefore, the goal of this report was to condense this new knowledge into a form accessible to a much larger audience.

Several major themes emerged during the review and study supporting this report. Perhaps the most fundamental issue surrounds the rationale for such models, where the motivating factors fall into two categories: those seeking more accuracy, and those seeking more sensitivity. This, in turn, appears to be influenced by the institutional settings of the modeler and their clients. Those who primarily use models to support the expansion of the existing transportation system appear focused on the need for more accurate models.

To date there is no evidence that the advanced approaches described herein are inherently more accurate or more capable of replicating observed traffic flows than their predecessors. Nor could examples of more accurate forecasts be identified. These modelers are likely to be disappointed by the gains in accuracy—or perceived lack thereof—obtained from advanced models.

However, to the pioneers of these new approaches that largely misses the point. These models are compelling because of the questions that can be posed to them and the resolution and fidelity at which they can be approached. The enhanced framework of advanced models allows for the model system to be sensitive to policy changes in a consistent way across more dimensions. For example, when the time or cost of travel changes, an activity-based model can capture changes in route, mode, time-of-day, destination, party composition, frequency of travel, or auto ownership. A traditional model would only consider changes to route, mode, or destination, often with route and destination choice sensitive only to highway travel time and not to changes in cost or transit time. Such responses are important in certain applications, especially when issues such as induced demand, equity, or the response to changes in accessibility are considered.

Many of these requirements and issues were never faced or anticipated by the creators of the four-step modeling paradigm. Such is hardly a criticism, as their work provided the tools that helped usher in an unprecedented era of construction of transportation infrastructure and systems. In places where construction of new major facilities continues today such tools unquestionably retain their utility. However, in many other places, the idea that we can “build our way out of congestion,” or that congestion is necessarily a failure that must be alleviated, no longer describes the priorities of federal, state, or metropolitan transportation agencies. Many agencies we interviewed or interact with are grappling with issues such as equity, growth management, environmental quality, or the need to study scenarios such as fuel scarcity. To the extent that their focus has changed it hardly appears surprising that travel demand modeling must change in equally significant ways.

Given the wide range of expectations and needs it is difficult to define success for these models. Two studies are currently underway that are closely examining the differences between trip- and tour-based models; however, neither are far enough along to report even preliminary results. Although the same criteria used to judge trip-based models are likely to apply to tour-based models the comparison is short-sighted, for the latter can provide measures and benefits simply unattainable with the former. Although standards for calibration and validation are still being defined, it can be argued that success could be measured in terms of client (decision-maker) satisfaction, ability of the model to appropriately respond to specific policy and investment scenarios, transparency, and tractability (in terms of run times, data requirements, and other resources). It is not possible at this time to point to a large body of literature that can substantiate such benefits of advanced models. In the absence of such, an attempt has been made to report anecdotal evidence provided by the users of such models.

With this broad context in mind we can return to the specific issues addressed in this report. In chapter two, the report describes the current state of the practice in advanced land use and transportation models. The coverage is not comprehensive by any means, but rather focused on operational models used in practice in North America. Several successful examples of advanced models are provided, suggesting that ample evidence of their efficacy exists and that tangible benefits have emerged from their implementation. The benefits of these models, as reported by their developers and users, are summarized in chapter three. Many of the topics covered in chapters two and three have already been reported in the literature and discussed at recent conferences, but are summarized here for completeness.

What has long been sought is an examination of the institutional issues surrounding the adoption of such models and the key lessons learned along the way. Chapters four and five are devoted to these topics and considered the key contributions of this report. Summarizing the most important aspects of what has been learned is challenging, because the significance attributed to them varied by agency and many are interrelated. However, several issues appear to define the challenges faced by the pioneers, and there is ample reason to believe that others will face them as well.

There was widespread agreement that human assets are the key factor limiting the adoption of advanced models. In almost all instances—and most certainly in the most successful ones—a visionary champion was clearly identified as the sustaining force behind the adoption of advanced models. It was widely believed that this champion, with the support of upper management in the agency, was the single most important ingredient for success. Although a consultant can play this role the results to date have been less satisfactory. Absent strong federal leadership in this area it is likely that the importance of the champion—from both management and technical standpoints—will remain high in the move toward advanced models.

An equally significant human constraint is the lack of agency staff capable of creatively and competently building and using advanced models. Most agencies do not have developers on staff, because they are difficult to find and afford. Moreover, unless the agency is continually developing new models they often seek out new challenges elsewhere once development gives way to application. As a consequence, there is a heavy reliance on a small number of consultants with the skills necessary to develop such models. The obvious potential for over-subscription aside, it was found from our interviews that many believed that the rest of the profession is falling progressively further behind the developers. That is, the knowledge and experience of the pioneers is perceived to be increasing more rapidly than their colleagues not involved in such pursuits. It is apparent that reading papers and attending conferences and short seminars cannot impart the necessary skills, yet absent studying under the few academics active in this area there appear to be no available resources for training new practitioners and, more importantly, retraining the current workforce. Moreover, there appeared to be agreement that widespread successes with innovative models cannot be achieved until this limitation is overcome.

There appeared to be a widespread perception that advanced models are far more data-intensive than traditional models. This might be true for land use and freight models if they replace sketch planning methods, models dependent on obsolete data, or no models at all. An agency using a land use model in conjunction with a travel demand model will have larger data requirements than one that does not. Current land use modeling practice is characterized by complex models with large data requirements. However, where this complexity is not required the data requirements are much more moderate. Dynamic network models are also likely to have larger data requirements. More detailed network representations and explicit representation of traffic signals and control schemes, not required by traditional static traffic assignment models, are required. Adopters of all such models will unquestionably bear the burden of expanding both their data collection and modeling efforts.

Ironically, the same is not necessarily true for tour- or activity-based travel demand models, against which such objections are more commonly lodged. Small changes to the structure of traditional household travel surveys are required, but otherwise they require substantially the same data as sequential trip-based models. To date, larger surveys have been specified for some of the models developed; however, their size has been driven by the desire for greater resolution and fidelity in the models. Equally larger surveys would have been required had the same increased level of detail been sought for traditional models. Otherwise, the data required are very similar for both modeling approaches. The microsimulated households—which do result in much richer detail within the model—are synthetically generated from easily tabulated marginal summaries rather than highly detailed exogenous data. Thus, the evidence gained by the experience with such models to date cannot support the perception that they have substantially more onerous data requirements simply because they are activity-based models, but rather because of the improved sensitivity of the model and greater levels of detail.

All of this is not to say that the costs of adopting advanced models are small. They are not. Although efforts to collect hard data on the costs of projects to date has proven difficult (and even harder to draw conclusions from), it can be observed that the implementation of advanced models has taken several years, required outside assistance, and would not have succeeded without a highly committed and empowered internal champion. In many instances the development of these models had to be preceded by data collection efforts, and their continued evolution depends on their continuation. Whether such an investment can be justified or sustained depends on the issues the agency is facing or expects to tackle within the next decade. For the pioneers the opportunity cost (of not moving forward) was too large a price to pay. For them the decision is easy, as the investment represented the cost of remaining relevant to decision makers facing much different issues than those that traditional models are ideally suited to address. These pioneers have borne the higher initial development costs. Subsequent adopters will benefit greatly from the knowledge, software, and successes they have put in place.

It might be argued that the cases for some of the advanced models described in this report are less compelling than for tour-based travel modeling, and even more dictated by local needs and capabilities. There are not as many success stories to learn from, although this situation will be remedied over the next five years. In the case of freight models, the consultant and internal costs appear to be less than for activity-based person-travel models, but that depends on the level of detail and sophistication sought. The evidence that such models perform better than more traditional urban truck models is mixed. Moreover, it is clear that the evolution of such models will entail significant data collection efforts. There are too few successes in land use modeling at the urban or statewide scale to generalize about what is required to deploy them and, as of this writing, there are only a few prototypes of dynamic network models at a city-wide or regional scale. The few that have been attempted have devoted a substantial amount of resources to testing, debugging, and developing the underlying software, making them unreliable indicators of the likely costs faced by future implementers. As with the advanced travel models, the pioneers have absorbed the initial research and development costs. The effort and resources required to implement these models will be significantly reduced for later adopters.

Finally, it can be noted that any foray into advanced modeling is as much a change in mindset as methodology. The four-step sequential modeling paradigm, and to some extent the modeling of land use with DRAM-EMPAL, are mature practices whose evolution has virtually ceased. Equally mature software is available for them, and the challenges in maintaining existing models are small. The opposite is true for advanced models, which in all cases are still evolving in both theoretical and methodological terms, and their software implementation is far from standard. These issues will be overcome in time, and the evidence to date indicates that they are not insurmountable obstacles. However, advanced models and their implementations are likely to continue to evolve in significant ways over the next decade as they adapt to the need to respond to challenges such as carbon footprinting and pricing, continued uncertainty about fuel futures, technological changes, and even greater needs to assess the micro-economic impacts and benefits of transportation projects. If that were not enough, some of the luminaries in the field of modeling are also questioning the very foundation of the practice. Wegener in particular advocates a return from models defined by statistical data mining to more theoretical structures capable of supporting explicit risk and uncertainty analyses in forecasts. Given the changing political and economic landscape the need for expansive thinking on such fundamental levels is imperative. This, in turn, will continue to drive the evolution of advanced models used by academics and practitioners. As such, advanced modeling is better thought of as a journey than a destination. The tools, methods, and practices described in this report mark the starting point of such a journey.

ABBREVIATIONS

AD	Agile development
DTA	Dynamic traffic assignment
HBW	Home-based work
ISTEA	Intermodal Surface Transportation Efficiency Act
MPO	Metropolitan planning organization
NHB	Non-home-based
NHTS	National Household Travel Survey
PUMS	Public Use Microdata Sample
SME	Synthetic matrix estimation
TAZ	Traffic analysis zone

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APPENDIX A

INTERVIEW PREPARATION GUIDE

NCHRP Synthesis 20-05/Topic 40-06
Advanced Practices in Travel Forecasting

Interview Preparation Guide

Parsons Brinckerhoff is developing a synthesis of advanced practices in travel forecasting under contract with the National Academy of Sciences. The synthesis report will cover a number of topics not easily found in the literature but highly relevant to the contemporary practice of travel forecasting, to include a description of current and emerging advanced models, their demonstrated benefits, implementation issues, and lessons learned. Several brief case studies will be included to illustrate how agencies are overcoming these and other obstacles to advancing the state of practice. We are contacting most of the agencies known to be active in this area to collect information about these topics. This research project will build upon the work—including surveys—already completed as part of *Special Report 288*: *Metropolitan Travel Forecasting: Current Practice and Future Direction*. This survey will build upon information already provided, and will focus primarily on the topics listed above.

We are interested in learning about your experience with advanced modeling practices, which we broadly define as those beyond the traditional four-step sequential modeling paradigm. These generally include tour-and activity-based travel models, as well as mesoscopic (to include dynamic traffic assignment) and microscopic traffic flow models used in conjunction with regional travel demand models. We are also interested in other advanced models, to include land use-transportation models, freight models, and linkages to statewide or multi-state economic, trade, or transportation models. There is as much innovation in these areas as in travel demand modeling, and in general we are interested in advances beyond those that are considered mainstream and accepted practice over the past two decades.

Your participation in this survey is sought to gain your insight, experience, and expectations about these current issues and models. This questionnaire summarizes the issues we wish to explore with you. It is provided in advance of the interview to stimulate thought, but will not be collected as part of the survey. Rather, we will contact you to conduct the interview in person or by telephone, at a time convenient for you. The depth of information we seek to gain lends itself to a conversational survey rather than a self-enumerated questionnaire. While we welcome written comments before or after the survey, the interview process is designed to place the burden of response on us, not you.

Please review the topics and notes about each of these issues on the following pages at your earliest convenience. If you have questions or comments about the issues please do not hesitate to contact us. You'll find the name of the interviewers assigned to you on the letter accompanying this questionnaire.

1. Have you read *Special Report 288: Metropolitan Travel Forecasting: Current Practice and Future Direction*? If so, please consider the following:
    a. Were you consulted as part of the survey for this report?
    b. Which of the summary findings (pages 1–5) do you relate well to, and why? (A copy of these summary findings are attached.)
    c. Do you disagree with any of the findings?
    d. Are there any that do not apply to your agency or practice area?
    e. Three significant obstacles to deploying improved models are summarized on pages 4–5. Which of these are most applicable to you? Are there obstacles that you would add?
    f. Several recommendations are listed on pages 5-9. Which of these are the most important to you? Which do you feel are the least important?

2. Please tell us about your institutional settings:
    a. Who were (are) the champions for moving toward advanced models in your agency?

    b. What resistance or obstacles did they have to overcome?

    c. Who were supporters or allies in moving toward advanced models (i.e., colleague, manager or director, department head)?

    d. What challenges have you faced in gaining acceptance of advanced models among other agencies, consultants, and other stakeholders or users of your models?

    e. Where did you obtain funding?

    f. We'd like to obtain information about your expenditures for advanced modeling by year or project. These would include internal staff costs, capital expenditures, consultant contracts, data collection, etc. We will ask for this information during the interview.

    g. Have you collaborated with academics as part of your work? Why or why not?

3. What benefits have you obtained from using advanced models? In this part of the interview we wish to learn how advanced models have enabled you to evaluate policies and investments that traditional models could not approach. Some of the benefits suggested by others include:

    - Improved model outputs (in terms of accuracy)
    - Better information for decision-makers
    - Sensitivity to policies
    - Improvements to architecture, data management, and transparency

    Please consider the following questions:

    a. What are the three largest benefits you have obtained from using advanced models?

    b. What benefits did you expect to gain but have not?

    c. Are you aware of benefits that others have obtained but which you have not?

    d. What benefits do you expect to gain but do not presently have (because your model is still under development, evolving, etc.)?

    e. Are the benefits you have (or expect to have) obtained worth the cost?

    f. Do you feel that decision-makers appreciate the benefits?

    g. Has anyone challenged you about whether you really have obtained benefits from switching to advanced models, or asserted that the benefits were not worth the cost?

    h. How do you evaluate the success of advanced models?

    i. What benefits have developers of advanced models claimed but for which you are skeptical?

4. Even when the benefits of advanced models are accepted, implementation issues often impede their adoption or productive use. A number of such issues have been raised at recent conferences and in the literature. Several are listed below. Please indicate how significant each of these issues are to you:

Issue	Not at all	Some-what	Very much	Unsure
Data and survey needs	☐	☐	☐	☐
Software and hardware	☐	☐	☐	☐
Development cost	☐	☐	☐	☐
Implementation cost	☐	☐	☐	☐
Specification requirements	☐	☐	☐	☐
Model calibration	☐	☐	☐	☐
Validation and reasonability checks	☐	☐	☐	☐
Time required to implement	☐	☐	☐	☐
Uncertainty about next steps	☐	☐	☐	☐
Perceived complexity	☐	☐	☐	☐
Risk associated with new models	☐	☐	☐	☐
Staff and skill requirements	☐	☐	☐	☐
Consultant versus in-house	☐	☐	☐	☐
Transferability issues	☐	☐	☐	☐
Inter-agency coordination required	☐	☐	☐	☐
Planning/operational issues	☐	☐	☐	☐
Model run times	☐	☐	☐	☐

Please consider the following questions in addition to the table above:

a. What implementation issues are you facing that are not listed above? How important are they?

b. Are there any issues that you feel are insurmountable?

c. What issues would most benefit from collaboration between agencies?

5. The important lessons learned from your work are highly valued. What have you found are the most important things to do—and not to do—when moving toward advanced models? You may use the space below for recording thoughts or ideas that we will discuss further with you during the interview. One question we are particularly interested in is, “if you had it to over again, what would you do differently?”

APPENDIX B

Interviewed Agencies

Public agencies across the United States who are working with advanced models were asked to participate in an interview. The Interview Preparation Guide shown in Appendix A was sent to the agencies in advance. This e-mail was sent to agencies asking for their participation in this study:

> PB is preparing a synthesis of practice for the National Cooperative Highway Research Project entitled, "Advanced practices in travel forecasting." The study aims to document the current state of implementation of advanced models, with particular emphasis on implementation and institutional issues and lessons learned to date. It will also include a brief general review of advanced practices and case studies of selected agencies. A precise definition of advanced practices hasn't been definitely nailed down yet, but our working definition is that it broadly encompasses those techniques beyond the four-step sequential modeling paradigm used over the past several decades. However, our purview extends to complementary models deployed by transportation agencies, to include integrated land use-transport, dynamic network (including TRANSIMS), freight, and statewide models.
>
> An important first step in our work is to interview practitioners to gain insight into the many issues they're facing on the road to advanced modeling. While such users obviously includes those actively using or developing such models, we also plan to interview agencies that have decided against the advanced models, those uncertain about how or whether to proceed, or those in the early stages of deciding on next steps. Your agency was one of several that we identified in consultation with the Synthesis panel and TRB staff. We would greatly value your input, and hope that you are able to participate in the survey.
>
> Attached you will find an Interview Preparation Guide. It covers many of the topics that we would like to discuss with all participants, although we realize that some might not be applicable in your case. We do not intend to collect the Guide; it is provided to provoke thought and possibly internal discussions on your end prior to the interview, and a convenient place for you to write down notes. If you have or are moving towards more than one of the advanced practices listed above we will ask for this information about each of them. Please make additional copies or consolidate your comments on one Guide, whichever works best for you.
>
> Please note that part of our questions revolve around your reactions to the major findings of TRB Special Report 288, "Metropolitan travel forecasting: current practice and future direction." If you have not read this report already it is available for purchase or free download at http://www.trb.org/news/blurb_detail.asp?id=7821. Please focus particularly on the summary findings and recommendations on pages 1 through 13.
>
> I will be contacting you in the next week to arrange for the interview. Whether completed in person or by phone we expect that the interview will take between one and two hours for most agencies. Please feel free to contact me at <phone number> or by email if you have questions or comments in advance of my contacting you.

Following, an interview appointment was set up. While some interviews were held in person, most interviews were done on the phone. A response rate of 95 percent was reached. The following agencies were interviewed about their advanced modeling work:

Person Travel Models

Boise (MPO for northern Ada County and Canyon County): Mary Ann Waldinger
Chicago Metro Agency for Planning (CMAP): Kermit Wies
Federal Transit Administration: Jim Ryan, Ken Cervenka, Nazrul Islam
Denver Regional Council of Governments (DRCOG): Eric Sabina, Jennifer Malm, Suzanne Childress
Metropolitan Transportation Commission (MTC): Chuck Purvis
Metropolitan Washington Council of Governments (MWCOG): Ronald Kirby, Ron Milone
Michigan DOT: Karen Faussett, Donna Wittl
Mid-Ohio Regional Planning Commission (MORPC): Rebekah Anderson, Zhuojun Jiang
New York Metropolitan Transportation Council (NYMTC): Kuo-Ann Chiao
Ohio DOT: Greg Giaimo
Oregon DOT: Bill Upton, Brian Dunn, Brian Gregor
Portland Metro: Dick Walker, Keith Lawton
Puget Sound Regional Council (PSRC): Kelly McGourty, Maren Outwater, Mark Simonson
Sacramento Area Council of Governments (SACOG): Gordon Garry, Bruce Griesenbeck
San Diego Association of Governments (SANDAG): Wu Sun
San Francisco County Transportation Authority (SFCTA): Billy Charlton, Elizabeth Sall
Southern California Association of Governments (SCAG): Hsi-Hwa Hu

Land Use Models

City and County of Honolulu: Steve Young
Metropolitan Council Twin Cities: Dennis Farmer
Montgomery MPO: Kenneth Groves, Michael Clay (Auburn University)
San Diego Association of Governments (SANDAG): Wu Sun
San Francisco County Transportation Authority (SFCTA): Billy Charlton, Elizabeth Sall
Sacramento Area Council of Governments (SACOG): Gordon Garry, Bruce Griesenbeck
Ohio DOT: Greg Giaimo
Oregon DOT: Bill Upton, Brian Dunn, Brian Gregor

Freight

Ohio DOT: Greg Giaimo
Oregon DOT: Bill Upton, Brian Dunn, Brian Gregor
Portland Metro: Dick Walker

Dynamic Traffic Assignment Models

Chicago Metro Agency for Planning (CMAP): Kermit Wies
Northwestern University: Hani Mahmassani

TRANSIMS

Federal Highway Administration: Fred Ducca, Brian Gardner
Portland: Keith Lawton
Sacramento Area Council of Governments (SACOG): Gordon Garry, Bruce Griesenbeck

APPENDIX C

Current TRANSIMS Activities

A large number of TRANSIMS initiatives are currently underway. Many area funded in whole or part under the SAFETEA-LU (Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users), the current federal transportation legislation signed into law in 2005. Four categories of activities are described: deployment case studies, collaborations, methodological research, and sponsored research and development.

1. Deployment case studies are currently being developed via practical deployments funded via SAFETEA-LU. Competitively awarded (2 in FY 06, 4 in FY 07, 4 in FY 08), these coalition efforts are working on topics of local interest, including multimodal evacuation, operational planning, long-range plan evaluation, and light rail evaluation. Peer reviews are planned for all case studies. These include:
    a. Burlington, VT: TSM and bottleneck analysis (recently completed)
    b. New Orleans, LA: Multimodal evacuation study (peer review completed, draft report under review)
    c. Atlanta, GA: Congestion and emissions study (peer review completed, final report under development)
    d. Minneapolis, MN: Before and after study of Hiawatha LRT (model validation underway)
    e. Des Moines, IA: Interchange location and configuration study (scenario analysis underway)
    f. Moreno Valley, CA: Simulation study of truck impacts from infill development and expansion of warehouse districts (underway)
    g. Sacramento, CA: Bridge expansion before-and-after study using the fully integrated DAYSIM activity-based model with TRANSIMS router (underway)
    h. Phoenix, AZ: Simulation study of downtown LRT line (underway)
    i. Detroit MI: Large area simulation with dynamic routing for MOT scenarios during interstate reconstruction (underway)
2. Several collaborations funded from various sources have contributed significantly to the program in various ways:
    a. Washington, DC: White House Area Transportation Study (special appropriation; peer reviews and preliminary findings completed, additional study of transit options underway)
    b. Buffalo, NY: Border trucking study (peer review completed, final report under development)
    c. Chicago, IL: Multimodal evacuation study (ongoing)
    d. Central NJ: Several topical studies (special appropriation; work complete)
    e. Community Building: Working to establish a self-governing group to manage and advance TRANSIMS technology using organizational and licensing models from the open source software community (ongoing)
3. University researchers, and others, are currently engaged in methodological research. Competitive awards (4 in FY 07, 6 in FY 08) for one year graduate research or similar activities are being made via a broad agency announcement (BAA):
    a. University of Virginia: Microsimulator calibration (completed)
    b. Virginia Tech: Congestion pricing proof of concept (ongoing)
    c. Georgia Tech: Travel time post-processor (completed)
    d. Cognometrics VII proof of concept (completed)
    e. Bob Balfour: TRANSIMS visualization (completed)
    f. New Jersey Institute of Technology: Integrating network simulation and land use (ongoing)
    g. Champaign County RPC: TRANSIMS use for small and medium areas (ongoing)
    h. Georgia Tech: TRANSIMS use for developments of regional impact (ongoing)
    i. SUNY-Buffalo: TRANSIMS model for university campus (ongoing)
    j. University of Utah: TRANSIMS visualizer (ongoing)
    k. University of Virginia: TRANSIMS safety evaluation module (ongoing)
4. FHWA sponsored research and development efforts have been de-emphasized during SAFETEA-LU. Current efforts are focused on advancing specific, deployment-related issues:
    a. Portland Case Study: Refining methods for multimodal dynamic traffic assignment, linking DTA with activity models, and further refinements (ongoing)
    b. Model Test Bed: Staff effort to establish a series of high quality data sets suitable for model research and development (ongoing)

(Information supplied Fall 2009 by Brian Gardner and Supin Yoder at FHWA)

Abbreviations used without definitions in TRB publications:

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