Implementing Innovation in Planning Practice:
The Case of Travel Demand Forecasting

by

Gregory Louis Newmark

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Committee in charge:

Professor Elizabeth Deakin, Chair

Professor Emeritus Michael B. Teitz

Professor David M. Henkin

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Abstract

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Travel demand modeling is a core technology of transportation planning and has been so for half a century. This technology refers to the structured use of mathematical formulae and spatial data to forecast the likely travel impacts of possible transportation, land use, and demographic scenarios. Although this planning practice is pervasive, critics have long argued that is has been resistant to innovation. As the policy scenarios explored through modeling become increasingly complex, particularly in the face of climate change, the question arises of whether regional planning agencies will be able to change their practices through implementing innovation. This research addresses this question by examining the history of travel demand modeling as practiced at regional planning agencies, interviewing travel demand modeling experts, conducting detailed case studies of model practice evolution at two metropolitan planning organizations, the San Francisco Bay Area's Metropolitan Transportation Commission (MTC) and the capital region's Sacramento Area Council of Governments (SACOG), and analyzing the early impacts of California's groundbreaking climate change legislation on the modeling practiced in the Golden State. The findings suggest that far from being a static practice, travel demand modeling at regional agencies has advanced, particularly with public interest in exploring the impacts of major policy interventions. The nature of travel demand models does not naturally foster changes in practice; however, government action can structure the innovation process by establishing clear expectations of agency modeling capabilities to meet legislative mandates, providing resources for investments in new approaches, and creating forums for interagency interaction and information dissemination.

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I dedicate this work to Kaye Bock, of blessed memory, whose big heart embraced me and every student in the department. I wish that I could hug her with my diploma in hand.

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1 INTRODUCTION AND OVERVIEW

The threat from climate change is serious, it is urgent, and it is growing. Our generation's response to this challenge will be judged by history, for if we fail to meet it – boldly, swiftly, and together – we risk consigning future generations to an irreversible catastrophe.

President Barack Obama's 2009 address to the United Nations *(1)*

We shall have special concern for the long-range consequences of present actions. We shall pay special attention to the interrelatedness of decisions. We shall provide timely, adequate, clear, and accurate information on planning issues to all affected persons and to governmental decision makers.

AICP Code of Ethics and Professional Conduct *(2)*

All models are wrong but some are useful.

George E. P. Box, 'Robustness in the Strategy of Scientific Model Building' *(3)*

A specter is haunting planning – the specter of climate change. This concern is particularly acute for transportation planners as, according to the most recent EPA inventory *(4)*, in 2009, mobile sources accounted for 28 percent of anthropogenic greenhouse gas (GHG) emissions in the United States. Of these mobile source emissions, 64 percent come from light-duty vehicles, the passenger cars and light trucks that populate America's streets and driveways. The policy response to these mobile source GHG emissions has been characterized as resting on three legs *(5)*, namely reducing the carbon intensity of motor fuels, increasing the efficiency of automobiles, and reducing the vehicle-miles traveled (VMT).[1] While the first two legs represent technical challenges, the last leg, reduced VMT, is a planning challenge.

This research examines a key factor in determining whether transportation planners are up to that challenge – the implementation of innovation in travel demand modeling.

Travel demand modeling is the core technology of transportation planning and has been for half a century. This technology refers to the structured use of mathematical formulae and spatial data to forecast the likely travel impacts, including VMT, of various land use and transportation scenarios. This practice emerged in the late 1950s as part of the planning work to site major roadways[2] within the metropolitan areas of Detroit and Chicago and has subsequently penetrated, in some form or another, all of the nation's metropolitan planning organizations (MPOs).

The question arises of whether the practice of travel demand modeling will be able to innovate to meet the planning challenge of climate change. For years, the modeling practiced by MPOs has been roundly assailed by critics as unwilling to innovate *(6-8)*. However, currently, a select set of MPOs are in the process of radically transforming their modeling practices. These changes are aimed, in part, on increasing the sensitivity of the models to the very policies thought to reduce VMT. Unfortunately, in most of these cases, there is no extant climate change legislation for these models to support.

The one exception is the state of California, which has become the nation's leader in climate change legislation. In 2008, the golden state passed Senate Bill (SB) 375 to use land use and

[1] More recently a fourth leg has been added which is to improve vehicle and transportation system operations.
[2] Ironically, these highways, by facilitating sprawling land use patterns, became the infrastructure most associated with increases in VMT.

transportation policies to reduce VMT as a means of curbing GHG emissions. The law expressly identifies roles for travel demand modeling in developing and monitoring regional plans to promote sustainability. These roles will require innovations in modeling practice and the law and its guidance provides some insight into how such advancement may be structured *(9)*.

This research examines the history of travel demand modeling, expert opinions on modeling, two MPO case studies, and a review of relevant state legislation to identify factors that advance or retard the implementation of modeling innovation. The work is divided into eight sections.

The first section introduces the research topic, method, and findings.

The second section provides a review of the literature that frames the current research. This section demonstrates, through citing a sampler of the literature, the longheld contention that the travel demand modeling practiced at metropolitan planning organizations is immutable in the face of innovation. This section then presents Everett Rogers' framework for identifying innovation and understanding its diffusion. This presentation is followed by a consideration of innovation within the field of planning and more narrowly within the subfield of travel demand modeling.

The third section presents the research approach and methodology. This section details the unique combination of qualitative approaches taken, including historical inquiry, expert interview, case study, and legislative impact analysis. This chapter explains my choice of research subjects, particularly the two case studies.

The fourth section presents a brief history of the practice of travel demand modeling. This section chronicles the major implementations of model innovation at metropolitan planning organizations, the federal legislative mandates that structure transportation planning, and the evolving nature of travel demand model theory.

The fifth and sixth sections present the case studies of travel demand modeling for the San Francisco Bay Area and Sacramento regions, respectively.

The seventh section examines the early impacts of California's groundbreaking climate change legislation on the practice of travel demand modeling.

The eighth section presents my conclusions and thoughts regarding policies and future research.

2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

This research engages the long held contention that the practice of travel demand modeling at metropolitan planning agencies is inherently resistant to change. The critics, who hold this view, argue that planning agencies seem unwilling to alter their travel demand models despite the evidence that the methods in use do not comport with the emerging behavioral theory of travel. In this literature review, I first demonstrate the longstanding nature of this contention to explore the position that this dissertation seeks to challenge. I then examine the literature on innovation in general to define the term and delineate the theoretical framework for this research. Finally, I examine how innovation has been addressed within the planning literature in general and in the specific case of travel demand modeling.

2.1 The Contention

A commonly expressed opinion among academics is that metropolitan planning organizations (MPOs) resist changing their travel demand modeling practices to embrace innovation. There is particular concern that the innovations drawn from a more behavioral understanding of travel are ignored. For example, Pas *(7)*, in a 1990 essay provocatively entitled *Is Travel Demand Analysis and Modeling in the Doldrums?*, explicitly notes the failure of planning agencies to reflect the idea that travel is derived from a desire to participate in activities.

> Doubt will still remain in some minds about whether we are making progress in travel demand analysis and modeling. Certainly, from the point of view of transportation planning practice, it is clear that travel forecasting models have seen little change in recent years. In particular, the activity-based approach has seen little direct application.

More recently, the Transportation Research Board (TRB) *(8)* concluded its 2007 special report on *Metropolitan Travel Forecasting: Current Practice and Future Directions* with the general criticism that

> the practice of metropolitan travel forecasting has been resistant to fundamental change. Every 10 years or so there begins a cycle of research, innovation, resolve to put innovation into practice, and eventual failure to effect any appreciable change in how travel forecasting is practiced.

In interviewing experts on the state of travel demand modeling in 2007, Rodier *(10)*, found they "used words such as 'dismal,' 'primitive,' 'disappointing,' and 'deficient' to describe the state of the practice."

This sampler illustrates the position that I challenge in this research, but also one that grounds my research. While I neither believe that there has been no innovation over the last half century nor that there is no hope of future innovation, I recognize that innovation has been slower than desired in some circles. Instead of passively accepting this situation, I seek to understand what has resulted in innovations in practice in the past to inform future policy.

2.2 Innovation

The main theoretical frame for this research is drawn from the extensive work of Everett Rogers, who first published his *magnum opus* Diffusion of Innovations *(11)* in 1962 and spent the following generation refining his ideas in subsequent editions. Rogers defines innovation simply as "an idea, practice, or object perceived as new by an individual or other unit of adoption." Innovations take the form of a technology, which Rogers defines as "a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome." This definition is readily extended to travel demand modeling whose main purpose is to reduce the uncertainty regarding policy outcomes. Most technologies combine both hardware and software elements. Having a physical tool, such as a screwdriver, is not useful without the information on how to use it. Some technologies are mostly information, such as a zoning approach or a political philosophy. Often multiple innovations are interrelated and it can be difficult to appropriately bound the innovation. For example, Rogers uses the example of the Green Revolution in agriculture which combined many new technologies (hybrid seeds, advances in fertilizers and pesticides, higher seeding densities, etc.) to produce greater harvests. While these different technologies represent distinct innovations and could be studied in isolation, they are interrelated and should be examined as a single technology cluster. Travel demand modeling innovations, as well, tend to result from a merger of several technologies.

Rogers *(11)* identifies traits that can be used to characterize innovations regarding their potential for diffusion. He argues that each technology can be assessed as to its relative advantage ("is it better than existing practice?"), its compatibility ("does it accord with expectations of possible adopters?"), its complexity ("is it difficult to use?"), its trialability ("can we try it out before committing a lot of resources?"), and its observability ("can we see it in successful use elsewhere?). Finally, Rogers discusses a trait that describes how "an innovation is changed or modified by a user in the process of its adoption and implementation," which he refers to as 'reinvention.'

Rogers *(11)* defines diffusion of innovation as "the process by which an innovation is *communicated* through certain channels over *time* among the members of a *social system*" (italics added). He then elaborates on the three main diffusion components, namely communication, time, and a social system.

Regarding communication, Rogers *(11)* notes the importance of interpersonal channels in providing subjective evaluations of an innovation among peers. He argues that these evaluations, rather than scientific data, tend to carry the most weight among potential adopters. Rogers *(11)* presents a model of communication in which people can be considered either homophilic, that is similar in certain attributes, or heterophilic, that is different in certain attributes. People tend to communicate with people with whom they share attributes; however, paradoxically, some degree of heterophily is necessary for the communication of a new idea. So the ideal communication channel for an innovation is between people who are largely homophilic except regarding their experiences with the innovation under discussion.

For Rogers *(11)* the time dimension enters in one of three ways. One area is the time between encountering an innovation and deciding to accept or reject it. A second area is the relative earliness/lateness of adoption by one unit compared to other members of the system. The third and final area is the innovation's rate of adoption in a system. My work is focused on primarily the first area with some consideration of the second area.

Rogers *(11)* identifies several stages to what he calls the 'innovation-decision process' namely knowledge, persuasion, decision, implementation, and confirmation. These stages accord to the experience of learning about an innovation, forming an attitude about the innovation, deciding whether to embrace or ignore the innovation, actually putting the innovation to use (if the decision is to accept it), and reinforcing whether that acceptance was a good idea or not. He also categorizes units of innovation adoption by their earliness or lateness of adoption. He uses the following ordinal terms ranging from first to last to adopt: Innovators, Early Adopters, Early Majority, Late Majority, Laggards. These terms will be used to characterize the travel demand modeling innovation decisions made at regional transportation planning agencies.

The last component of Rogers' *(11)* model is the social system, which he defines as "the set of interrelated units that are engaged in joint problem-solving to accomplish a common goal." For the purposes of my research, the social system consists of the MPO employees, consultants, and academics that are involved in metropolitan transportation planning.

Rogers *(11)* further distinguishes a social structure within that system which helps provide predictability and uncertainty reduction. This structure exists in both formal and informal levels. Social systems have norms that represent the established patterns of behavior. Within any social system, a few people earn the role of opinion leadership through their technical competence, social status, and conformity to the system's norms. Another role is played by change agents who seek to influence the adoption of an innovation. These actors are often not of the adopting agency, although they may be. Their role is to push the adopting unit to change behavior and to do this they often seek to influence the opinion leaders.

Rogers *(11)* identifies three types of innovation decisions that can be made within the social system. These decisions are important for understanding how changes are made, particularly in formal organizations. These decisions can either be an individual choice which is independent of the other people in the system, a consensus choice among the members of the system, or a choice made by the relatively few people that are invested with power that is handed over to them.

2.2.1 Innovation in Planning Practice

Several researchers have addressed innovation with the practice of planning. Their insights provide a useful background to the current research.

One key issue is the role of innovation within planning. Mandelbaum *(12)* argues that planning is characterized by the use of certain technological innovations and that users of specific tools, such as travel demand models, carve out 'ordered enclaves' of practitioners, who define that tool's meaning, refine its functions, and extend its range to new problems. This view sees innovation as essential to the planning practice while Dueker *(13)*, himself a modeler, sees such innovation in practice as largely driven by external factors. He examines the incorporation of computers in planning. He notes that the time period between 1960 and 1975 was one of economic growth and development during which new infrastructure was being constructed which required new or expanded planning agencies. During this time period, there was tremendous hope in the potential of new computer models and this technology was supported and transferred by the federal government via demonstration projects. By contrast, the subsequent decade was a period of constraint which altered the planning agenda from growth to maintenance. During this period, there was a new use of localized, ad hoc models with the role of technology transfer becoming the domain of private consultants as well as the private companies that provided combined software/hardware packages.

Guttenberg *(14)* somewhat reconciles these positions by considering a mix of internal and external factors. He argues that innovations are adopted when there is a need within a planning agency. He offers a list of factors that promote methodological innovation: a mismatch between the planning problem and the instruments on hand to tackle that problem, the consideration of that planning problem as a 'hot issue' to ensure the sustained investment of resources and interest, the ability for one type of planning problem to 'piggyback' on another to get more attention, a sufficient financial and bureaucratic resources base, importable paradigms from other fields, and a high profile provenance that legitimizes the practice. Friedmann *(15)* is more doubtful of the ability of planning agencies to innovative and emphasizes their institutional inertia. He argues "once a particular method has been successfully applied, it is likely to be repeated even under different circumstances: experiment is a dangerous gamble."

Innes and Simpson *(16)* discuss ways to foster the implementation of a new technology, specifically geographic information systems (GIS), within planning practice. They argue that the biggest challenge for implementing an innovation is in making it "compatible with the culture, language, skills, practices, understandings, and organizational and social structures of the community that is to use it." They see communicative processes as central for bridging this gap and creating a shared meaning for a new technology. While they see implementation being primarily mediated through practitioners, they note an important role for academics to take a more strategic perspective which would include "first codifying existing practices and documenting and explaining successes and failures. Ultimately they can build a framework for practitioners to apply in the overall innovation effort."

2.2.2 Innovation in Travel Demand Modeling

The focus of this research is on the practice of travel demand modeling, the process by which the use of transportation infrastructure is forecasted across a metropolitan region given potential land use and transportation policies. Several researchers have considered elements of innovation within the history of travel demand modeling. This work has typically identified barriers to implementation and then proffered solutions. A common concern is that work of academics to advance modeling is not effectively translated into practice and may in fact be counterproductive to practical implementation. Oppenheim *(17)* characterizes this problem very well when he writes

> little attention is being paid to practical problems. The majority of models are developed in a policy vacuum rather than for the solution of real urban and regional problems. There is a danger that urban modeling will, in advancing its frontier, increasingly widen the existing gap between theory and practice. Model developers should be more aware of the needs of the practitioners, particularly the pragmatic conditions under which the models are normally used. ... Practitioners, in turn, should be more aware of the theoretical issues in urban modeling, for instance in choosing among models for specific problems, or to communicate their needs effectively to model developers.

More specifically, Oppenheim *(17)* argues that the range of new modeling approaches is too wide, with the result that implementers are wary of choosing the wrong one and therefore are willing to stay with earlier traditional model designs. He calls for the systematic comparison of models to identify the appropriate use of each type.

Mayes and Nix *(18)* build on this position to argue that from the perspective of the implementing agency, there are concerns about the level of abstraction in models and the models' ability to truly assist in policy formulation. The authors feel that travel demand models are being used in ways that exceed the reach of their underlying data and that more effort needs to be invested in testing model predictions with real data and including sensitivity tests before public agencies will feel more comfortable with their use. Pas *(7)* echoes this view arguing that models may have been introduced into practice too fast: that the early success and rapid diffusion of travel demand models may have led to a state of "hypertrophy" in which a field and its supportive institutions advance rapidly, but without careful quality control. Such a state tends to stymie further advancement as institutions have already committed themselves. The unfortunate result is that an immature field is then presented to policy makers as if it were mature and begins to function as a 'folk science' which gives comfort to believers, but does not foster internal criticism and review. Pas notes that modeling must avoid hyperbole lest it alienate policy makers who will then not take modeling serious in the future.

A particular concern for academics is the lack of implementation of models that reflect the understanding of travel demand as derived from the desire to participate in activities. Models that incorporate this behavioral basis are known as activity-based models as they focus on the activities people seek to engage in and then generate trips rather than generating trips based on more simple assessments of land uses. Pas *(7)* attributes the slow diffusion of such ideas into practice to the fact that activity-based models were aimed at behavior explanation and not prediction and that those models have demonstrated the complexity of travel behavior, which does not facilitate application in practice. More recently, Lawson *(19)* postulates barriers to moving simulation methods, which are closely related to the activity-based approach, in travel demand modeling from experiment to practice. She identifies institutional inertia which slows any attempt to 'retool' agency operations, the added costs of new data and more extensive model maintenance, and concerns that outputs from microsimulation models will not meet with current federal regulatory requirements. Lawson suggests that increasing agency comfort with updating technical systems, the emergence of data collection technologies that reduce costs, and the movement of microsimulation to open source platforms, which will expand participation in the field, will help overcome these barriers. Lawson also proposes a 'hybrid' implementation through which microsimulation would augment rather than replace traditional models. She advocates collaboration with universities, whose activities are not as constrained by local decision makers and strict financial budgeting.

A 2007 TRB report *(8)* has emphasized institutional barriers to travel demand model innovation. The report argues that "obstacles to advances in modeling practice include preoccupation with the immediate demands of production, fear of legal challenges, and significant budget and staff limitations." The report authors call for significant intergovernmental cooperation in the research and implementation of advance models, staff training, data collection, and funding. There should be goals set for improving forecasting practice, traditional/advanced model comparisons, and a national modeling handbook.

There exists a small literature devoted to addressing advancing travel demand modeling. Holmes *(20)* describes the process by which new ideas in travel demand modeling were adapted through meetings that permitted participants to discover shared meanings and begin a process for their diffusion. He chronicles a series of conferences and reports whose participants and authors brought together researchers and public officials to determine core planning principles as well as an extensive outreach program sponsored by industry advocacy groups to bring these ideas to implementers across different levels of government. The 2007 TRB report *(8)* argues that innovation is limited as MPOs lack the staff and budget resources to advance practice while addressing their existing production demands, fear potential legal challenges if they move away from an established modeling practice, do not have strong evidence that advanced models justify the development costs, and do not have strong and coordinated support from various stakeholders to change modeling practices. Suggestions for overcoming these barriers include finding more state funding for advancing modeling practice, cost-sharing and coordination among MPOs, partnerships between MPOs and universities, modeling user groups, and standardization of assumptions and input data. Individual states are seen as critical for fostering much of this coordination among MPOs.

This existing literature provides a framework for considering the diffusion of technological innovation in planning and also identifies some of the issues that modeling faces and modelers contend with. The purpose of the research presented here is to marry the theoretical framework to a systematic and in-depth consideration of innovation within modeling to address the question of what factors moderate or advance the implementation of new practices at regional planning agencies.

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3 RESEARCH APPROACH AND METHODOLOGY

This qualitative research combines several distinct methodologies, namely historical inquiry, expert interview, case study, and legislative impact analysis. The main sources of data are interviews, articles, planning documents, and legislation (and the associated policy guidance). Each section of the research employs different portions of these methods and is discussed in order.

The first portion of this research traces the major practical innovations in the half-century history of travel demand modeling in the United States. This focus on the actual modeling that was put into practice by metropolitan transportation planning agencies is unique as other retrospectives tend to focus on the theoretical development of new methodologies, not their actual application. This approach is distinct in not seeking a comprehensive chronicle of travel demand modeling at the almost three hundred MPOs. Rather it is quite deliberately a history of the most innovative practice in transportation planning and modeling, which tends to occur at the larger and more well-funded planning agencies. Specifically, this section focuses on those MPOs which Rogers *(11)* would identify as Innovators. This section relies on the vast literature of planning practice, specifically agency reports, research papers, planning textbooks, and government documents. Of these source materials, Edward Weiner's Urban Transportation Planning in the United States: An Historical Overview *(21)* has been particularly useful for establishing the broader context and for identifying specific events.

One might reasonably also ask why present the general history before presenting the specific case studies. This approach seems to suggest a deductive approach which seems inconsistent with my desire to learn inductively from case studies. Or, more challenging, why have cases studies at all. Would not a broad history be more encompassing of the experience of US metropolitan planning agencies? To best address this query I offer a literary motif most apparent in modern cinema and sports broadcasting. Namely, the rough presentation of the course the hero (or athlete) is to traverse to the audience prior to his or her commencing the actual journey. Far from ruining the surprise of the adventure, portraying the contours enables the audience to more keenly observe the specific actions of the hero, the overall narrative being mapped out. In this framework, the focus is therefore on the individual case, not the general trend. This approach assumes that important things do not happen generally, but rather in unique contexts and with a specific mix of factors. Only by observing these processes in different instances can we induce knowledge that can be then applied generally. To once again resort to a model from the natural world, an exploration of the evolution of a species, including dead ends on the cladogram, is best undertaken at the microlevel, because evolution fundamentally is a process of individual adaptation to a specific environment.

This historical work has also been guided by my interviews with modeling experts. This history is strongly guided by the people who were most active in defining modeling practice over that time period, particularly over the last thirty years in which most of the main innovators are still active in the field. These informants help to direct the history to cover the most significant and noteworthy changes. I first identified possible experts by reviewing the membership lists of the Transportation Demand Forecasting Committee (ADB40) of the National Academy of Science's Transportation Research Board (TRB) with the executive board of the International Association for Travel Behavior Research (IATBR). I contacted prospective interviewees by email. In the body of each email, I included a brief description of the project and requested their participation in an hour phone interview. I also attached a second document that provided a more detailed description of the project as part of the consent process. People who would like to participate in an interview were to contact me via email to set up a time. Typically, each interview required a few rounds of email to establish an appointment. At the appointed time, I would call the expert and use the open ended Expert Interview Protocol (see Appendix). At the end of the interview, I would ask if there were other people they thought I should speak with. By this snowball method, I expanded my interview list. In total, I conducted seventeen interviews with experts.

These expert interviews provide the basis for the second portion of this research. In this section, I made a content analysis of the interviews. This analysis was focused on five themes of MPO modeling, namely the purpose, the state of the practice, future improvements, key historical innovations, and factors that affected the implementation of innovation. These interviews provided an external check on my historical inquiry. They also identified general themes for my understanding of the case studies.

I selected two metropolitan planning organizations (MPOs) for in-depth case studies. The cases studies were designed to provide an ideographic understanding of the process by which innovation is implemented at a specific MPO to complement the nomothetic understanding developed in the historical research and expert interviews. I contend that following the experience of actual organizations is necessary to fully exploring the implementation of planning innovation.

The MPOs chosen were the Bay Area's Metropolitan Transportation Commission (MTC) and the California capital region's Sacramento Area Council of Governments (SACOG). Both of these MPOs have been identified as being or having been the leading edge in implementing modeling innovation. The MTC was the first MPO to employ discrete choice methods which heralded the introduction of disaggregate techniques. More recently, SACOG has been innovative in its inclusion of detailed land use factors in its activity-based model. Furthermore, they are both in California, a fact which makes them appropriate for my final consideration of the impact of the Golden State's Senate Bill (SB) 375 legislation on modeling. These case studies also vary in interesting ways. SACOG represents a region with a single dominant city that is facing pressure to expand. The MTC represents a region with multiple centers that has developed much of its habitable area and looking towards infill.

The research process for both cases is the same. I began by collecting the reports and memoranda published directly by each MPO as well as the articles and documents that referred to the modeling activity of the case study MPOs. The latter selection includes papers published by the MPO staffers in external journals as well as outside researchers looking in at MPO practice. Since both MPOs have a history of innovation, this external literature is rather robust. The purpose of the documentation review is to identify stated rationales for investing in changes to the model. From this documentation, I constructed as detailed a case as possible before conducting a set of interviews focused on that MPO. (It should be noted that because these MPOs have been innovative, a number of the expert interviewers were knowledgeable about them and in some cases had worked directly with them. This information preceded my focused interviews at the selected MPOs.)

For the two MPOs, I interviewed the modelers who are responsible for managing the travel demand models, the planners who rely on the outputs from the models, and the agency leadership that authorizes investment in model changes. I developed two interview protocols for case studies (see below), one for the modelers and one for the planners/policy makers. I began by interviewing current staff and board members, but asked them to direct me to formerly involved people, if relevant. For example, the longtime head of modeling at the MTC was newly retired as I began the interviews, so it was important to track him down. The purpose of the interviews is to identify other rationales for changing the model, to identify changes perceived as 'important,' to assess whether changes have resulted in the anticipated benefits, as well as to understand the MPO use of travel demand models.

From this longitudinal perspective, I shift to a cross sectional one, to examine the critical current issue of how MPOs across the state of California are (or are not) altering their travel demand models in response to the SB 375 climate change legislation. This groundbreaking legislation expressly calls for new approaches in modeling and as such presents a sort of natural experiment to examine innovation.

This research has two components. The first identifies the features of the two related laws (SB 375 and SB 732) likely to advance the practice of travel demand modeling. This portion employs a content analysis of the approved legislation. The second component examines the early implementation of these laws. This portion combines a content analysis of the guidance documentation (as well as the documented process of developing that guidance) with structured interviews of the actual implementers, namely the planners and modelers at California's MPOs.

The content analysis has been immeasurably helped by California's leading efforts to make available the documentation of all public meetings related to implementing climate policy. Therefore, this research is not limited to the final guidance alone, but can incorporate the debates that informed that guidance.

The crucible of such guidance, however, is in its implementation in practice. This research interviewed planners and modelers from MPOs throughout the state. Specific staff members were contacted based on their job description with an information letter to arrange an interview. In some cases, people contacted referred me to other people whom they thought were more appropriate for this research. In other cases, the people contacted arranged for several additional people to participate in the interviews. As part of the research design, separate interview protocols had been developed for planners and modelers. These protocols structured the interview with open ended questions tailored to the respondent's expertise. In practice, a single interview often pulled from both protocols (particularly when several respondents participated). The interviews were conducted either in person or over the phone and lasted between one and two hours. The interview request letter asked for only an hour, but in many cases the respondent extended the interview. In total, interviews were conducted with eight of the state's eighteen MPOs.

4 A BRIEF HISTORY OF THE PRACTICE OF TRAVEL DEMAND MODELING

In this chapter I set forth a brief history of the practice of travel demand modeling. I argue that travel demand modeling practice has innovated in response to the perceived solutions to urban problems and not merely to advances in modeling theory. This conception emphasizes the role of the policy environment in setting the stage for change. I claim that within this environment a planning problem must be identified and a specific, socially acceptable solution proposed, the analysis of which would require implementing modeling advances. The policy solution provides the impetus and the political cover for practitioners to invest in new modeling technologies.

Travel demand modeling here refers to the process of forecasting the future demand for travel across a metropolitan region's infrastructure in light of different possible land use and transportation policies. Much of the innovation in the field relates to the representation of and sensitivity to different policies. The modern practice of travel demand modeling is distinguished from previous attempts by the use of computers, which, by automating the many calculations performed, enables the variation of growth factors across the metropolitan scale.

This history traces the three main eras in modeling and couples each era to a specific policy environment and travel demand model implementation. In each case, the policy environment is presented first, followed by the model innovation itself, and then a specific discussion of the first implementation of the change. The eras denote the start of new practices, not the end of pre-existing ones, most of which continue to the present.

4.1 Theoretical Framework

This history presents a theoretical framework that is drawn from Rogers' *(11)* work on the diffusion of innovation. Specifically, I argue that the implementing agencies of model innovations are the key units of consideration. These agencies exist in a policy environment that is defined by federal and state government and is shaped by local concerns. The opinion leaders of these agencies interact with change agents who propose innovations. The change agents are typically a mix of consultants and academics. Furthermore, since many academics in the field of transportation also consult, the boundary between these groups is fairly porous. In some cases, the implementing agency will be willing to risk investing in a new technology. Factors that increase that willingness include the desire for a showcase project, perhaps as part of a metropolitan or agency rivalry, strong local pressure to make a policy decision, and federal support, both financial and political, which serves to reduce the potential costs of failure. The agencies that do so become, in Rogers' categories, innovators.

4.2 The Roadbuilding Era: Chicago (1955) and the Traditional Model

Traffic congestion has been a thorn in the side of metropolitan urban life since ancient times. Scholars often cite Julius Caesar's ban on wagon traffic during daylight hours by way of illustration *(22-27)*; however, the specific response to this problem in the United States in the second half of the twentieth century directly impacted the practice of travel demand models. The United States chose to invest in highways and to route those highways through urban areas. This policy decision required identifying where those routes should actually go.

Already in the first half of the twentieth century there was a movement towards building limited access highways in urbanized areas. Parkways, such as the Merritt in Connecticut or the Arroyo Seco in California, emerged as one aesthetic response to the needs of a motoring public *(28)*. An alternative approach was a more utilitarian highway represented by the Pennsylvania Turnpike which broke ground in 1937. The 1939 Bureau of Public Roads publication Toll Roads and Free Roads argued that toll roads could only succeed in limited areas, but nevertheless advocated a system of major highways extending to all states. Road building paused during World War II as construction materials were diverted to the war effort and gasoline was rationed, but by 1944, with victory in sight, Congress turned its attention to post-war plans. The Federal-Aid Highway Act of 1944 recommended a national system of interregional highways to connect major cities. While this system was not expressly designed to serve urban commuting patterns, the law did authorize, for the first time, funds for studying the urban extensions to the proposed interstate system *(21)*.

Detroit, the Motor City, famously hired a newly minted PhD in City Planning from Harvard to use those funds to undertake its Detroit Metropolitan Area Traffic Study (DMATS) from 1953 to 1955. The planner, J. Douglass Carroll Jr., had deeply thought through the problem of allocating roadway investment and experimented with implementing a new approach to transportation planning. Critical to his approach was what would become the traditional travel demand model.

While the modeling criticisms that motivated this research are largely aimed at the traditional model, this approach was itself a tremendous innovation that warrants description. The traditional model has been historically most often referred to as the 'four-step model,' although more recently, it has been referred to as a 'trip-based model' to distinguish it from newer activity- and tour-based approaches. Both terms are descriptive. The traditional model has four sequential submodels or steps and the unit of analysis is the trip. The four steps are trip generation, trip distribution, mode split, and traffic assignment. Banister *(6)* notes that these steps reflect the travel decisions of "whether to make a trip, where to go, what mode to use, and which route to take." This description is useful for illustrating the steps, but is misleading as the four step model does not consider individual trip making behavior rather it reflects observations made at a geographic unit typically called traffic analysis zones (TAZs). TAZs are typically aggregates of census tracts, an approach which facilitates the use of Census Bureau data in the analyses. The four submodels are developed using population and employment data for the TAZs, traffic counts, surveys of households on the number and destination of trips made by household members, and highway and transit network data. Once estimated, the models can be used to forecast the effects of changes in the transportation system, population, or employment on travel.

In the conventional forecasting process a critical activity precedes the first step of the travel demand submodels. This activity is forecasting the future population and employment, and the allocation of that future growth and change to specific TAZs. This allocation of households and jobs is typically represented as a function of current and planned land uses. Historically, land use forecasts have been based on combining local land use plans with expert opinion; however, many attempts have been made to automate these processes and therefore more explicitly consider the implications of economics and public policies on land use. Although my research does not focus on these land use modeling efforts, I want to make clear that these activities can serve as a critical prologue to the travel demand modeling process. In any case, forecasts of the future population and land use are necessary for the four step modeling process.

The first step, trip generation, estimates the number of trips to be produced from or attracted to a given TAZ. These trip productions and attractions are calculated based on the underlying land use and, in the more advanced applications, the characteristics of the population as well. Although at its core, this step essentially applies relationships generated through counts or through a simple regression analysis, typical applications use a cross-classification approach that divides the population into household types that have distinct trip generation characteristics. For example, a household with two adults and three kids living in a detached home is likely to generate a different number of trips than a household of a single person living in an apartment. Home locations are thought to generate trip productions while non-home locations are thought to generate trip attractions. The attraction ends are also generated based on rates for a given land use, with different attractions allocated to different land uses and development intensities. Therefore, a downtown TAZ with multistory office buildings would attract a different set of trips than a suburban TAZ with retail along a major arterial. The end result of the trip generation step is a listing of the number of trips produced from and attracted to each TAZ.

The second step, trip distribution, takes these lists that are output from the trip generation step and turns them into a matrix that connects the production and attraction ends of each trip. This step allocates the trips produced at an origin TAZ to trips that are attracted to a destination TAZ. This can be imagined with the rows representing attractions and the columns representing productions. In such a matrix, the row and column totals would still equal the values on the lists output from the first step. The challenge of this second step is to best allocate the trips among the different origin and destination possibilities. The typical method used to make this distribution is the gravity model which allocates trips based on the attractiveness of the destination zone divided by the difficulty in arriving at that zone. This approach is called the gravity model as it mimics the Newtonian insight that objects are attracted to each other proportionally to their masses and inversely proportional to the square of the distances separating them. (In travel models, the distance decay function need not be squared, the parameter is fit to the observations.)

The third step, modal split, takes the trip matrix output from the trip distribution step and separates it into several matrices based on the choice of travel mode selected. The simplest models skip this step, which may be appropriate if the objective is to estimate highway flows and the area under analysis has no or only trivial amounts of transit. Traditional models only considered two modes, driving and transit, yielding two modally defined trip matrices. A conventional approach to modal split is to use a diversion formula based on the differences between the expected travel times between origin and destination TAZs for the two modes. Typically, in these models, where transit times are large in comparison to driving times, there are fewer and fewer trips diverted to transit.

The fourth step, traffic assignment, takes the modal trip matrices output from the previous step and assigns them to the appropriate modal network. These models require that road and transit networks are coded as nodes and links on top of the TAZ network. The coding of these networks includes their type and travel characteristics. For example, the road network would distinguish between highway and arterial roads and alter the travel times along those different road types accordingly. Typically, road networks are abbreviated to consider only major streets although the full transit network is represented. All trips from a given TAZ are assumed to originate at the geographic center or centroid of that zone and end at the centroid of the destination zone. In its simplest structure, the traffic assignment model allocates trips to the network path which results in the shortest interzonal travel time. This final step outputs traffic volumes which are then analyzed. In traditional models, the major variations between model runs would be in the coding of the networks for different alternatives.

Although Weiner *(21)* argues that the Detroit modeling effort (DMATS) “put together all the elements of an urban transportation study for the first time,” I would claim this attempt was better seen as a trial run for what Dr. Carroll brought to fruition in his second major study, the Chicago Area Transportation Study (CATS), the study that established traditional travel demand modeling.

The origins of the CATS study are not entirely clear. Evidence suggests that it was at least in part designed as an urban showcase to demonstrate that Chicago was keeping up with New York and Los Angeles, who were then far outstripping the Windy City in highway construction. The study was also a tool in the political debate among agencies regarding the location of free and toll roads in Cook County. Certainly, the imminent expenditure of vast amounts of public funding on highways and the recognition that expanded transit services would still be necessary had spurred discussions in 1954 among public officials at the federal, state, county and city level regarding initiating a comprehensive transportation study for the Chicago region. A delegation of the interested parties even visited DMATS to see what was underway in Detroit. One historian of the agency argues that the federal involvement of the BPR, with their deep pockets, played the critical role in instigating the study *(29)*.

In January 1955, CATS was formed with an advisory committee made up of representatives of each of the four founding agencies. The BPR was responsible for half of CATS funding. The Illinois Department of Highways contributed a fourth and the remaining quarter was split between the Cook County Highway Department and the Chicago Department of Public Works. CATS staff were to be state employees and from the outset efforts were made to ensure that the products of the work would be updated to provide a lasting value to the region *(29)*. This arrangement of a locally initiated, ad-hoc organization, disconnected from any direct unit of government, overseen by a policy committee made up of representatives from several agencies, incorporating large and multi-disciplinary fulltime staff, charged with making a plan and reporting on it was to become the model for this era of transportation planning. CATS set the tone for others in planning at a regional rather than a corridor scale although focusing primarily on highway planning with transit as a secondary consideration *(21)*.

Carroll was brought in from DMATS to lead the study, an unusual move in the local politics of Chicago. He was seen to be the top transportation planner in the country and Chicago was willing to ignore the conventional patronage process to ensure a showcase study. It perhaps helped that Carroll had grown up in the region *(29)*. By all accounts, Carroll was an exceptionally effective director. He had been influenced by Walter Gropius at Harvard to foster collaboration across disciplines and brought that idea to CATS. Furthermore, Carroll's own conviction that transportation infrastructure could only be planned as a system undergirded the effort *(30)*. Carroll managed the policy committee very well, always emphasizing the groundbreaking nature of the study with the result that CATS staff was given a freehand *(29)*.

In 1956, as CATS was preparing its travel survey, the federal government passed the Federal-Aid Highway Act which provided funding in the form of a 90 percent federal match for highway program. About 20 percent of the proposed 40,000 mile system was designated as urban *(21)*. Plummer *(29)* writes that "this funding kicked highway construction in the area into a high gear and put pressure on CATS to produce a method to provide design help in constructing the system." That method would be the traditional travel demand model often referred to as the CATS model.

Carroll significantly expanded on the work that he had done in Detroit. (Incidentally, he imported many key people from the DMATS staff to CATS which helped launch the project quickly.) The scope of the study was larger than any that had gone before. The project lasted seven years and cost $3.5 million. Carroll brought a decidedly research-oriented direction to the project, which facilitated the development of new approaches. A major innovation was in the vast scope of the data collection which cost over a million dollars. CATS used computers, another innovation, to process this information and was able to derive many relationships between land use and travel upon which to ground its trip generation models. CATS chose to run their modal split model between the trip generation and trip distribution stage on the assumption that mode use is fixed by household and car ownership characteristics. This sequencing requires fewer calculations as it occurs only for the number of TAZ rather than the square of that number, but is thought to potentially underpredict the demand for transit in an era of rising car ownership as it does not account for the actual characteristics of the trip. This sequencing is one area in which the CATS approach has been criticized. The trip distribution model represents a major innovation as the project created its own approach called an 'intervening opportunity model' in which probabilities of selecting various destinations are estimated as a function of distance and the availability of closer options. The intervening opportunity model was seen as more theoretically based than the gravity model as it distributes trips based on the opportunities in a given zone versus competing opportunities elsewhere, a more intuitive understanding of why people travel to destinations. (Ultimately, this model was shown to be a variant of the gravity model, which is more computationally tractable. Nonetheless, to this day, Chicago's travel demand model uses the intervening opportunity approach to distribute trips.) Finally, CATS was particularly innovative in developing a traffic assignment technique. The study modified an algorithm designed for telephone switching to the question of how to choose the best path through a network. However, given the large numbers of nodes and links in the representation of the network, CATS required the most powerful computer then in existence, the IBM 709. One was identified in Cincinnati and a CATS staffer would fly there to use the computer at night *(30-32)*.

Carroll widely disseminated all of the CATS work. The project published a bi-weekly CATS Research News which created a forum for discussing CATS approaches. Plummer *(29)* notes that "every significant activity that CATS undertook also warranted a stand-alone report that covered everything from a coding manual to the use of the Cartographatron[3]." Thousands of copies of the final volumes of the study were printed.[4]

CATS affected studies elsewhere more directly as all of its principals scattered to work on similar studies in its wake. Already during the last years of CATS, Carroll arranged for himself and his contract staff to begin consulting elsewhere, most notably the influential Pittsburgh study that overlapped with the last years of CATS. After the final completion of CATS, Carroll moved to New York City to head up their transportation study *(29, 31)*.

The CATS approach to urban transportation planning was institutionalized by the Bureau of Public Roads in their regulatory implementation of provisions of the the Federal-Aid Highway Act of 1962 *(26)*. The law put in place what became known as the '3C' process through which any federal highway project in an urbanized area of at least 50,000 people must be predicated on the existence of a "continuing, comprehensive urban transportation planning process carried out cooperatively by the states and local governments." The provisions were introduced at the behest of urban interests who were concerned that the federal government was funding a program directed by state highway departments with little consultation with local interests. The act mandated that a 1.5 percent takedown of all transportation funding be used for planning and research and that the state could chose to spend another 0.5 percent for such activities, ensuring a steady source of funding for planning *(21)*.

In some metropolitan areas, a regional planning agency or a council of governments was designated to carry out the 3C process. However, the need to create a metropolitan plan required a new agency in many metropolitan areas, as suitable ones did not exist *(21)*. In some cases, such as the San Francisco Bay Area, new planning studies were established, modeled after the Detroit, Chicago and Pittsburgh studies, and the staff of these special studies became the 3C planners.

The methods developed at CATS were implemented across the country as the new legislation set aside "unprecedented large budgets for planning" *(26)*. The Bureau of Public Roads fostered this institutionalization of travel demand modeling *(7)* through its Urban Planning Division which developed and disseminated an entire suite of planning procedures and accompanying software. The Division also created training and technical assistance programs to help metropolitan areas put the new planning approaches to use. By the July 1965 deadline, all 224 urbanized areas had embarked on the '3C' process, which included the traditional travel demand model *(21)*.

4.3 Minimizing Transport's Impacts: The Bay Area (1975) and the Choice Model

While the 1962 Highway Act served to spread the CATS methodology across the nation, the Act also signaled the dawning of a new era in urban transportation planning and policy. The 1962 Act recognized that constructing highways in urban areas was likely to lead to controversy and

[3] This was a device commissioned by CATS that used a cathode ray tube to plot lines connecting origin and destination pairs from the survey. A visual from this device decorated all CATS publications. More importantly this can be seen as an early attempt at computer mapping and Geographic Information Systems.

[4] UC Berkeley Professor Emeritus Martin Wachs would pass around his personal copy in introductory transportation planning classes he taught over four decades later.

sought to engage local politicians in making the difficult decisions about highway routings. This was a major departure from the CATS approach, which was entirely divorced from the political process, with absolutely no citizen input into the plan. The CATS staff assumed that current trends would continue and felt that to propose alternatives would be to engage in value discussions which (in their view) were beyond the scope of a rational planning exercise *(31)*. However, it was precisely those unanticipated issues which would shift the nature of transportation planning and the scope of policies to be analyzed with travel demand models.

The policy environment shifted away from the uniform focus on highway construction. Black *(26)*, an alumnus of CATS, identifies four factors that challenged public commitment to urban interstate development during this era. As road construction encroached on heavily built up urban areas, there were ‘highway revolts’ across the country with affected people seeking alternative transportation policies. There was a resurgence of interest in mass transit, which had been unanticipated during the early transportation studies. The emerging environmental movement objected to the many ecological impacts of highways, particularly the air pollution. Finally, the oil crises of the early 1970s brought into question the sustainability of an auto dependent lifestyle. Black argues that this resistance to highway building led to challenges and eventually discrediting of the transportation studies and the travel demand models they used to derive their conclusions. It also reflected a new economic condition in the country which no longer had seemingly unlimited funds for planning and implementing projects. In this new environment, the metropolitan planning agencies retreated from active innovation and the development of new modeling techniques shifted from practice to academics.

By the mid-1960s a new emphasis on transit began to emerge. The Urban Mass Transportation Act (UMTA) of 1964 expanded piecemeal programs of federal assistance for mass transit capital costs. The 1966 amendment to this act also funded research into alternative transit options, such as demand responsive transit and personal rapid transit. The 1970 UMTA further expanded transit capital funding. This era also saw several demonstration programs aimed at low-capital intensive approaches to reduce congestion, including bus lanes and park-and-ride schemes. Furthermore, over time, there were fewer sections of the Interstate left to build and planning became more focused on optimizing existing resources than building new ones *(21, 33)*.

Federal legislation pivoted to seek to reduce the impact of highways on the environment. The 1966 Act which created the Department of Transportation prohibited, for the first time, infrastructure construction on parks, recreation areas, wildlife refuges, and historical sites unless there was no ‘feasible and prudent’ alternative. This provision was in response to controversies such as the proposal to build an interstate highway through the beloved Overton Park in Memphis and the Vieux Carré in New Orleans. This language was explicitly applied to highways in the Federal-Aid Highway Act of 1968. The National Environmental Policy Act (NEPA) of 1969 formalized environmental protection as national policy and required that all federally funded projects be evaluated for their impact on the environment. The Clean Air Act Amendments (CAAA) of 1970 created the Environmental Protection Agency to set national ambient air quality standards (NAAQS) and to mandate and oversee State Implementation Plans, which were to use reasonably available control measures “including transportation and land use” to meet the standards by CAAA deadlines. Since motor vehicles were a major source of such pollution and the new car emission standards would not reduce emissions fast enough to meet CAAA deadlines for NAAQS attainment, the CAAA had a tremendous impact on transportation planning by necessitating a rethinking of investment priorities. These NAAQS were published in 1971 and metropolitan areas had a relatively short time frame (initially to 1975 or 1977, if an extension was granted) to meet the standards which made infrastructure changes impossible and thus focused on traffic management techniques *(21)*.

These were tasks beyond the design of the traditional model. Weiner *(21)* aptly describes the growing disillusionment with the established practice.

> Critics argued that conventional procedures were time-consuming and expensive to operate and required too much data. The procedures had been designed for long-range planning of major facilities and were not suitable for evaluation of the wider range of options that were of interest, such as low-capital options, demand responsive systems, pricing alternatives, and vehicle restraint schemes. Policy issues and options had changed, but travel demand forecasting techniques had not.

As metropolitan areas completed their initial transportation studies and transitioned to the 'continuing' mode, the locus of innovation in travel demand modeling moved from the field to universities *(26)*. Academics brought a distinct concern to modeling. Prediction that lacked "concern with whether the models explained the phenomenon or were even reasonable representations of the underlying processes" was no longer valued. Instead of using metaphors from physics, such as the gravity model, travel demand researchers looked to explain actual behaviors *(7)*.

In 1965, UC Berkeley Professor Daniel McFadden, a future Nobel Laureate, was asked to help a graduate student with her master's thesis on highway route choice. Although he was in the Economics Department, he had received his PhD in an unusual and experimental multidisciplinary program in the social sciences at the University of Minnesota. As a result, McFadden was familiar with models of discrete choice in psychology which incorporated known attributes and a random component. He reinterpreted this approach as a selection among known and unknown utilities and recast it as an econometric function, the form of which is now commonly known as the multinomial logit model *(34)*.

This work on representing how individuals make choices between discrete alternatives transformed the theory behind travel demand modeling. MIT Professor Moshe Ben-Akiva, who had worked with McFadden at the economic consulting firm Charles River Associates, explicitly applied McFadden's ideas to travel demand modeling in his MIT doctoral dissertation in 1972 *(35)*. That same year McFadden launched a multi-year research project at UC Berkeley to apply econometric techniques to travel forecasting with a focus on the soon to be built Bay Area Rapid Transit (BART) system *(34, 36)*. Also in 1972, the federal government sponsored a conference on Urban Travel Demand Forecasting at Williamsburg, Virginia to discuss the state of modeling. The conferees recommended several paths to improve forecasting, specifically using research results to upgrade existing methodologies, pilot test emerging procedures in urban areas, improve the understanding of travel behavior, identify ways to translate research into practical methods, and develop a two-way dissemination program "to get new methods into the field and for the results of these applications to flow back to the researchers to improve the methods" *(21)*.

The Federal-Aid Highway Act of 1973 provided some support for such efforts. The law funded metropolitan planning directly for the first time by obligating a half a percent of all federal aid funds to a new regional agency, the metropolitan planning organization (MPO), responsible for comprehensive transportation planning. The federal government viewed the creation of MPOs as a better way to plan for metropolitan development and an opportunity to shift transportation planning away from state departments of transportation which historically had favored highway construction. MPOs were to prepare a short term (3 to 5 year) Transportation Improvement Plan which was "required to give special consideration to projects that reduced or better managed, rather than just facilitated, traffic" *(33)*. Such activities required a different type of travel demand model.

The Bay Area's MPO, the Metropolitan Transportation Commission (MTC), had been involved with and impressed by McFadden's work on BART. In 1975, the MTC hired Prof. Ben Akiva as part of a consultant team to implement the new modeling ideas in practice. The resulting model, MTCFCAST, was the first to extensively incorporate theories of individual choice, as represented by the multinomial logit model, within a travel demand model. (This model is discussed in detail as part of the case studies below.) The first three steps of the four step model were replaced with disaggregate choice formulations. The fourth step, traffic assignment, relied on the existing suite of software programs promulgated by the Department of Transportation for traditional modeling *(37)*.

Although the model's authors claimed the ability to fit within the existing suite of travel demand modeling programs was a benefit of their approach *(37)*, this structure constrained the innovation of the model *(38)*. For example, instead of truly representing the disaggregate choices of a sample population, the model segmented the population into three groups, stratified by income, and then aggregated their choices at the TAZ level *(37)*. Despite these limitations, the introduction of discrete choice into travel demand models would definitively alter the statistical approaches to modeling, particularly in reducing sample sizes and in predicting modal choice. The shift to considering travel at a more disaggregate level, even within the largely traditional framework, did move travel demand modeling towards a more behavioral framework; however, it would take many more years to more fully realize that innovation *(7)*.

There was resistance to the introduction of econometric methods within the traditional travel demand model. Weiner *(21)* in discussing a conference on modeling in 1982, writes that "it was clear....that new disaggregate travel analysis techniques were not being used extensively in practice. The gap between research and practice was wider than it had ever been" with researchers uninterested in repackaging their ideas for application and practitioners unwilling to undergo retraining. The 1980s were also a time of relative weakness of MPOs, while suburban growth skyrocketed. It would take new legislation from Congress to empower MPOs *(33)* and turn the tide towards modeling innovation.

4.4 Managing Travel Demand: Portland (1996) and the Activity-Based Model

Congress began the 1990s with a deep concern about the future of transportation for the nation. The 1990 Clean Air Act Amendments (CAAA) required that no transportation developments could worsen air quality. This law resulted in extensive guidance from the EPA on how to forecast vehicle miles traveled and the associated air quality *(21)*. The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) sought to boost the role of the MPO in regional planning decisions. The law doubled MPO funding and expanded their responsibilities. MPOs were now required to evaluate a range of multimodal solutions to transportation problems, broaden public participation, and work to achieve the goals of the CAAA *(33)*. In 1993, the National Association of Regional Councils put out extensive guidance on how these two pieces of legislation were likely to affect the practice of travel demand modeling, particularly regarding air quality conformity and the analysis of transportation control measures. The report reviewed existing modeling practices and identified key areas for improvement *(39)*.

To accompany the new requirements for better and more detailed transportation planning, in 1991, the DOT and EPA jointly initiated the Travel Model Improvement Program (TMIP). TMIP was designed to gather and disseminate information on best travel demand modeling practices and to promote research into new approaches *(21)*.

The CAAA increased the ability for citizens and interest groups to legally challenge transportation plans with the result that lawsuits or the threat of lawsuits became a major factor in travel demand modeling. In Portland, one environmental group, 1,000 Friends of Oregon, which had sued the MPO, Portland Metro, began an extensive modeling project to counter the proposed development of a highway bypass. This project, entitled Making the Land Use, Transportation, Air Quality Connection (LUTRAQ), ultimately brought together the MPO, academic advisors, and consulting firms to examine modeling practices related to land use and transportation *(40)*. This project shifted the focus of modeling from assuming a fixed land use and then designing an appropriate transportation network to considering altering land uses to reduce the need for transportation investment. Portland Metro became very engaged in considering land use elements to travel demand as well as non-motorized travel.

In 1993, the lead modeler at Metro, Keith Lawton, convened a panel of expert modelers, academics and consultants in Portland to discuss the future of travel demand models. The impetus for the discussion was an upcoming travel survey. The panel convinced Metro that the future of modeling would be beyond the trip based paradigm to fully consider travel as derived from the participation in activities. Such ideas had been percolating for years in academic circles, but had not been applied at a metropolitan level by a planning agency. Metro designed their travel survey to cover both travel behaviors and activity participation, even when those resulted in no travel, such as dining at home. The survey was conducted in 1994 and 1995 by NuStats, a firm specializing in travel surveys. An unusual outgrowth of focusing on activity participation was that the reported percentage of trips made on foot was double what had been recorded in previous surveys.

As the Portland survey was being completed in 1995, John Bowman, a student of Moshe Ben-Akiva at MIT, completed a master's thesis that presented a practical approach for implementing an activity based travel demand model *(41)*. The timing of this work was fortuitous. Portland had received a federal grant to study a possible managed toll lane with peak hour pricing. Lawton felt that since the time shifting that would likely be caused by the toll would not be reflected in a trip based model, it was a good opportunity to try out an activity based model which can incorporate time of day decisions. His consultant team, which was initially Mark Bradley and Greig Harvey, but grew to incorporate Cambridge Systematics as well as Ben-Akiva and Bowman, recommended trying out Bowman's day scheduling approach. The resulting Portland Traffic Relief Options Study (PTROS) yielded the first activity based model used in practice by an MPO in the United States *(42)*. To reduce the computational burden, the model used microsimulation of individual trip patterns. The output of this model was a trip list that looked essentially like someone had filled out a travel survey form for the day. The added detail of the actual traveler enabled many more analytical options, particularly for equity for different social groups. The Portland project ran out of funding and many of the kinks were not worked out of the activity based modeling system; however, the approach was applied and improved soon afterward in the City of San Francisco and started the trend among regional planning agencies towards switching from trip to activity based models.

Different formulations of activity based approaches have been favored by different consulting teams. For example, the Parsons Brinckerhoff approach known as CT-RAMP has been applied in Columbus, Atlanta, the Bay Area, Chicago and San Diego while the DaySim formulation that grew out of Portland has been applied in Sacramento. As with the earliest CATS model the alumni of the early activity based modeling efforts have spread the idea widely. The actual applications however tend to reflect specific policy concerns of the implementing agency. For example, the Bay Area was interested in pricing and equity impacts while SACOG is focused on smart growth. Nonetheless, the general policy that is underlying the transition to these models is a desire to manage the demand for travel. Such a concern represents an about face from the earliest models that sought explicitly to meet that demand.

5 EXPERTS VIEWS ON THE STATE OF MODELING

A key part of my research protocol was to interview experts in the field.

5.1 Purpose of Travel Demand Modeling at MPOs

To frame this portion of my research, I sought experts' opinions on the purpose of travel demand modeling at MPOs. Their responses were bifurcated between the ideal role of modeling and the real role of modeling in practice.

5.1.1 Ideal Role of Modeling

There was consensus among experts that the ideal role of travel demand modeling at MPOs is to inform decision making.

Experts emphasized that modeling should not be considered as a decision making device as they incorporate so much inherent uncertainty and remain open to manipulation. Models, as simplifications of highly complex systems, cannot claim to either represent or foresee all relevant factors. Instead models rely on reasonable assumptions and these assumptions should be made clear to the decision makers. Furthermore, since models have so many components, they are susceptible to manipulation which may skew their results. Experts noted that while this manipulation may be intentional or unintentional, decision makers should not blindly defer to modeling in making decisions; rather, models should be considered a tool within the planning toolbox.

The modeling tool exists to bring disciplined, rigorous, and neutral analysis to systems that are too complicated to be considered through intuition alone. Modeling should enable planners and decision makers to think through difficult problems. Because models yield fine grained results, they allow the calculation of impacts of different options, which facilitate comparisons. Such comparison is possible because model relationships are specified and somewhat transparent.

Experts noted three conditions of how models are applied to fulfilling their purpose. Models should be an exploratory tool as they represent a relatively inexpensive way to try out scenarios (when compared to the costs of the actual policy implementation). One modeler noted that models provide "good bang for the buck." Models should be applied broadly rather than in isolated situations, such as infrastructure expansion. One expert expressed this position succinctly stating, "I think models are the main tools to do planning. Period." Finally, models should be used for comparing scenarios among each other, not as definitive predictions of future conditions. Given modeling's limitations and the unforeseen developments that are bound to occur, "models will never be good at forecasting 25 to 30 years into the future." The potency of modeling is in comparing likely outcomes of proposed policies given what is currently known about metropolitan areas. Ideally, the relative differences between model outputs should be compared. Furthermore, this comparison is only useful when the proposed interventions are applied to a number of base scenarios with varied assumptions. These three conditions work together to promote the ideal use of travel demand models at MPOs.

5.1.2 Real Role of Modeling

Whether the ideal role of modeling is fulfilled hinges on whether the models themselves are applied properly and whether their results are taken seriously by policy makers.

To preface the discussion of whether models are applied properly, it must be noted that in many cases models are not applied at all. Most commonly, models are not employed due to resource constraints. One expert gave the example of evacuation planning for a small coastal community. A travel demand model could inform such necessary planning, but many small communities do not maintain a model. Alternatively, a model may not be applied because it lacks sensitivity to a specific policy concern. For example, non-motorized travel has historically not been incorporated into travel demand models with the result that the modeling tool can not be applied to many active transportation policies.

Models are often not applied well at MPOs. Instead of being used broadly as an exploratory tool for plan development they are used narrowly as a confirmatory tool to meet legislative requirements, particularly regarding air quality conformance and capital project design. Air quality conformity, which threatens all MPOs with a loss of federal funding if it is not met, was seen as particularly problematic for good modeling practice. One expert noted air quality "conformity is what it is all about in a lot of places. The model is not helping to develop plans. It is just ratifying that those plans are OK after the fact." To demonstrate conformity, modelers are encouraged to manipulate the regional model until it yields conforming results. This represents a less than ideal use of the modeling tool. Similarly, models are often applied to consideration of major capital projects. Here, it is common to test all the alternative plans on the same, relatively optimistic basic economic scenario, eliminating the modeling power of examining multiple conditions. In both cases, modeling is being used episodically and reactively, rather than continuously and proactively. Such use limits modeler, planner, and decision maker familiarity with the model and consequently for its application.

For models to achieve their role at MPOs, they must both be appropriately applied and taken seriously by decision makers. The experts interviewed all noted that MPO decision makers have varying levels of confidence in the results of travel demand models. As confidence wanes decision makers are less likely to request the technical analysis to inform policy and more likely to ignore it when offered.

A history of poor modeling practice at an MPO is seen as the major factor in reducing decision maker trust in model results. Modelers have oversold the technology to suggest that forecasts are facts or that the tool can address more policy issues than it can. When forecasts turn out to be rather inaccurate (or current predictions seem unreasonable), decision makers lose faith in modeling. A related problem is that modelers have not effectively educated decision makers so they know how the tool works and when and where it can be helpful for informing policy. At other times, modeler have been too timid and either given politicians the results that they wanted or been paralyzed by the search for the right answer and given politicians nothing. One expert noted the problem of the quality of modelers, that "some modelers are not creative in how you use models." Often times the better modelers at weaker agencies leave for better career satisfaction at consulting firms or larger agencies leaving a hole in the modeling. In other cases, modelers are honest in saying "Sorry, can't help you" with the result being that decision makers cease to ask for their input into decision making.

By contrast, when the technical process is highly regarded internally at the MPO or has a public constituency decision makers take models more seriously. Factors that contribute to a high internal regard included whether the executive director has a technical background or is at least friendly to modeling and values the technical analysis and understands its limits. Similarly if the technical staff is able to articulate their value and advocate for resources. This in turn leads to stronger modeling at the agency and a reduced reliance on outsourcing and modeling thus becomes a more regular part of the agency operations. Such MPOs are thought to be in the faster growing western and southern states who are facing major development pressures and, as one expert noted, often have strong pro-environment constituencies. Two MPOs were noted for successfully creating a public constituency for modeling through taking the tools to the public through visioning exercises, namely the Sacramento Area Council of Governments (SACOG) and Metro, Portland Oregon's MPO. That public support in turn is believed to influence the decision makers.

This description hints at what one expert called the "Chicken and the Egg" Problem between decision maker confidence in modeling and the quality of the modeling. If confidence is low to begin with decision makers are unlikely to allocate resources for technical analysis resulting in poor modeling confirming the earlier perceptions which in turn reduce the faith in modeling. Instead of such a vicious cycle, there are places experiencing a virtuous cycle through which a positive conception of modeling leads to more funding which leads to better results which confirms the initial perception and repeats the cycle. It was felt that a vicious cycle could be turned around with modeling staff engaged with planners and decision makers leading to targeted model investments and clear successes and more investments. In general, the areas with the most engaged staff and the decision makers who take models seriously were seen as having the most advanced practices.

5.2 State of the Practice

Academics, consultants, and MPO experts all hailed activity based models as the state of the practice. These new models are seen as providing a much firmer behavioral basis for understanding travel demand, particularly at the individual level. These models are seen to expand the range of policy analysis to more easily and finely consider mode, price, destination, and time of day options and constraints as well as to consider more nuanced demand shifts to potential policies. This commitment to activity based modeling can be seen in the major MPOs, many of which have embarked on a process of developing activity based models over the last five years.

Although the trend to model development is accelerating, there is very little practical experience with activity based models at MPOs. No MPO has been identified that is exclusively running an activity based models. More commonly, MPOs continue to do most of their required analysis with the trip based model while they experiment with the new activity based one. Some MPOs intend to maintain the models side by side to compare results while other are planning on dumping the trip based model once they feel confident in their activity based model.

The novelty of activity based models at MPOs has been somewhat problematic. There are concerns that both MPOs and consultants are not entirely sure of what to do with the new models, in part because they offer many new potential features. It has been noted that consultants often deliver models without ensuring that the MPO can adequately run them with the result that the MPO reverts back to the older trip based models. The MPOs that had extensive modeling staffs and worked closely with their consultant teams were seen as faring better than those who outsourced the development work to a greater degree. Each activity based modeling implementation remains a very customized affair with contractors altering the model to respond to the policy concerns and data constraints of a given MPO. In some cases, these implementations share many features and MPOs with closely related models may work together to develop their models.

Several experts looked beyond the activity based paradigm to argue that the state of the practice was to integrate the travel demand model with either a land use model, which forecasts future land use distributions, or a dynamic traffic assignment model (DTA), which simulates driver adaptation on a network. There has been little experience using dynamic traffic assignment models for metropolitan regions. These remain better suited, currently, to subregional analysis, but there is work underway to scale these models up for an entire region.

By contrast, there has been a number of state of the practice models at MPOs that combine travel demand and land use models. Perhaps the most noted integration is the Portland Metro model that has been used extensively for policy development. Although Portland was a pioneer of the activity based travel demand modeling, their land use integration uses a simpler trip based model. Areas that have attempted to integrate activity based models with land use models have found it challenging. The land use models iterate far faster than the activity based models. They offer much more policy sensitivity, but a lot more overhead as their results are not so cut and dry and require significant review by an analyst. One expert suggested that for the near term these might be viewed as complementary tools rather than fully integrated ones.

Federal officials represented one dissenting voice to the chorus of praise for activity based models. They questioned whether a transition to activity based models would be effective for many MPOs, particularly the smaller ones. Instead, they preferred to have MPOs determine their policy concerns and then select a modeling approach that best met their needs rather than jumping on the activity based modeling bandwagon. There was concern that the focus on activity based models had crowded out other approaches that might be more effective. One official identified several small MPOs that had implemented creative solutions using traditional models to effectively address their policy concerns. There is a philosophical split between tweaking the four step models and embarking on the activity based world where there are not a lot of extant examples.

This dissenting position would like to gather more evidence on activity based models to ensure that their theoretically improved level of policy sensitivity carries through in practice. They would like to compare the results of trip based and activity based models to see if the newer approaches actually return better outputs. The Mid-Ohio Regional Planning Commission (MORPC) is currently undertaking such a comparison in Columbus, Ohio. However, this consideration is rare. More commonly, MPOs that have invested in the new models want to use them. One expert expressed this position against maintaining an old model for comparative purposes. He argues that “the old model is wrong by definition. The new one is the best that you have.” He described trip based models “like old men who can’t do much, but have experience at the things that the old model is designed to do” whereas the new models are like babies, who are untested but have vastly more potential.

The dissenting line of thought also argued for best practices rather than the most advanced ones. “MPOs would be better off focusing on the basics before getting in the deep end of doing what other MPOs do, which is invest a lot in activity based modeling.” Specific suggestions include investing wisely in the data needed to answer questions, analyzing models more closely to understand where they work and where they do not, ensuring the data is clean, ensuring the networks are well coded, examining model sensitivity, and testing model results against reality, either through backcasting, running the model for a near term year and comparing results, or before and after studies with major infrastructure projects. Too often modelers will avoid directly addressing problems in a model by doing a model update with new data, rather than seeing where the model went wrong. One official noted, “Getting the theory right may not be as important as getting the model right.” Ideally of course such modeling practices should accompany any modeling effort.

5.3 Future Improvements

Experts noted three major areas for future improvement for travel demand models, namely theory, data, and application.

5.3.1 Theory

A major concern about the current state of modeling is that it remains cross-sectional rather than longitudinal. Models predict how people, given their current habits, would travel given a new set of infrastructures and policies, but they do not model how people will actually adapt their behavior to the new situation nor how their own behaviors will change over time. This lack of information represents a weakness in using models for policy formation as they do not directly consider how people will actually change their behaviors. Therefore, adding dynamic elements to modeling is seen as a critical future improvement.

A second theoretical area for model improvement relates to the unit of analysis in the model. Experts praise the trend towards increased consideration of individual agents that is taking place with the development of activity based models; however, an important area of future improvement is to better account for agent interaction, particularly within a household. Increased consideration of the household as a key modeling unit would better account for coupling of trips and the distribution of activities that actually occurs. There is also concern for better considering agent interactions beyond household members. For example, two co-workers may decide to eat dinner together after work which would shift their return to home trips to a later hour. These interactions are currently ill-considered in travel demand modeling.

Much of the future improvements to travel demand models relate to the theory of the choices made within the model. One general concern about choices is that they might be more successful using a bounded rationality or satisficing model than an optimizing model.

Activity choice remains a poorly understood element in travel demand modeling. There is a need to understand more about why people choose their activities, how activities are linked, and among those linked activities, which ones are the ones that are mandatory and that are used to characterize the trip. There is a need to understand real-time activity scheduling. Some work on the dynamics of scheduling on models in Europe is addressing these concerns. Furthermore, there is a need to understand which type of activity participations will actually lead to a trip being made. For example, with the array of on-demand services, one need not leave his or her home to see a movie.

Closely related to activity choice is time of day choice. There is need to understand scheduling flexibility/rigidity. Currently, models only know when activities were performed. Future improvements would understand what constrains scheduling and when certain activities may actually be pursued.

There is need to improve the models of vehicle ownership and type choice. This concern is particularly relevant as there are increasing numbers of alternative technologies to the internal combustion engine. To address the air quality and climate change concerns that dominate much of current modeling it is critical to accurately consider the new range of vehicles that are on the road. Similarly, vehicle ownership is becoming a more flexible concept as car sharing grows in popularity in urban areas.

Route choice also need to incorporate dynamic elements as current assumptions about people's willingness to change route to optimize their travel are unrealistic. For models to be more accurate, they will need to incorporate the stickiness through which drivers cling to preferred routes rather than alter them.

There is tremendous amount of work to be done to improve the theory undergirding location choice / trip distribution models. One expert decried current approaches saying, "People do not want to talk about this because it is not easy; it is a can of worms." Historically, modelers in the US "just calibrate like crazy." The transition to activity based models does not solve this problem as the reasons why people choose one location over other remains unclear. Future work must better determine the choice set that was considered by the traveler rather than the current practice of "shooting in the dark based on some measures of accessibility or activity."

Finally, in aggregate the choice sets afforded to each user of the transportation system are too large to effectively compute. As a result, heuristics are used to constrain the choice set. There needs to be more research to confirm the appropriateness of these heuristics as they can strongly influence the model outputs. Another related problem is the order in which the choices are sequenced. Again, more research needs to be undertaken to ensure that the order of the choices is appropriate.

There is some concern about improving the supply side of travel demand modeling. Experts have called for more nuanced network models that better characterize how travel times change throughout the day and feedback loops that can return that information back to the choice models. There is also a need to better understand travel time reliability across a network.

5.3.2 Integration

A major area for model improvement is in integrating the travel demand model with complementary models. Experts repeatedly used the term "holy grail" to refer to different aspects of model integration. In composite, an ideal model would integrate land use, travel demand, and dynamic traffic assignment models into a single system. Such a model would also provide direct linkages to an emission model rather than the current approach which just considers total VMT outputs from models. Furthermore, an ideal model could be run in real time to provide feedback at public meetings and have native tools for displaying the outcomes of runs visually.

The underlying land use form determines a huge portion of travel demand. Despite this understanding, there are often very limited feedback loops between transportation and land use development. One expert likened not considering the developing land use as “working with one hand tied behind your back.” Another lamented that “you can’t just build [transportation] for a certain land use” because the land use changes with the transportation network along the way. The barriers to integration seem to have two main etiologies. The first is that land use modelers comprise a different community from travel demand modelers. The second is that these models run at very different rates, which complicates their joint use. A solution offered for the first problem is improved data interchange standards that would enable each community to use the other’s data. A solution for the second problem is to either improve the computational rates for travel demand models, which are the speed laggards, or restructuring travel demand models to be optimized for integration. One possible example of the later situation occurs in Portland. As mentioned earlier, although the MPO has an advanced activity based model, it uses its legacy trip based model in its state of the practice land use and travel integrated model. Another possibility, is to reconsider the boundary between land use and travel models and shift some of the longer term choices, such as car ownership or job location, from travel demand to land use models.

In terms of integrating travel demand models with dynamic traffic assignment models there are several areas for future improvement. First, many of the DTA models are designed by private companies for intersection use. These need work to function at a regional level. Second, these models are designed for the trip based world in which the outputs of the model are a trip table. Currently, most activity based models run similarly, so they can feed their outputs into the DTA model. However, that sequential use does not provide the feedback loops that truly constitute integration. At a minimum, the information on how travel times are changing throughout the day should inform the choice models. A more advanced approach would be “to really tightly couple activity based models and dynamic traffic assignment models . . . to choose route and the duration of every stop along the way simultaneously.” Given that activity based models remain highly tailored for each implementation there has not developed a standard linkage to DTA. SACOG is the most advanced in this regard and is making strides with funding from the Federal Highway Administration (FHWA).

5.3.3 Data

Many of the future improvements discussed above will require new or better data collection. In terms of new data, improved models will need panel data to introduce dynamic elements, an explicit accounting of who else participated in an activity to improve interaction elements, information on how new computing and telecommunication technology use impacts traveling, and more information on discretionary travel. In terms of better data, efforts will need to be made to minimize gaps in the survey record. Such gaps are particularly prevalent for the travel of children. Small children are often excluded from surveys altogether and, when they are included, less concern is given to make sure that the data is complete. In a household travel model approach children’s behavior is important and often structures that of the adults. These behaviors need to be more thoroughly recorded. One tool that experts noted might be promising for data collection is GPS, where a traveler would carry around a GPS recorder and when prompted list the activity being undertaken. Other critical gaps include freight movement data, which is collected, but typically proprietary, and land use data, particularly pricing data which is chronically incomplete due to uneven property transfers.

Many future modeling improvements also require more efficient approaches to data management and exchange. Currently, many distinct agencies collect transportation data; however, there is little sharing of this information among agencies. For example, a transit agency will collect ridership data while a state highway department will collect traffic flow data and a city department of transportation will maintain signal timing information. These data streams are all likely to facilitate travel demand modeling efforts, but they are often separate, stovepiped endeavors. There is need for data interchange standards to facilitate interoperability between modeling efforts. The data bases could be directly connected or possibly managed by a data clearinghouse that could shield sensitive information while still offering broad access.

5.3.4 Applications

Many of the future improvement relate to how travel demand models are applied in practice.

A major improvement will be to make the advanced practices, which are currently seen as experimental, a part of everyday practice. Many of the MPOs that have developed activity based models outsourced that development. A consequence of this arrangement has been a lack of capacity for many agencies to run the finished models in house. As a result, MPOs that want to use their new model, particularly for analyses that may not have been a part of the original work plan, must return to the consultants. This reliance on consultants is costly in terms of both time and money. The extended turnaround time of contracting out work is thought to reduce the ability to consider and develop scenarios. In many cases, MPOs will chose to avoid the expense of outsourcing entirely and use simpler methods to do the analysis. Such back of the envelope calculations, by their nature, cannot incorporate the same nuances of an activity based model. As a result, many of the benefits of advanced models go unrealized in practice and other agencies examining the practice of leading MPOs may chose not to pursue advanced modeling techniques as impractical.

A second set of application improvements relates to the assumptions made to facilitate running advanced models. Fundamentally, there is a need to rewrite activity based models to run faster. State of the practice implementations run such models across multiple computers each with multiple processors and still take overnight to finish. This runtime is too long for active everyday use. Currently, several assumptions are employed to expedite model runs. One assumption is the structuring of the choice sets as noted above. Another assumption is the classification of trip chains by their ‘mandatory’ activity. There needs to be more research to understand how this classification should be made. Assumptions are made to artificially fill in gaps in the travel habit survey data that is the basis for the travel demand model. While improved data collection is certainly primary, there is a need to improve the algorithims for filling these gaps. Finally, the assumptions regarding the uncertainty of the model need to be more explicit and ideally carried through each modeling process. While many experts feel the probabilistic nature of the new activity based models is a major advance, they do fear that some of this information is lost in the application of the model.

Another area for improvement in model application relates to the functioning of models within an MPO environment to serve the needs of policy makers. A longstanding problem of modeling continues into the activity based era, namely the desire to tweak results for policy makers. Investments in new models may actually further this desire as modelers anxious to show that the new investment was worth it will alter outputs so that they conform to expectations. For example, a modeler may alter the speed/flow outputs so that one or the other variables will appear reasonable to policy makers. Future improvements will need to be made to discourage such tweaking. One area for improvement is to create programs to allow models to generate scenarios and indicators for policy generation. The indicators should ideally go beyond common ones such as VMT to include broader indices of quality of life or environmental friendliness. Finally, public agencies are likely to be served by having a hierarchy of models, all of which are consistent with each other. Such multi-level modeling is another future improvement to model application. Some have argued that California is currently moving in that direction with its statewide and regional models.

The last major improvement for model application relates to how modelers learn from their modeling efforts. There is seen to be a real need for modelers to spend time understanding and refining their models. As one expert noted "Currently the strength of activity based models is that they have a lot more sensitivity, but we don't know that the sensitivities are really correct. The way to learn that is over time to see if they really work." Some programs have attempted to institutionalize this examination, most notably the Federal Transit Administration (FTA) New Starts requirements for before and after studies for major transit infrastructure investments. However, these programs take resources and, when not mandatory, are scarcely employed.

5.4 Key Innovations in Practice

To consider how modeling innovations enter practice, experts were asked to identify what constitutes an innovation and major innovations in the course of modeling history.
One expert described a model innovation as "something that substantially and substantively changes the way we do modeling, presumably for the better. It enhances the utility of the model for policy and decision making." Another emphasized that innovations respond to a generally perceived need. This approach requires that a problem be identified whose solution requires a novel approach. This approach also suggests that there is often a community of people working in parallel on a modeling problem that is able to recognize an innovation. Such a social view reflects the views of one expert who referred to innovation as "opportunity within a network."

Experts all noted the key innovation of discrete choice in travel demand modeling starting in the 1970s. Previously models had assumed mode splits by traffic analysis zone, a procedure that left no possibility for modal shifts in response to changing travel policies. This assumption seemed fine in the initial design of models which were aimed at assessing the need for new highways; however, as policy makers became interested in transit, particularly as an alternative to road construction, the models were clearly inadequate. While researchers initially considered varying approaches, the field coalesced around probability choice. This approach was strongly influenced by contemporaneous work in other fields, especially mathematical psychology which was trying to understand why people behaved the way that they did.

The introduction of discrete choice was, in the words of one expert, "a game changer." This innovation improves the technical ability to model decision making while introducing a strong behavioral basis into modeling. Over time discrete choice has been extended from the modal decision to other factors, such as car and household ownership. The increasing concern for air quality is seen as furthering the entry of discrete choice into the practice of travel demand modeling.

Another key modeling innovation that emerged in the 1970s was the user equilibrium assignment algorithm. Previous approaches at network assignment were ad hoc and lacked a strong theoretical and mathematical basis. Researchers combined mathematics, theory, and operations research to find a solution procedure. The Frank-Wolfe algorithm was considered the key breakthrough for computing a network equilibrium in a computationally tractable manner. This new assignment procedure added a new rigor to modeling.

A third critical innovation in travel demand modeling is activity based modeling. Its history is more diffuse. There was a general realization that traditional travel demand modeling lacked a behavioral basis. The activity paradigm replaced the trip as the unit of analysis with the tour which began to couple behaviors, incorporate more feedback, and take into account time throughout the day rather than at a single period.

It has taken a long time to develop practical methods to move activity based modeling from an academic idea to a reality. Such methods relate to a series of ancillary technologies including advances in estimation procedures, improved survey methods that include geo-coding, improved ability to handle larger data sets, integration of GIS, availability of parcel level land use data sets, advances in computer processing, and the development of object oriented programming to facilitate writing all of the necessary software.

Among MPOs Portland Metro is generally believed to have had the first activity based model, but this model is not actively used. More recently, there has been a series of activity based models introduced by different consulting firms. Experts tended to refer to MORPC and SACOG as having the first functional activity based models. The New York region's best practice model is also cited as a forerunner as the New York region incorporated so many zones that focusing on households seemed easier.

The last major innovation in travel demand modeling is microsimulation. Such agent based modeling is the logical way to implement discrete choice models and completes that trend to a more behavioral framework. Microsimulation is continuing to develop and only beginning to enter actual modeling practice. In practice, it is closely related to the activity based paradigm. Some experts thought that activity based modeling is implicit in an agent based approach.

Microsimulation is particularly relevant for the land use and dynamic traffic assignment models that support travel demand modeling. Microsimulation has transformed land use modeling from an allocation to a pricing problem. Similarly, microsimulation of traffic patterns has developed the field of dynamic traffic assignment. This field came out of intelligent transportation systems (ITS) research, which introduces computing to infrastructure management and operation. DTA was applied to the planning for Boston's Big Dig and since entered planning.

5.5 Implementing Modeling Innovation at MPOs

Finally, the question of what factors modulate the implementation of innovation in travel demand modeling at MPOs was explored with the experts. The responses covered a broad territory. This section organizes these into three main categories: private actors, public actors, and the MPOs themselves. The private and public actors represent forces external to the MPO that structure the environment within the MPO, while the MPO discussion focuses on internal factors.

5.5.1 Private Actors

There are three main groups of private actors that affect the implementation of innovation at MPOs. These are academics, consultants, and software developers.

Academics originate and test many of the modeling innovations through their research. Since academics rarely have the opportunity to extensively work out their ideas within the context of a practical modeling system, their efforts typically explore narrow slices of the larger picture. These slices are often tested on abstracted data sets and are not easily translated into practice. Some experts felt that the creation of new knowledge that drives academics may be in conflict with what modeling practitioners need.

Rarely, do academics work directly as consultants and thus have a wider purview to implement their ideas. Two notable efforts in California are the development of the new SCAG model by a team of academics and the statewide modeling project lead by UC Davis. Some academics would like to see more interactions between research and practice on the assumption that these interactions would inform theory and speed the transfer of new ideas to practice. It should be noted that land use modeling practice remains closely tied to academics.

More commonly, academics influence practice through indirect means. For example, academics train the professionals who staff both consulting firms and planning agencies. Academics may also seed consulting firms to implement their ideas or provide an advisory role to consultants. Finally, academics often populate public boards which set transportation policy. In California, many of the new modeling requirements in the most recent statewide transportation guidelines were drafted by a UC professor.

Consulting firms are seen as the prime translator of innovative ideas into actual practice. They keep abreast of the latest research through alliances with universities, professional forums, and following literature. The construction of innovative models entails some risk for the consulting firm. One expert noted that "PB [the consulting firm Parsons Brinkerhoff] lost its shirt on Columbus['s MORPC model] as everything was from scratch." All consulting firms need to manage their risk and profit the most by replicating work they have already done, both factors may cause them to act in ways that slow innovation. Nonetheless, experts interviewed identified a short list of "usual suspects" that are driving the transition to activity based models in the US, namely PB, Cambridge Systematics, and to a lesser extent Resource Systems Group. These firms see profit in supplying the most cutting edge technology.

These leading edge consulting firms affect the implementation of MPO innovation in two ways. First, they are commonly hired to guide MPOs in a learning process that both explores the MPO's modeling needs and ambitions and introduces the MPO to the existing universe of advanced modeling solutions. This approach can appear like a conflict of interests as the consulting firm has an incentive to advocate for its own product. An alternative method that has been used by some MPOs, for example the Chicago Metropolitan Agency for Planning (CMAP) and the Dallas-area North Central Texas Council of Governments (NCTCOG), is to invite representatives from each firm in together to discuss and debate their approaches. Second, these firms actually build the advanced models for the MPO. Experts noted that this arrangement could take several forms depending on the level of MPO participation. For example, the consultant may build the model largely on its own or alternatively may do so in a more integrated fashion with the MPO. The latter approach is thought to better translate an understanding of the new techniques to the client.

Software developers also provide a critical role in mediating the implementation of innovation. They have an economic incentive to introduce new features to MPOs. One expert noted "software companies are the least celebrated actors in modeling and may have the largest impact." This impact comes both through providing the software frameworks to implement models and the accompanying support and training to use the software. However, if innovations outpace the vendors, software companies may hinder the update of the innovation. For example, since "vendor support provides a comfort level and a lifeline," MPOs hesitate to invest in innovations that do not have tried and tested software from a major vendor. Furthermore, given the sunk costs of committing to a particularly software framework, MPOs resist innovations that might cause them to switch. The activity based model implementations to date have all been built with custom software, although portions, such as travel assignment, may use some of the commercially vended product.

5.5.2 Public Actors

The main two public actors are the different levels of government and the organized public themselves.

The federal government is the most influential in moderating the implementation of modeling innovation at MPOs, primarily through legislative directives, sponsoring research, and promoting knowledge dissemination.

Federal legislative directives largely structure modeling at MPOs. Federal law requires modeling for long range transportation planning, to ensure air quality conformity, and for building new transit infrastructure. These requirements have kept modeling viable, as without them many smaller MPOs may have jettisoned their modeling programs, but it also impedes modeling's advance as MPOs are wary of altering their model structures in any way that would cause them to no longer be in compliance with these regulations. One expert said that these regulations “put a straitjacket on modeling” as each requires separate criteria. Often these criteria represent a lowest common denominator of modeling to ensure that MPOs will be able to fulfill the requirements, but that limits the more innovative MPOs from trying new approaches. The standardized nature of these analyses also encourages them to be considered official forecasts of the future rather than a good means to analyze policy. This reification can ultimately limit the role of modeling. Furthermore, these rules encourage modelers to be conservative in order to have as much similarity as possible among the model outputs. In short, the federal requirements currently discourage innovation and to date all MPOs with more innovative models, except SACOG, still use their older models for such regulatory work. There is some hope, particularly among the government experts, that the next federal transportation bill will include statutes to require performance based planning. As of December 2011, that bill has yet to pass. Such planning would establish indicators that would need to be derived from models and likely result in a wave of innovation implementation. Another area of success has been the lawsuits which the federal regulations make possible. Actual lawsuits or fear of lawsuits, has led to innovation in modeling over the years. In some cases, the environmental activists who sued later worked closely with the MPO to craft the new modeling policies.

The federal sponsoring of research has also affected innovation at MPOs. Compared to the initial development of these models, very little federal money is flowing to research or to the development of new models. A generation ago, the federal government accelerated innovation by developing and distributing software for running all elements of the travel demand models. This Urban Transportation Planning System (UTPS) software was seen as critical for lowering the entry threshold for engaging in innovation. However, ultimately the UTPS system was seen as limiting the market of modeling ideas and stifling innovation; as a result, the government has funded different programs directly rather than attempting to create a single unified software suite. This new process has been bumpy. The most notable effort was the TRANSIMS project, through which researchers at Los Alamos were to reconceptualize travel demand models from the ground up. However, the TRANSIMS license was initially proprietary which stalled dissemination. Currently, that project has become open source and the federal government is trying to balance the incentive structure of software developers with the federal interest in that software being widely available. One well received program among academics has been the university transportation center program, through which federal funds are directed to research, which has been seen as an effective way to develop new modeling techniques. A major failure has been in the analysis of the comparative benefits of innovations, particularly of activity based models. One expert called this the “justification gap.” There is a shortage of documentation explaining why the new models are worth the investment or which of the new models work better than others. There is a real need to develop this data to provide effective guidance to MPOs that are considering investing in innovation. In the interim, researchers and consultants are clamoring to advance their particular vision of where modeling should be.

The federal government seems to be succeeding in disseminating ideas. The TMIP program has become a clearinghouse for documentation on modeling innovation as well as offering an on-line forum for information sharing among the interested community (as well as webinars, research series, peer reviews, etc). The multiple conferences sponsored by the Transportation Research Board have become critical arenas in which theorists and practitioners come together to hear about the latest work. There was a special push among several TRB committees to accelerate the introduction of activity based models into practice which appears to have been successful. Furthermore, the peer review system that TMIP has encouraged which brings in academics, consultants, and MPO modelers to review models, has been highly effective for sharing ideas among MPOs. MPOs are highly motivated to participate in these programs as they offer an imprimatur of credibility to their efforts.

In the absence of federal leadership, some states have been more active in encouraging modeling innovation. California's recent greenhouse gas reduction legislation (SB 375) has set the type of performance standards that experts hope to see in the next federal transportation bill. While in California, the revised modeling guidelines are technically recommendations and not requirements, the state's major MPOs have viewed them as required and are innovating accordingly. Furthermore, the recommendations have also encouraged smaller MPO regions, such as those in the state's Central Valley, to embark on an activity based model far sooner than an equilavalent MPO would do elsewhere. Part of the motivation for implementing these innovations is that the state has made available money for planning grants that must be used on improving modeling programs. Despite these successes, many California modelers remain confused about the practical modeling requirements of SB 375, which again bespeaks the need for better guidance.

Public sentiment has proven to be a strong indirect push to implementing model innovation. In many cities, it has been the public demand for policies that are difficult to analyze with the older models that has resulted in model innovation. This impact can be clearly seen in the MPOs that have been more active in engaging the public in the planning process, for example in Portland or Denver, where extensive community visioning exercises were held. While this element has been important historically, as the resistance to increased urban highway building led to modeling innovation regarding modal choice in the 1970s, currently public pressure on many fronts simultaneously, from smart growth to social equity, is encouraging MPOs to find better ways, and invest in better models, to address their policy concerns.

5.5.3 MPOs

MPOs, for their part, are facing a planning environment with greater needs but smaller budgets. In trying to understand more financially constrained tradeoffs in policies, many are finding their existing travel demand models inadequate. Those legacy models were designed for an era that was interested in major infrastructure development and then more recently regional air quality; however, neither of these uses required a very detailed understanding of travel or a high level of spatial or temporal resolution. Now MPOs are focusing on more subtle questions such as time shifting and smart growth and social equity, which are not natively addressed in trip based models. One expert noted "there is a revolutionary change in the kind of questions we want to ask models and the penalties for getting those answers wrong has really put a lot of pressure on people to start changing the models."

Nonetheless, the existing production demands at MPOs make innovation difficult. The legacy models, while limited in sensitivity, still take a lot of work to maintain. These older models are designed to meet the existing federal requirements, yet meeting those requirements while maintaining the old models take a tremendous amount of labor. As a result, MPOs have great difficulty working steadily and incrementally to improve their modeling programs. One expert described the existing production demands as leaving the modelers "up to their waist in alligators."

Ideally, MPOs would like to maintain two modeling tracks, an operational track with the current model and a development track where improvements are explored. As improvements prove useful (and stable), these would then be incorporated into the operational model. However, even these ongoing investments are costly. MPOs often lack the professional capacity for undertaking this development in house and will thus need to hire consultants to do the work or at a minimum to provide training so that the work can be done in house. This expense can seem superfluous and is often deferred. Thus models often remain somewhat static until updating becomes unavoidable. Such crisis situations may reduce the willingness for MPOs and consultants to invest in much innovation. For example, if the MPO has a tight time frame and budget, the consultant may offer a smaller, less risky scope of work to ensure they are successful. In other words, a crisis is not a great environment for innovation. Furthermore, waiting until many improvements need to be made at once is likely to increase the complexity of the upgrade which makes setbacks more common.

Another factor that may inhibit active model development is that "MPOs are conservative creatures" who are wary of investing in technologies that are seen as experimental, such as activity based modeling. One expert noted "agencies loathe to be the first kid on the block to do something. They would rather be the second or third one in." Modelers who seek to implement major new approaches will need to have the strong support of the executive director and the board. Garnering this support is likely to require not only a strong vision and commitment to the project but the ability to effectively advocate. In some MPOs, the executive director is the former head of modeling and therefore in a slightly better position for supporting such technical change and those MPOs are generally more technically innovative.

One insight that runs slightly counter to this discussion, is that some MPO leaders take great pride in having the most advanced methods and being able to give more complete answers to policy questions. As different structures (conference, peer reviews, etc) develop that bring MPO leadership in contact, competition does develop among them. This competition can be a powerful force for trailblazing, particularly for MPOs who suddenly appear behind. For example, the Southern California Area Governments' (SCAG) commitment to hiring an academic team to design its model is seen as a way for the Los Angeles region to try to catch up and overtake its peer institutions in California, all of which have been significantly more innovative to date. Collaboration among peer institutions is seen as a way of reducing the risk of investing in activity based models. Notably, the Bay Area's Metropolitan Transportation Commission (MTC) and the Atlanta Regional Commission (ARC) worked very closely together on their activity based models as did the Denver Regional Council of Governments (DRCOG) and SACOG.

The peer comparisons may also prove useful for convincing political boards of the wisdom of transitioning to a new modeling approach. The relationship of the political boards to the modeling process varies. As noted earlier, a long history of poor modeling may have reduced the trust of politicians in their MPO's technical activities. Nonetheless, the most innovative MPOs have successfully educated their boards as to the value of the modeling and the boards actively seek model results. However, even for less engaged boards, the knowledge that peer institutions are investing in a certain way, may prove compelling and improve their ability to invest several million dollars in a process that could take up to a decade to come to fruition. The danger, of course, of following the herd is that the course may not be correct. The dissenters to the rush to embrace the activity based paradigm, as noted above, would like MPOs to remain more circumspect. One noteworthy case is CMAP for whom the entire board was reconfigured as it shifted from a state to a regional agency. The new board very much wanted to set a new tone and encourage a change from previous methods in many arenas, including modeling.

The modeling staff at MPOs plays a critical role in innovation. As noted earlier, they play a critical role in advocating for resources for such change among the MPO leadership. Modeling leadership sets the tone for innovation and willingness to take risks to solve difficult problems. In many cases, such as Portland or Dallas, the head of modeling can leave but the commitment to innovation remains. In some cases, such as Columbus, the pace of innovation flagged with the departure of the head modeler. The quality of the modeling environment is particularly important as the practitioners with the most advanced skills are likely to be able to find much higher paying jobs within the private sector. Activist work environments are seen as important for retaining the best staff. Such staff is more capable of making changes in house, of understanding changes made by consultants, or of making sure they get the work they contracted for with consultants. A problem with finding good staff is there is no good training route to arrive at the profession. The successful candidates tend to marry a programming background with a strong interest in planning. The formal professional education of planners (and engineers) does not really provide all the skills. In some cases, modeling staff is seen as resistant to new methods as change may threaten their position at the agency. Some experts feel therefore that in certain cases it is not the modelers, but the higher up planning staff that is demanding innovation.

There are some particular elements to activity based models that make them a complicated innovation for MPOs to implement. These models offer many new possibilities and modelers are unsure of how to use them, particularly if the modelers are used to the limitations of the older travel demand models. Thus, the model capabilities are seen as advancing faster than the agency's ability to exploit them. These models are sufficiently distinct from existing models that MPOs have had trouble investing in them incrementally. A more incremental process would facilitate the transition for MPOs. The technology for such models remains very customized and lacks standardized components. As a result, many MPOs are waiting in the wings until there are more established structures for them to base any change on. Similarly, there is currently no possibility of transitioning in house. There is limited ability to transfer models from one region to the next which keeps the costs high. There has been some effort in this direction. Notably, the MTC did import model components from ARC that were seen as transferable. Finally, there are still concerns about these models presenting outputs that serve the policy makers. For example, their more probabilistic outputs, which vary with each model run, are seen as a challenge to meeting federal requirements, which results in a continued reliance on the older deterministic models, which return consistent results.

6 TRAVEL DEMAND MODELING FOR THE SAN FRANCISCO BAY AREA

The San Francisco Bay Area represents a region that has led the nation in implementing innovation in travel demand modeling practice. Its landmark MTCFCAST model of the late 1970s was "the first to fully incorporate theories of disaggregate choice into an operating and functioning forecasting system" *(43)* and was heralded as "the most ambitious planning application of individual choice models yet attempted" *(44)*. A quarter century later, modeling experts acknowledged that the region's MPO "took a large risk in the early [19]70s with early model development, and advanced the state of the art. Its pioneering work became the starting point for many others in the nation" *(45)*. Despite these encomia from modeling experts, the modeling practitioners for the Bay Area were not entirely pleased with the result. The models focused on individual behavior but they did not produce cordon count traffic flows that were any more accurate than those of previous aggregate models. The combination of this dissatisfaction and the large investment in this new approach deterred future model risk taking. In the years following MTCFCAST's development, relatively little innovation was made at the MPO level. Only recently, with the development of an activity-based model, has the region begun again to adopt innovative new modeling practices.

The modeling history of the MTC can be divided into four time periods. The first time period saw the MPO come somewhat late to the game of travel demand modeling and seeking, not entirely successfully, to quickly become a major player. The second time period, saw the MPO become the most innovative MPO in implementing disaggregate choice methods within travel demand modeling. This transition reflected the acute sensitivity of the region to a shift in planning trends from major infrastructure to ongoing planning and programming. This period was followed by a long period of maintenance, in large part because the innovations already incorporated in the model were not readily superseded by newer technologies. However eventually, newer approaches did emerge and the MTC once again was in the position of playing technological catch-up with its development of an activity-based model.

6.1 Modeling Catch Up 1965 - 1974

Metropolitan modeling occurred relatively late in the San Francisco Bay Area because metropolitan planning occurred relatively late. The polycentric nature of the region had stymied attempts at metropolitan planning *(46)* until the 1962 Highway Act threatened a loss of federal highway funding. The region responded by creating a metropolitan transportation planning body, the Bay Area Transportation Study Commission (BATSC), and the subsequent development of a travel demand model. This linkage is clearly noted in BATSC's study design which states, "in order to qualify the Bay Area for the continuation of federal transportation grants, the Study will -- at the earliest practical time -- develop advanced analytical capabilities [i.e. travel demand models] to test and evaluate transportation proposals within the framework of a comprehensive regional transportation planning process" [i.e. BATSC] *(47)*. This quotation also signifies a traditional conception of modeling's objectives as the testing of proposed infrastructure policies. The study specified its transportation infrastructure evaluation criteria as meeting the anticipated travel demand *(47)*. This approach of using travel models to identify future demand and then seeking to develop transportation infrastructure policy to meet that demand is a classic example of what has been subsequently termed the "predict and provide" approach to planning, in which modeling is a tool for prediction.

The BATSC planners addressed concerns about modeling innovation in their original study design. They recognized that the field of travel demand modeling was "comparatively new and subject to extremely rapid development, especially because it is closely related to the swift advancement of computer technology." To allow for future development, they used a modular design approach which would facilitate piecemeal upgrading as new techniques emerged. BATSC sought to take advantage, where possible, of the proven model components disseminated by the Bureau of Public Roads, while still injecting some innovation. The study design noted that "it has seemed advisable to augment existing methods with new techniques which greatly expand the ability to prepare and test alternative planning proposals" *(47)*. This targeted innovation reflected the tight time schedule the agency was facing and its consequent need to limit risk, while still demonstrating to its peers that it was a leading agency during this time of rapid modeling implementation. The BATSC final report reveals this pride concern by stating "almost every urban transportation planning study (including ours, we are pleased to know) adds to our ability to analyze and understand complex urban interactions" *(48)*.

The BATSC model development began with a short form travel survey of roughly 30,000 households *(48)* which accounted for 2% of households in the region *(49)*. All trips over a single day for each household member over four were recorded. These surveys were taken for all days of the week (to include weekend travel).[5] This data collection was extremely expensive, a fact that would deter later modeling efforts.

The completed BATSC model was quite similar to others of its era, the classic four-step, trip-based models. Modal split was applied on a zone-to-zone basis according to a derived formula which compared transit use to the ratio of transit and auto travel times. One innovation of the BATSC model was that these formulas were stratified based on the residential density of the production end of the trip to provide a finer grain of transit diversion *(50)*. The ambitious attempts to advance modeling practice often were dropped due to the pressing time demands for model outputs. For example, BATSC had hoped to use regressions based on individual household characteristics for home-based trip purposes, but lacked the time to complete this work and relied instead on traditional, but less theoretically robust regressions based on the aggregated zonal characteristics *(51)*.

The modeling resolution was "intended to supply sufficient level of detail to meet the needs of regional transportation planning and traffic engineering throughout the Bay Area" *(47)*. The focus was on highway and transit infrastructure and the proposed interventions were presented in these two categories. As a result, the analysis zones were relatively large with only 291 zones describing the entire Bay Area. Similarly, the information on walking trips, which was collected in the survey and accounted for a fair number of trips, was left out of the model. The study did anticipate that future efforts would use higher resolutions, particularly as computer technology facilitated those calculations. In general, the study was quite self aware that the BATSC model was a first take on regional modeling for the Bay Area and was therefore the first step in a long process of urban inquiry. "There is still much to learn and much that will be learned in the years immediately ahead" *(48)*.

In 1969, BATSC completed its mission. The effort cost over $5 million, roughly 60% of which went to data collection. The technical work of the modeling cost $1.1 million dollars and accounted for 19% of the project budget. A factor that eased these high costs was that four-fifths of the total costs were covered by the federal government *(48)*.

The state was legally required to maintain the metropolitan transportation planning function that BATSC had developed and thus created a successor organization, the Regional Transportation Planning Committee (RTPC). The RTPC was a joint agreement with the Association of Bay Area Governments (ABAG), the land use and demographic planning agency, and the California Division of Highways, and served somewhat as a placeholder agency. The RTPC did not embark on any major modeling efforts, but did provide a venue for much of the BATSC technical documentation to

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[5] Interestingly, there was also a long form travel habit survey of 2,500 households which included additional data on "household mobility, migration, location history, and seasonal trips" *(48)*. The longitudinal information is generally lacking in travel behavior analyses.

be completed. In 1970, California designated a permanent agency charged with metropolitan transportation planning, the Metropolitan Transportation Commission (MTC) *(52)*.

While regional planning authority was transitioning to the MTC, local transit agencies had independently begun five major transit trunk-line extension studies by 1972. Three of these studies were within the BART district. A fourth looked at rapid transit from the San Francisco airport to the southern border of San Mateo County, while the fifth looked at the corridor from San Francisco through Marin and Sonoma Counties. Since these studies all required transit patronage forecasts and were also likely to impact each other, the MTC joined BART and the California Division of Highways (renamed the California Department of Transportation or Caltrans in 1973) in the Regional Transit Travel Projection Project (RTTPP) *(49)* to provide a common data base and forecasting system. BART directly managed this project, but under the guidance of a technical advisory committee composed of BART, MTC, Caltrans, and local agencies. The MTC also supplied staff for the work *(52)*. The models developed were to become MTC's "long range transportation planning tools" *(49)*. This project marks the first time that the regional transportation agencies largely outsourced model development to a consulting firm. Wilbur Smith and Associates was hired as the lead contractor with DeLeuw Cather and Company as a subcontractor *(52)*.

The RTTPP model was designed to predict peak and off-peak transit patronage by considering the response to the proposed transit extensions and different possibilities for transit access. The model relied on the 1965 travel survey as well as the 1970 census journey to work information. No additional data collection was undertaken.

The main innovation in this model was to consider the choice of travel mode and the trip destination as an interrelated decision with a modified binomial logit function to determine the probability of choosing either the auto or transit mode. A similar modified logit model was also intended to be used for the transit access submodel, but this was never realized. These models were made for stratifications of the zonal population, not yet for disaggregated individuals, so they did not yet truly consider actual choices. This approach was taken to make the models more sensitive to the main policy concern which was transit introduction *(49)*. The parameters were estimated by trial and error to fit the data from the 1965 survey, not through statistical estimation *(53)*.

The RTTPP model development was cut short due to a lack of time and money and the forecasting system was therefore never validated *(49)*; The ongoing "lack of an appropriate mode choice model" at the MTC was criticized by an Environmental Protection Agency (EPA) study in 1973 as "the most obvious data gap in the region" *(54)*. Such concerns raised by the RTTPP experience spurred local discussions regarding the future direction of modeling. "The MTC staff sought new approaches for improving the accuracy of Bay Area travel models, and for increasing the responsiveness to agency information needs" *(52)*. This approach would lead away from long term models solely focused on infrastructure, to new methods focused on a variety of planning needs.

6.2 Setting the Curve for Model Innovation 1974 - 1980

Two concurrent developments altered the planning environment to move the Bay Area into the forefront of travel demand modeling. First, the legislation that created the MTC framed a new emphasis on short range, strategic planning, which in turn necessitated a new planning tool. Second, the ongoing transit infrastructure development in the region fostered extensive experimentation and research into disaggregate modeling methods at the University of California, Berkeley. The new technical approaches were seen as critical to fulfilling the new planning mandate.

The 1970 act that created the MTC also defined its major task in the form of the Regional Transportation Plan (RTP). The RTP was being developed in a very different era from that which had preceded it. Highway revolts had halted controversial roadbuilding in the Bay Area and many other cities. Federal programs to build new transit lines and refurbish existing ones had been established. Environmental protection laws had been passed, including the Clean Air Act, which required metropolitan areas that did not meet federal ambient air quality standards to develop transportation control plans. The changing times and new programs and requirements significantly shifted the role of transportation planning from that which had previously occurred. The RTP guidance emphasized

> short range programming, promotion of transit as an alternative to the auto, evaluation of a wide range of impacts [including social equity, environmental quality, energy use, and land activity shifts], conducting an open decision making process, emphasizing corridor level planning, modal coordination, and the reinforcement of urban development and environmental goals *(55)*.

This vision is quite distinct from the one that preceded it. Previously, transportation planning focused on the construction of major infrastructure, particularly highways, considered only user impacts, without differentiation by social group, emphasized region wide planning, projected out 20 to 25 years, limited public engagement (and the existence of conflict), and assumed the planned system would be constructed with only minor changes. Now, transportation planning included a focus on operational policies and explicitly sought a reduction in automobile use, considered impacts on a differentiated population as well as to the environment and land development, focused on a range of geographies, including subregional ones, projected for different time frames, assumed public engagement (and the need to resolve conflicts) and anticipated that the plan would be revised and amended on a yearly basis *(55)*.

While the MTC was participating in the RTTPP effort for forecasting the demand for transit infrastructure, researchers at the University of California, Berkeley were investigating far more sophisticated tools to address the same topic through the Travel Demand Forecasting Project (TDFP). This project was designed "to provide transportation engineers and planners with the information necessary to select and use policy-oriented disaggregate behavioral travel demand models" *(36)*. Since the TDFP focused on the BART system as a test case, the MTC was very aware of its efforts and contributed financially to some of its data collection *(43)* which would later be used in the future MTC model development *(56)*. As a result, the MTC was relatively well informed about emerging modeling options. "An evaluation of the MTC modeling needs was undertaken by MTC management in 1974. Other regional agencies and transit operators were sympathetic towards a quantum jump in the state of the art of travel forecasting. It was decided to put the region in the forefront and have a commitment to a continued effort in model development" *(53)*.

In November 1974, the MTC issued an RFP for the Travel Forecasting Model Development Project (TMDP). The projects purpose was:

> To develop an operational travel forecasting model system for MTC to use as a tool in its transportation planning effort. The models developed are to be efficient, up-to-date, easy to use, reliable and must help answer policy relevant questions. The effort in this project is to apply the knowledge and experience gained from the development of models in the Bay Area and in other national studies to the task of revising, improving and completing the existing MTC system of transportation models *(49)*.

MTC selected a consultant team of Comsis Corporation, Cambridge Systematics, Inc., and Barton-Aschman Associates, Inc. who split the work into two phases. The first phase addressed what the model should look like and the second phase constructed the model *(56)*. The design phase helped identify that the new legislative requirements would result in models helping to clarify the goals to be addressed in the annual RTP review. The consultants envisioned this process as highly iterative and therefore would need to create a tool that could be run easily enough to support such cycles *(55)*. The specific requirements for the Phase II development, according to the consultant, were

> Validity: The system must accurately represent travel behavior, which occurs as a result of an interconnected set of household and individual decisions;
>
> Comprehensiveness: The system must represent the full range of urban travel decisions;
>
> Policy relevance: The system must be sensitive to all relevant policy options; and
>
> Flexibility: The system must be usable for analysis at varying levels of detail and spatial and time scales *(37)*.

The consultants saw disaggregate approaches as critical to achieving these goals *(37)* yet were constrained by the MTC requirement to fit the new work within the established structures of modeling *(49)*. Their solution was a hybrid approach through which a new set of disaggregate demand models would fit within the traditional UTPS four-step structure and software.

The core innovation of the new demand models was to recognize that travel behaviors are the outcome of choice processes by individuals and households and to represent all travel-related choices within the model. The models structured the theoretically unlimited choice possibilities into a tractable tripartite set of relationships, which the model authors termed a "hierarchy of choice." The levels corresponded to the temporal nature of the choices. The highest level defined the urban development decisions which are long run in nature, such as where employers locate jobs and where developers locate residences. The decisions at this level were calculated by MTC's land use model and given as inputs to the travel demand model. The second level of the hierarchy defined the household mobility decisions which are medium term in nature, such as where to live and work, how many cars to own, and what modes to use for work trips. This choice level included a separation of primary ("breadwinner") and secondary workers within a household, based on the highest income level. The lowest level of the hierarchy defined the daily travel decisions which are short run in nature, such as scheduling non-work trips and choosing the time of day and route for work and non-work trips *(37)*.

The choices at the lower levels were conditional upon those made at a higher level. For example, if you chose not to own a car, you would not have that option available for a shopping trip. Conversely, feedback from the lower level models was included in the decision of the higher level models. For example, the decision to own a car may be affected by the level of service by transit for shopping purposes. The model would therefore include a measure of transit accessibility within the decision to purchase a vehicle. These composite variables, meant to represent a general condition (e.g. ease of shopping on transit) rather than one's particular shopping trip, were calculated in ways that were consistent with the model structure, a major advance in the field *(37)*.

The model retained the traditional three trip purposes of Home-Based Work, Home-Based Other (although these were further split into Home-Based Shopping and Home-Based Social-Recreational), and Non-Home Based trips and, while it improved the choice modeling for these last type of trips, did not yet fully consider them as chained tours. Similarly, the model only considered traditional travel modes thus excluding truck, taxi, or non-motorized trips. Despite the commitment to choice, the time of day and vehicle occupancy decisions were modeled based on historical data rather than any decision process. Similarly, the choice models resulted in a travel demand that was input into the conventional UTPS route assignment module. Therefore, route choices were not modeled as behavioral choices *(37)*.

While all the models were generated at the disaggregate level, the resulting trips were aggregated for analysis at the zonal level. The model designers note that this aggregation adds more possibility for refinement as each component can be tested at either the disaggregate or the aggregate level. The disaggregate approach uses the same data base as for a traditional model, in this case, the data from the 1965 BATS survey. However, disaggregation does reduce the sample size necessary to yield statistically significant parameters since each observed trip can be included in the model rather than aggregating to produce an average trip. Aggregating the disaggregate data did result in aggregation bias, when the average behavior of all households varies from the behavior of an average household. To address this problem, the model designers manually adjusted the utilities of the destination choice alternatives to add distance related factors to match observed trip length distribution. Additional adjustment factors were used to reflect the travel between actual zones *(37)*.

The model designers presented the MTC with two model application procedures. The first was called MTCFCAST and represents an alternative to the demand component of the traditional four step model within the UTPS package. This aggregate tool is designed for detailed regional analysis in the short or long term. The authors touted the integration with the UTPS system as "greatly enhancing the effectiveness of MTCFCAST" *(37)*. Others recognized this integration as a constraining compromise which discarded much of the value of choice modeling *(38)* as the disaggregate information needs to be aggregated in some way. MTCFCAST tried to retain some nuance of the underlying data by aggregating based on market segmentations defined by income levels and auto ownership levels. The second model application procedure was called SRGP, and was a tool for short-range generalized policy analysis. SRGP was a sample enumeration model that takes a subset of the travel survey and examines how each of those households would change their travel behavior given a policy change. The SRGP model had no component to predict changes in the long term choices of the population, which limited its use to analysis to under five years, but also made it capable of very rapid turnaround times *(37)*. The SRGP model had five main data bases. The included the households and their existing travel patterns, the zone to zone travel times and costs, the demographic and land use characteristics of the zones, the coefficients estimated as part of disaggregate modeling exercise, and an accounting of the changes made to describe various policies for testing. The model was augmented in short order with auto emissions and fuel consumption modules. The SRGP model, by examining an impact for each household individually, represented an early use of microsimulation within travel demand modeling and took full advantage of the underlying model disaggregation *(38)*.

The designers of the MTCFCAST model recognized that fitting a disaggregate demand approach into an aggregate forecasting model framework entailed some compromise. They argued that such a model is relevant to the new policy environment that emphasizes less capital intensive interventions and requires less survey data to estimate. Furthermore, the SRGP model provides a highly detailed and inexpensive tool to quickly analyze a range of policies, thus returning disaggregate advantages that are somewhat lost in the full modeling tool. The only disadvantage to these tools, according to their designers, was the increased complexity of more submodels requiring estimation, a process which practitioners were not yet entirely ready to take on *(37)*.

Those practitioners at the MTC were not as pleased with the outcome of the TMDP project and chose to publicly report their unhappiness with the project as an addendum to two articles in the Transportation Research Record in which the model designers presented their products. The MTC response was based largely on their work with the MTCFCAST model as the MPO had not worked much with the SRGP model at the time. The practitioners stated that "our position is one of concern that the models may not do the job we need or may not do it within reasonable time and resources constraints." They argued that although "a claim made for these models is that they represent travel decision-making behavior. Experience with our models indicates that such claims may be somewhat inflated." The model required significant manual adjustments to match existing trip patterns and the MTC feared these changes would not be appropriate for predicting future travel demand. The MTC was upset that the model designers were unable "to identify a function that adequately and consistently reproduced trip distribution behavior." They found the consultants solution of adding a distance correction variable by district of production which was determined through trial and error to be unsatisfying as "this is reminiscent of the traditional fitting of older trip distribution functions (friction factors)." The MTC felt that the work mode choice, which was the focus of most of the disaggregate effort, should at least perform well and were again let down by the model which required adjustment factors. MTC found that extensive data processing was necessary to run the model and the cost of each run, at $6,000 in 1978, was prohibitive. They questioned whether behavioral claims were valid given the amount of adjustments that needed to be made, noted that subsets from the survey had too large an effect on the model estimation, and posited that the extensive adjustments suggests that the models were not transferable *(57)*.

The model designers responded that adjustments of constants in a logit model "do not change in any way the behavioral validity of the relative weights estimated statistically for the variables of the model." They reiterated that a disaggregate model contains more relevant variables and requires fewer observations for model estimation. They argued that the trip length adjustments vary by distance and by trip purpose, which reflect behavioral processes rather than analyst adjustments. They argued that the running costs are low compared to aggregate models and will drop further when the MTC uses the SRGP model. They voiced concern that "the technical quality and capability of the model system are not being taken full advantage of by the agency for which it has been developed." If they had to do the project over, the designers would have "rather than "formulating and estimating additional model components" put more effort "on thoroughly testing and validating the fewer model components estimated. This strategy is required to prevent the disillusionment likely to occur when, near the end of the model development process, some component produces unreasonable results under certain input assumptions." They would have spent less time on MTCFCAST and more time on SRGP, which is potentially more cost effective for many of the questions asked by the MPO. They also would have put more effort on "ensuring, throughout the project, that the end product be precisely what is needed to meet the agency's planning needs and that the agency staff have full knowledge of the end product and complete facility in using it." They note that "the problems of implementing and successfully using a major new model system require a large amount of cooperative effort by modelers and practitioners to be completely solved" *(58)*.

While this model was not well received by the MPO, it was heralded by academics and featured as state of the practice in three landmark texts *(44, 59, 60)*, a point of pride subsequently for the MTC *(53)*. The MTC did further develop the SRGP model, calling its improved version the Short-Range Transportation Evaluation Program (STEP), but "after a flurry of exploratory activity with STEP, MTC lost interest in it" as the MPO focused instead on collecting new travel data to update the 1965 survey information *(38)*.

6.3 Model Maintenance and Simplification 1980 - 2005

In the long aftermath of the TMDP effort, the MTC shifted its approach from ambitious model creation to model maintenance and tweaking. During this period, the MPO coordinated major data collection efforts with the decennial census. These efforts would be followed by model re-estimation and refinement. These developments were carried out over typically eight-year time frames. An outside consultant was only hired briefly to provide training on discrete choice estimation to MTC staff. All other modeling work was conducted in house. A 1989 recounting of the MTC model development process characterized this era well by commenting that "continuity is seen as the key to maintaining and updating regional travel demand model systems" *(53)*.

As noted above, all the modeling in the Bay Area had been based on the costly 1965 survey. By the late 1970s, the MTC thought that the extensive new provision of transit in the region had likely altered travel patterns and that new travel data should be collected, but was concerned about the costs of such an effort. The TDFP project at the University of California, Berkeley had shown that smaller samples could be sufficient for estimating disaggregate models. The MTC opted to supplement the 1980 decennial census with a smaller travel survey of 7,100 households in 1981 *(53)*.

The new data offered an opportunity to update the MTFCAST model, a project which was taken on entirely in-house *(43)*. This project was designed to make the MTFCAST model easier to use, primarily by reducing the complexity of the non-work travel model. "The idea was to keep the main structure of work trip models and to introduce warranted simplifications wherever possible" *(53)*. The non-work trip model had its innovative logit destination choice submodel replaced with a traditional gravity model based on off-peak door-to-door highway times *(61)* and its feedback loops to work trips removed. The MTC did make one addition to the model to add sensitivity to a new policy concern. The work trip mode choice model was extended to distinguish between two- and three-occupant vehicles for consideration of HOV lane projects *(53)*. This model became known as MTCFCAST-80/81, based on the years of the travel survey, and was completed in 1988.

While the MTC was finishing the development of MTCFCAST-80/81, the MPO was forced to implement its contingency plan having failed to attain the federal air quality standards by 1987. The plan called for a detailed review of the impacts of all new highway investments in the region. The agreed-upon methodology required the consideration of feedback loops in MTCFCAST that were not typically analyzed due to the time it would take to program them. The MTC recognized that the mothballed STEP model, which retained all those feedback elements, would provide a more expedient alternative to address these concerns and devised a way for STEP to calculate new trip tables for inclusion in MTCFCAST. In 1988, STEP was again used to study transportation control measures considered to meet the new California Clean Air Act. Finally, the STEP model was applied to study congestion pricing on the Bay Bridge *(38)*.

In 1990, the MTC again updated its data base with a large scale travel survey of 10,838 households *(43)* and sought to take advantage of that opportunity to revise its modeling system. The literature surrounding this revision provides insight into the MTC's vision of modeling at the time. "Models are essentially 'decision-support tools' to assist transportation planners and policy makers in analyzing the effectiveness and efficiency of various transportation alternatives in terms of mobility, accessibility, environmental and equity impacts" *(62)*.

The MTC sought to design "an advanced state-of-the-practice trip-based travel forecasting system. . . to be tractable, sophisticated, and user-friendly" as well as to transition the system from a mainframe to a microcomputing environment. The MTC decided to make these changes in house, but contracted with Cambridge Systematics Inc, who had been part of the TMDP team, to provide a set number of hours of in-house tutoring to MTC modeling staff on discrete choice methods *(43)*. This training focused on logit estimation using the elogit software program.

The model produced in 1998 was called the Bay Area Travel Demand Model Forecasting System (BAYCAST-90). The model completed the simplification trend that MTC had introduced with MTCFCAST-80/81 to replacing the difficult to estimate logit choice formulations with gravity ones, this time for the home-based work trip distribution model. Other simplifications included removing the relative transit/highway accessibility variable in the auto ownership model and the primary ("breadwinner")/secondary worker stratification in home based work models.

BAYCAST-90 also added new features. For example, the MTC modeling director had been influenced by the work that had been done in Portland on non-motorized travel, so BAYCAST-90 included such modes for all trip purposes. In general, there was now an extensive use of nested logit choice structures. Home based school trips and truck trips were included in the model for the first time. Household income segmentation was introduced for work trip models, as was a departure time choice model, and auto ownership segmentation was introduced for non-work trips. BAYCAST-90 would consider peak and off-peak periods for both work and non-work trips, while previously work trips were only in the peak period and non-work trips only off peak *(43)*. The time of day model was a binary choice between morning peak and off peak periods to enable consideration of peak spreading *(61)*.

BAYCAST-90 would be the model used for the Regional Transportation Plan (RTP) and for updating the congestion agency model systems, while MTFCAST-80/81 would be updated to the 1990 data for more sensitive analytical purposes, such as corridor analyses. The STEP model would be updated to be called the Short Range Travel Demand Model Forecasting System (SRFCAST) *(61)*.The literature surrounding BAYCAST-90 does note the disadvantages of trip based modeling system and references MTC's interest in tour based approaches that were then underway elsewhere as a likely future course for model development *(43)*. However, the simplifications that were introduced removed many of the advances pioneered in the TMDP program and brought the MTC model system back closer to the average modeling practice.

While the MTC was commencing the BAYCAST-90 development in 1990, a statewide ballot initiative resulted in the creation of congestion management agencies (CMAs) at the county level. These subregional agencies were charged with developing biannual congestion management plans (CMPs) for allocating monies collected with a concomitant increase in the state gas tax. These new agencies increased the market for modeling in the region as the CMAs developed travel demand models to meet their subregional needs. Most CMAs relied on modified forms of BAYCAST-90, however, over time, two CMAs found this framework limiting and invested heavily in new model development. The most notable example of this subregional innovation is the San Francisco County Transportation Authority (SFCTA), which decided in the late 1990s to develop an activity-based model to provide the necessary temporal and spatial resolution to examine the proposed seismic retrofit / replacement of Doyle Drive (US-101), the access road to San Francisco from the Golden Gate Bridge. This model, completed in roughly two years in 2001, became the first activity-based model to be put into continued practice in the US, although not by an MPO. Its successful application to a vast array of planning problems has been a major encouragement to the development of activity-based models elsewhere *(63)*. The second example of subregional innovation is the Santa Clara Valley Transportation Authority (VTA), which is both the transit operator and the CMA. A local ballot initiative in 2000 resulted in a dedicated tax for transportation development. To leverage this funding, the VTA significantly enhanced BAYCAST-90, particularly regarding resolution within Santa Clara County to meet the modeling requirements for the FTA New Start process. The CMA was successful in garnering federal funding for major fixed rail transit extensions in the county.

The decennial census again provided an opportunity for the MTC to collect new travel data and begin to consider changes to its modeling system. In 2000 and 2001 the MTC conducted a two day travel and activity survey from over 15,000 households, with all households, activities, and trip ends geo-coded. These data were to form the basis for the next generation of MTC models *(64)* and were collected at a cost of $1.5 million *(45)*. The MPO has a history of actively analyzing its travel data and spent the early years of this century processing the survey results. MTC began looking ahead to how it would use that data in a new modeling system. Agency staff began to attend training put on by the USDOT Travel Model Improvement Program (TMIP) *(64)*. When the modeling production for the 2005 RTP was completed in 2004, the agency modelers felt they had time for creative work on their travel demand model. Their initial intention was to re-estimate and expand the advanced activity-based model that had been developed previously by the SFCTA with the new survey data. To vet that idea and entertain others, the MTC hosted, in December 2004, a Peer Review Panel sponsored through the USDOT Travel Model Improvement Program (TMIP). The panel included academics, consultants, MPO modelers, and federal representatives who had significant experience with the most advanced models available *(45)*.

"The primary focus of the Peer Review Panel was to review MTC's plans and desires for building the next generation of travel behavior model systems for the San Francisco Bay Area." The MTC presented four possible modeling development tracks. The first was to continue to work with BAYCAST-90, an unlikely option. The second was to update BAYCAST-90 with the new travel data creating a BAYCAST-00. The third was to adopt the specific structure of the SFCTA model and re-estimate it using the new data. The fourth and final track was to adopt the general structure of the SFCTA model as a starting point for an expanded model to be estimated with the new data *(45)*.

The conclusions of the panel were that the MTC should not invest more in BAYCAST-90 as "the expansion plans of many MPOs have often been truncated [at that stage] never making a fundamental paradigm shift." The panelists argued that the value of continued investments in trip based models was limited given their marginal returns in output quality; furthermore, with several extant examples of activity-based implementation, the risks of such approaches had "decreased substantially." The panel thought that in the short term the SFCTA model might suffice, but encouraged quickly expanding upon it, as much knowledge had been gained in the intervening years and new programming and computational technologies were available. One panelist noted "it might be helpful to bootstrap MTC's modeling effort to other current efforts elsewhere in the U.S" rather than committing to the SFCTA approach. That comment led to some debate on the panel about the transferability of models and their parameters. The panelist urged the MTC to take the risk of developing a new model as the appropriate step for a sophisticated MPO. They even referred to the MTC's storied history of innovation from the 1970s as a form of encouragement *(45)*.

The panel also weighed in on MTC's plan to continue to do most of the work with only limited consultant support. The panel affirmed the MTC desire to be actively involved with the model development. One panelist noted "it is important to have staff involved so that they are not just pushing buttons on black boxes. Staff has to lead the consultant direction, not the other way around. Ultimately staff has to take possession of the model systems." Nonetheless, the panelists suggested that the MTC might be overreaching to expect to do so much work in house. The panelists, many of whom were from the leading modeling consulting firms, gently urged the MTC to avail itself of the expertise and additional capacity consultants can provide *(45)*.

6.4 Model Catch Up Part II 2005 - 2011

In April 2005, the MTC returned to a more active pursuit of model innovation. The MPO issued an RFP "to assist MTC staff in developing the next generation of regional travel models for the Bay Area. The intent is to advance from a traditional trip-based modeling system to a tour-based travel/activity modeling system" *(64)*. This action set in motion the model development that is in 2011 being implemented in the preparation of the latest RTP.

It is worth noting that the MTC had been increasingly interested in policies that were not easily modeled with a trip-based approach. Given the development limitations in the region, the MPO has been particularly focused on smart growth, greenhouse gas reduction, and pricing policies, particularly variable pricing for HOT lanes. The MTC, which is actively scrutinized by local non-profits, is very interested in the equity impacts of its policies. One consultant noted, "Activity based models allow you to slice and dice results by any explanatory variable that you want and that was important to MTC."

The model development study was envisioned in two phases with the consultant training and assisting MTC staff in estimating the models in the first phase and development of the model application software, model calibration, and validation in the second phase. This approach honored the 25 year history of no consultant support for MTC modeling, other than the short training course for BAYCAST-90. The consultant was to first provide a training course for the MTC and then later offer mostly guidance, oversight, and debugging during the model estimation phase *(64)*.

In 2005, the MTC began working with Parsons Brinckerhoff (PB) to develop an activity based travel demand model for the Bay Area. The hopes of relying on in-house estimation evaporated early on when a key staffer with the requisite skills and schedule availability left the agency. The MTC changed its approach with PB taking the lead rather than just providing support. PB built a model with its Coordinated Travel – Regional Activity-Based Modeling Platform (CT-RAMP) as its base with components transferred from models already developed for the Atlanta

Regional Commission, the Mid-Ohio Regional Planning Commission, and the San Francisco County Transportation Authority. The Metropolitan Transportation Commission is currently calling this new "Frankenstein model," as it was referred to by one MTC modeler, Travel Model One *(65)*.

Travel Model One uses the existing 1,454 zone system, but further subdivides these according to three levels of transit access. The destination choice models operate at the new subzone level. Decision makers in the model are households and persons, both of which are synthesized based on 2000 census data. The model segments all people into eight distinct and mutually exclusive person types are used to characterize their roles within a household. Four household types are characterized according to income level. The persons in each household are assigned a value of time based on the distributions generated by a toll choice model conducted by the San Francisco County Transportation Authority. Ten activity types are included within the model and their participation is limited to distinct person types. For example, the 'escorting' by car activity is only available to persons age sixteen and older. Activities are scheduled at one hour increments. Eighteen modes are defined. The reason for the high number of modes is that transit modes vary by walk or drive access and auto modes vary by car occupancy. Walk and bike modes are explicitly considered in the model *(24).*

The model design is distinct from a trip-based model. The base input is the synthetic household population. The model predicts the long term choices, defined as work/school location, car ownership, and availability of free parking at the workplace. A daily activity pattern is generated for each person in the household with activities classified as mandatory, non-mandatory, and home. The model links the patterns chosen to consider intra-household interactions. The frequency and time of day for the mandatory activity tours are chosen. Next the model identifies any tours that will be made by more than one member of the household. These joint tours are assigned to include tour participants, destination, and time of day. The non-mandatory tours for individuals are then modeled. Then mode, number of stops, and stop locations are identified. Finally the last set of submodels adds information on trip departure time, trip mode details (for example, if one walked between stores after parking a car), and parking locations for auto trips. The resulting trip tables are then assigned to the appropriate road and transit networks by conventional approaches. The model is run iteratively with network supply conditions being fed back to the demand models *(24).*

Travel Model One was first applied in 2011. The main focus has been on production for the RTP, however it also has been used to examine an additional Bay crossing as well as HOT lanes. PB is contracted to provide support for a series of applications and with the MTC is comparing results from BAYCAST-90 to Travel Model One to understand their comparability. Early signs suggest that Travel Model One is fulfilling expectations, with the chief benefits being expanded analytical capability as well as a far more intuitive reporting to the public since the outputs are trip lists tied to individuals rather than abstract and unconnected trip types.

There are some remaining concerns. First, there is a need for upgrading the model's supply components to offer more detail on land use, transit networks, road networks, and transit analysis zones. Such changes may be necessary to achieve the touted benefits of tracking non-motorized travel. Second, there are concerns that while the model will provide answers to many new queries, it will not be possible to verify that those answers are accurate without validating data. The population synthesizer enables many ways to consider the population, but raises questions about how accurate those slices actually are. This issue may also be critical to understanding non-motorized travel. Unfortunately, the data to validate such analysis may be too difficult to acquire despite improvements in data collection. Third, the new model requires a new way of considering transportation which may at odds with established practice. For example, the close tracking of every tour segment complicates a previously simplistic conception of travel mode. Finally, the Travel Model One takes a lot of time to run well. BAYCAST-90 was not complicated and consequently was run all the time. Presumably, the growing experience with the new model will address these concerns.

7 TRAVEL DEMAND MODELING FOR THE SACRAMENTO REGION

The Sacramento region represents a metropolitan area that is currently leading modeling practice. Its activity-based model, SACSIM, was developed in record time and it is the only such model to consider travel demand at the parcel level. The Sacramento experience is intriguing because the region transformed itself from a modeling laggard to a modeling innovator. This transition from passive to proactive practice can be divided into three phases, which structure this chapter. The first era saw the development of a traditional four step model that remained largely unchanged for two decades. The second era saw a new interest in upgrading the four-step model as the region sought to attract transit funding and to address new air quality requirements. The third era saw a transition to an activity-based model with parcel level data as the region revolutionized its approach to metropolitan planning.

7.1 Mandated Modeling and Little More: 1965 - 1989

As for much of the United States, metropolitan transportation planning, and consequently travel demand modeling, came to Sacramento as a result of the 1962 Highway Act; however, unlike many regions, such as the neighboring San Francisco Bay Area, which took this federal mandate as a challenge to advance practice, the Sacramento region merely fulfilled its minimal modeling obligation.

In 1963, the Sacramento County Planning Commission initiated the creation of the Sacramento Regional Area Planning Commission (SRAPC) *(66)*, as a Council of Governments whose "central purpose [was] to provide a forum for planning and for formulation of recommendations on area-wide problems of mutual interest and concern to its local governments," chief among them maintaining federal support for transportation infrastructure. The commission began its work in January 1965 *(67)* and hired the consultant firm Alan M. Voorhees and Associates to design the transportation study. The design report, published in 1966, called for the State of California Division of Highways, not SRAPC, to handle all of the technical elements of modeling and forecasting *(68)*, thus separating the modeling and planning functions. SRAPC approved the study design in late 1966 for the Sacramento Area Transportation Study (SATS) *(69)*. Between August 1968 and April 1969, SATS interviewed 12,300 households *(70)*. The resulting data were used by the Division of Highways to build the travel demand model in 1970 and 1971 *(67)*. A 1971 SRAPC progress report describes the model development as "slow and difficult" *(69)*, but by 1972, SATS was able to use the model to test different policy scenarios *(67)*.

The SATS model represented a classic trip based, four step model. Trip generation relied on trip rates applied to households in a simple cross classification scheme of housing type and car ownership. Trip distribution allocated trips from production to attraction zones based on a gravity formulation. Since the trip generation and distribution steps did not, on their own, well account for trips observed at certain activity centers, SATS developed special procedures for zones containing air force bases, colleges, shopping centers, hospitals, and the airport. The SATS model, as was common for its era, excluded walking, biking, and motorcycle trips altogether; therefore, mode split was only between transit and automobile travel. Mode split was based on an N-logit model that estimated the transit proportion of Home-Work trips as a function of income and travel costs at a zonal not individual level. Mode shares for other trip purposes or between Auto-Driver and Auto-Passenger were factored from the results of the N-logit model. Trip assignment for car trips generated two possible paths (a true minimum path and one that favors city streets) between origin and destination zones and used a formula to assign a percentage of trips to each route. The SATS assignment neither considered the capacity of the route to handle traffic nor the impact of congestion on travel times. All transit trips were assigned to the minimum path *(71)*.

Soon after its implementation, the model received criticism on several fronts. DeLeuw, Cather & Company *(72)* noted that SATS did not estimate trip generation rates directly for each production zone, that mode choice model was only estimated for Home-Work trips and extended by constants to other purposes, that the travel time inputs to the mode split model assumed free flow conditions and did not properly account for capacity constraints and the resulting congestion. SRAPC *(73)* itself noted that the high cost of running the model made its use prohibitive for most planning applications, but doubted whether funds would be available to streamline the process. Dowling *(71)* identified additional limitations of the model, namely that trip generation was unaffected by factors such as gasoline prices or the availability of new transportation facilities that improved accessibility, that trip distribution was unaffected by changes in travel costs, that mode split was unaffected by off-peak transit or auto improvements, and that the model failed to differentiate costs to an Auto-Driver and those to an Auto-Passenger – a distinction necessary for carpool analysis. Reinke, Harvey, and Deakin *(74)* questioned the decision to rely on the state for running SATS, rather than develop SRAPC's own in-house staff, as a major impediment to timely and thorough response to policy questions. They also identified the weakness of the mode choice model, which did not incorporate the new behavioral approaches being implemented elsewhere, most notably the Bay Area. This privation limited the SATS model's applicability for transit analysis as well as the for the air quality concerns of this non-attainment area.

Two of these criticisms led to changes in modeling practice. First, in January 1981, SRAPC became the Sacramento Area Council of Governments (SACOG) and an informal agreement was made to move the modeling responsibility from the Division of Highways (by then renamed the Department of Transportation) to SACOG *(75)*. This change united the planning and forecasting functions and facilitated use of the model for answering policy questions. Second, in the mid-1980s, SACOG migrated the SATS model from a mainframe application to a less expensive and more accessible microcomputer platform. This transition reduced model costs and also facilitated its use.

The now microcomputer-based model was used to forecast travel demand as part of the 1989 Sacramento Metropolitan Area Transportation Study ('Metro Study') which presciently noted that "alternative land uses, if implemented on a large scale throughout the Metro area, can significantly reduce travel demand" *(75)*. Although the Metro Study was seen as "a pivotal project" for broadly linking planning issues and identifying policies for future study *(76)*, this effort did not result in any advances in the actual modeling tools, which remained rather limited.

7.2 A Shift to Active Modeling: 1989 - 1999

The backdrop for the second era in regional modeling in Sacramento was also new federal statutes, specifically transit New Start requirements and the Clean Air Act Amendments (CAAA). However, interestingly, the change was initiated outside of the MPO at the Sacramento Regional Transit District (RT).

In 1987, RT had opened a new 18.3 mile light rail transit system and by 1989 was seeking to gain federal New Start funding for an extension. New Start funding requirements had been enhanced to require a behaviorally-based mode split model. RT had been unhappy with the SATS approach to mode split and felt the Metro Study, despite its recommendations, had produced results unfavorable for transit. To address this issue, RT undertook its own modeling improvement project as part of its Systems Planning Study from 1989 to 1991 *(76)*.

RT contracted the consulting firm Parsons Brinckerhoff (PB) to build a new mode choice component. PB designed a multinomial logit model with five different modal options of transit and auto travel for home-based work trips. Non-work mode choice remained factored from results of the home-based work trip model *(77)*. The new model was expanded to include 812 traffic analysis zones and was revalidated to 1990 *(76)*. RT handed over this enhanced model to SACOG. This model retrospectively became known as the first of the Sacramento Regional Travel Development Models

(SACMET). By convention, these models are named for the year they are completed, so this model was later referred to as SACMET 91.

RT's actions primed SACOG for a more active engagement with modeling. The 1990 amendments to the Clean Air Act provided the legislative cover for that new involvement. The legislation, in the words of one modeler, "upped the ante on the quantitative analysis that the agency needed to do to show that the RTP and TIP conformed to air quality goals." Such conformity was crucial for SACOG, as the Sacramento region had been designated as a "serious" non-attainment area for ground level ozone pollution. Regions with such a designation are required to develop plans to reduce this health-threatening condition and can lose federal transportation funds for failure to make reasonable progress toward attainment of the standards. The passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) a year later in 1991 further encouraged, without mandating, new modeling practices to achieve its expanded transportation planning requirements.

SACOG saw these new federal requirements as an opportunity to upgrade their model. SACOG began bolstering its in house travel demand modeling capacity by hiring new staff. The MPO sought to repair its relations with modeling consumers, such as RT, by creating an inter-agency modeling task force *(76)*. SACOG prepared for the model upgrade by purchasing additional surveys from the statewide travel surveying effort in 1991 for a total of 4,400 households. Finally, in 1993 the MPO began the effort to upgrade, re-estimate, and validate the model to that new data *(78)*. SACOG brought in a team led by DKS consultants with support from independent consultants Keith Lawton, the head of Portland Metro's advanced modeling process, and Greig Harvey, one of the nation's leading modelers. A federal review of modeling practice at SACOG in 1993 reported the agency's newfound modeling momentum *(76)*.

One area where this more active approach was more obvious was in SACOG's outreach to partner agencies. The RT involvement in SACMET demonstrated clearly how SACOG had not been effectively meeting the needs of local agencies with its model practice. To remedy this situation, and repair relations with RT, SACOG reached out to both gain input for the upgrade and educate partner agencies. The MPO hosted a day- long meeting for people in the public sector in the region to identify what policy issues needed to be included in the model upgrade. The meeting identified the core issues as complying with the CAAA, meeting New Starts criteria, and meeting the specific needs of the Caltrans, the counties, and the cities.

The model that resulted from these efforts was SACMET 94. SACMET 94 included feedback loops from the trip assignment to the generation and distribution steps, added a PM peak period (to an AM peak and Off peak periods) and extended the time periods of the peaks, added bike and walk modes, developed a Pedestrian Environment Factor, created an auto-ownership model, and assigned auto trips in categories based on auto-occupancy *(79)*. SACMET 94 also was the first model in Sacramento to incorporate parking costs and auto operating costs into its mode choice model. These elements reflect national recommendations made for improving modeling practice and *(39)* enabled the model to be sensitive to different policy strategies, such as raising parking prices or gas taxes, the latter of which was occurring in the early 1990s in California *(76)*. SACMET 94 had 1,061 traffic analysis zones *(79)*.

SACMET 94 imported two innovations that had been previously implemented in Portland: the consideration of non-motorized modes and the Pedestrian Environment Factor . This factor is a simpler measure than the one used in Portland as Sacramento has very limited terrain. The introduction of these policies caused led SACOG, in the words of a modeler, "to dip our toe into land use," as they got a hint of modeling smart growth policies.

SACMET 94 also included a new trip purpose for commercial travel with its own three step model (as transit mode choice is not an issue for freight). Previously, commercial vehicle information was hidden in the non-home-based trips. The trip generation rates were based on employment rather than households and SACOG borrowed trips rates from the MTC which had recently done an extensive analysis of truck trips.

The first application of SACMET 94 was to look at HOV lanes on US 50, which resulted in additional model enhancements to look at HOV lanes *(80)*.

After the major development of SACMET 94, subsequent changes to the travel demand model were typically made as part of the preparations of a new metropolitan transportation plan (MTP). These changes were by and large incremental and would include a revalidation to the latest traffic counts as well as small tweaks to improve performance. For example, SACMET 96, which will not be discussed in detail, saw a revalidation of the model to 1994 travel conditions, the re-estimation of some non-work trip attractions, and a re-formulation of transit assignment away from an approach that allocated all work trips to the peak period and non-work trips to the off-peak period to an approach based on the actual time of travel. The zonal system was altered slightly *(79)*. This new pattern of ongoing model maintenance and improvement characterizes this new era of active modeling at SACOG.

SACOG also began to develop its land use modeling capacity, an effort that would ultimately affect its travel demand model. The 1993 federal model review of SACOG had criticized the lack of an automated land use model, particularly as ISTEA sought improved concern for land use – transportation interactions. The review recommended that "SACOG could develop land-use models capable of forecasting the impacts of transportation on land use" *(76)*. These concerns were echoed locally by a University of California, Davis professor, Robert Johnston, who would serve as an important observer of SACOG's modeling approaches. In late 1994, SACOG invested in DRAM/EMPAL, a popular spatial interaction model. The choice of this model was criticized by Prof. Johnston, who argued that, although popular in the US, DRAM/EMPAL lacked a behavioral basis *(81)*. The model was never implemented as SACOG's board was unsupportive of an approach that would take land use projections away from local areas and SACOG lacked the staff resources to commit to the project. Despite the lack of implementation, the land use model development process proved to be useful for SACOG as it forced the MPO to closely examine its employment and household data. This consideration affected the travel demand modeling as employment within SACMET was reclassified from two types, retail and non-retail, into five, and the zone structure was changed to afford more resolution in areas of future growth. With these changes, zones that currently had few residents, and were therefore quite large, were subdivided to better consider likely future changes.

Meanwhile, Prof. Johnston began to independently bring the more behaviorally based land use models, such as TRANUS and MEPLAN, to the Sacramento region as research projects. In both cases, Johnston brought in the developers of these land use models to participate in the model development process and share their knowledge with the researchers at UC Davis, who were in turn in contact with SACOG. Johnston's team and SACOG did pursue a joint project in the late 1990s to compare these models to the SACMET model and the SACMET model running with DRAM/EMPAL *(82)*. These interactions laid the groundwork for future SACOG engagement in behavior-based land use modeling.

The SACMET travel demand model was again updated for the 1999 metropolitan transportation plan. This update warrants special consideration as it "included major revisions to the commercial vehicle submodel" *(79)*. In 1998, SACOG received money to improve their modeling of commercial vehicle trips. The MPO hired the California Trucking Association to interview its members, but only had a five percent response rate. At around this time, Cambridge Systematics, a consulting firm specializing in advanced model development, published a quick-response commercial vehicle travel analysis tool, which SACOG used to update their model. The main change for SACMET 99 was that commercial vehicle trips were segregated to split out all trucks that had more than two axles.

One modeler characterized this era in model building as "SACOG kept making small improvements as they saw problems in the model that they wanted to address as they thought they could do better."

7.3 Innovative Modeling: 1999 - 2011

SACOG embarked on its current era of modeling innovation when its developing culture of improvement intersected with a new policy role of the agency.

With the completion of the 1999 MTP, SACOG's modelers began looking ahead at the next stages of model development. They had been convinced by a University of California, Berkeley travel demand modeler conference that activity-based approaches would soon be operational at a metropolitan level. SACOG wanted to prepare for its possible transition to such advanced methods by ensuring that its upcoming data collection effort would yield sufficient information to enable activity-based model estimation. The statewide survey SACOG had relied upon for its previous data collection was unlikely to be repeated due to funding issues; therefore, the MPO had an opportunity to make its own survey and wanted to make sure that it would consider both travel and activities. SACOG again hired Keith Lawton from Portland Metro, this time to help design the survey based on his experiences in preparing for Portland's activity based model. NuStats, the surveying company that had prepared the Portland survey, also participated in the survey design and were contracted to undertake the survey in the spring of 2000.

SACOG surveyed 3,941 households as part of its efforts. The survey was timed with the census to enable the sample to be appropriately weighted.*(83)*. "All aspects of the household survey (questionnaires, sampling approach, recruitment strategy, data retrieval, and data coding) were carefully designed to allow for the development of the new modeling approaches for the Sacramento region" *(83)*. The survey also served to update SACMET for the 2002 MTP. (SACOG anticipated that it would take three years to develop the activity-based model.) DKS Consultants used the survey data to update SACMET 01 which saw some submodel re-estimation and a full recalibration. The model was revalidated to 1997 data *(79)*.

While its modelers were preparing for a new level of modeling, the public response to the 1999 MTP would result in a transformation in SACOG's role in the region. This transformation would delay SACOG's transition to an activity-based model, but would radically expand the importance of modeling to the MPO.

The 1999 MTP, like all of SACOG's work to that point, was based on combining the transportation plans of the member agencies. SACOG's current executive director noted that "while this approach had a certain perceived benefit to member agencies and partners, it did not optimize the regional travel performance of the transportation system or the air emissions" *(84)*. As a result, the 1999 MTP's "project performance was modest-to-disappointing" *(84)* with no change in transit mode share, despite significant investments, and an increase in per capita VMT, particularly during the congested commute period. The modeling for the MTP suggested that SACOG was going to spend a lot of money and congestion was only going to get worse.

These findings were not warmly received by the environmental community. A coalition of three local groups, the Sierra Club, the Environmental Council of Sacramento (ECOS), and the No Way L.A. Coalition immediately sued SACOG, claiming that the MPO had improperly calculated ozone emissions for the MTP. The suit was intended to block roadway projects included in the plan and encourage greater consideration of transit *(85, 86)*.

SACOG, who had just hired a new executive director, needed to defend its work both legally and in the eyes of the public. Legally, SACOG was found to have calculated its emissions properly. However, the public exposure was more critical. *The Sacramento Bee* sponsored a roundtable discussion which brought together key stakeholders to discuss SACOG's activities and options. Two key points emerged from the discussion. First, SACOG should be a more active regional planning body rather than a repository for subregional plans. Second, SACOG should engage in economic and land use planning, rather than focus only on transportation *(87)*. Regarding the first point, SACOG had begun to move in that direction. A 1997 board statement had endorsed principles for long range regional transportation planning that included 'Be More Proactive in Planning' and had noted that while "SACOG's current role includes convener, facilitator, and educator . . . over the next five years, SACOG will attempt to develop a more proactive role, working towards the development of a regional vision" *(88)*. Regarding the second point, SACOG had since the Metro Study explicitly recognized the potential for land use policy to improve transportation outcomes and had also made some investment in land use models. The problem was there was a lack of political will that SACOG had a role to play in land use policy.

SACOG was determined to take a more active role in regional policy, if not yet explicitly engage in land use planning. The MPO appointed a 55-member Transportation Roundtable to oversee the development of the next MTP. The Roundtable membership was designed to represent a broad range of diverse interests. To bracket the discussion, the Roundtable had SACOG model two scenarios, one in which all the available resources were invested in roads and the other in transit. When the results suggested that neither extreme was promising, the Roundtable promoted a balanced scenario and began to explore land use changes, but did not have time to pursue this very far before the MTP was due in 2002. The resulting *MTP for 2025* was hailed as "a true regional plan and not, as some had pejoratively described prior plans, a stapled complication of the individual plans of the cities, counties and transit operators" *(84)*. Nonetheless, like the previous MTP, the plan projected heavy growth in congestion despite transportation investments. In addition, it became widely accepted that the MPO could not convincingly show attainment of air quality standards, or could only show attainment with high levels of uncertainty and risk. These findings led to a shift in thinking that transport infrastructure alone would not be sufficient, but that SACOG would need to consider land use growth patterns. The *MTP for 2025* thus set the stage for the Sacramento "Blueprint," a planning process designed to articulate a land use transportation vision for the long term future of their region, and identify ways to manage growth so that air quality standards could be attained.

While SACOG had been developing its new proactive regional planning approach in the wake of the 1999 MTP, the modeling staff had managed the travel survey and sought consultants "to design the next generation travel demand forecasting models, which will be used for regional travel forecasting by SACOG" as well as helping SACOG with "reviewing its land use forecasting process and evaluating an integrated land use and travel forecasting model" *(89)*. The consultant teams therefore were to include both travel demand and land use modelers. SACOG ultimately chose between two teams: Cambridge Systematics with Paul Waddell and DKS Consultants, Mark Bradley, and John Bowman with HBA Specto. It appears that the decision came down to the land use model, with SACOG favoring HBA Specto's PECAS model over Paul Waddell's UrbanSim approach. PECAS was seen to have more inherent theory in its input-output base whereas UrbanSim was perceived as requiring extensive amount of data before it could run. SACOG was not confident that those data would be available. SACOG was also acquainted with HBA Specto's principals who ran the MEPLAN model as part of the land use model comparison effort in the mid 1990s.

The Land Use and Transport Model Design project lasted for most of 2001. It began with three outreach sessions to public agencies, as opposed to the one that was conducted for SACMET 94. The agencies determined that linking land use and transportation to understand their interdependence was "a key functional requirement of the new forecasting tools" to address smart growth, road pricing, ITS and environmental justice issues. Agencies were concerned about the credibility and transparency of the new models.

The consultants completed their design approach at the end of 2001. All of the options proposed included a path dependent forecasting approach, simulated behavior, interactivity between land use and travel, and the heavy use of GIS. The selected model, the New Standards Model, was the simplest of the proposed options. It combined an activity based travel model with an input-output economic and land use model. SACOG liked that Bowman and Bradley had tested the activity based concepts previously in Portland and San Francisco and thought that would lead to cost savings *(89)*. In 2003, Bowman and Bradley submitted an addendum to the design report in which they suggested improving the spatial resolution by using locating trip ends at the parcel level *(90)*.

The 2001 proposed model design was put on hold as SACOG shifted to support the Blueprint planning process. While the Blueprint delayed the implementation of more advanced travel demand modeling, it also set the stage for an improved technical approach and elevated the role of modeling (as well as regional planning) within the region. SACOG's executive director fully supported the Blueprint process of scenario planning to define the vision that the Sacramento region sought for itself. The planner hired to manage the Blueprint process was a key developer of the PLACE^{3}S planning method and software. PLACE^{3}S (Planning for Community, Energy, Environmental and Economic Sustainability) is an approach that marries community involvement with a GIS based analytical tool, which assesses and accessibly presents the outcomes of proposed development scenarios. SACOG's commitment to using PLACE^{3}S required an extensive development of its GIS resources, particularly information on zoning, lot size, and ownership of all parcels in the region. This data development effort was substantial as the six county region contained 800,000 parcels *(84)*.

SACOG saw the need for other enhancements to its ability to model change in the region. Specifically, the MPO wanted to predict what a base land use case might look like for 50 years into the future. This vision was necessary to begin the visioning process. SACOG returned to the work that Robert Johnston had done at UC Davis and developed a MEPLAN model with HBA Specto for the region. Although the MPO was already looking ahead to a PECAS implementation, which was to be a more advanced approach, they chose to go with a more established technology to ensure they would get quick turnaround on their product. This MEPLAN implementation represented the first use of an integrated forecasting model in the region *(84)*. MEPLAN allocated growth to 70 major zones and SACOG would sub-allocate that growth by hand within the zones.

SACOG also realized that the changes in land use patterns that they were calling for in PLACE^{3}S were not being reflected in the outputs of SACMET. To remedy this problem, SACOG invested in a model post-processor, which uses elasticities to adjust SACMET outputs, especially trips and vehicle-miles traveled, for changes in density, diversity, design, and access to destinations – traits referred to as the '4Ds.' SACOG would use PLACE^{3}S to determine the land use inputs for SACMET and then run SACMET to determine the travel impacts. These impacts would be adjusted based on the post-processor, which would also be supplied with inputs from PLACE^{3}S *(91)*.

The augmented SACMET remained the core travel demand modeling tool through the adoption of the Blueprint in 2005. At that point, the head of modeling for SACOG pushed for the move to the activity based model planned in the 2001 design report. He argued that there were more examples beyond Portland and San Francisco of a functioning activity based model and that such a model, particularly at the parcel level, was likely to natively have better sensitivities to land use patterns than were currently achieved through the post-processor. These benefits are in addition to the core advantage of activity-based models being able to carry through all travel through tours without losing trips. SACOG developed its activity based model, SACSIM, while preparing for the 2008 MTP and SACSIM was used for a portion of that plan. The development team was the same as those who did the design report in 2001. One of DKS consultants, who had worked at SACOG previously, returned to the MPO which facilitated the model development.

The most notable innovation in the model was the high spatial resolution, with all activities and trip ends coded at the parcel level *(92)*. SACOG had these data in place from its Blueprint process and was committed to the fine grained approach. One modeler noted, "to lose that robustness would be a step back. It is more work, but worth it." SACSIM also represents a fine level of temporal disaggregation with “all activity and travel episodes are identified within a specific 30-minute time period” *(92)*. These attributes also reflect SACOG’s focus on detailed land use planning to affect transportation outcomes. “SACSIM provides SACOG with the capacity to represent detailed land use patterns in travel demand forecasting, and capture the value of good land use / transportation planning, in [a] unique and unprecedented way” *(93)*. The executive director noted “SACOG built the SACSIM model to function at the parcel level to enhance the ability to capture the benefits of fine grained smart growth planning options.” He emphasized the complementarity of PLACE3S and SACSIM with the former providing the inputs to the latter *(84)*.

SACOG has committed to SACSIM for its major modeling uses. In 2008, they used the new model to develop a new air quality plan to enable SACSIM use for conformity. SACOG does retain SACMET for three purposes. First, a simplified version of the travel model with its 4D post processor has been incorporated into the internet based version of PLACE3S. This enables SACOG to further augment their scenario planning in public workshops as they can get almost real time feedback from how a land use scenario will affect transportation performance measures. This online application of SACMET may be unique for travel demand models and was used extensively in preparing *MTP2035* in 2008 *(84)*. Second, the online version can be used with pull down menus for assessing the air quality impacts of local transportation projects. This application is used by SACOG’s partner agencies. Finally, SACMET is maintained for the PECAS, land use model development, although this project seems to have stalled. It should be noted that agencies around the region do retain their own older versions of SACMET for planning purposes.

8 CLIMATE CHANGE AND MODELING: SB 375 AND ITS IMPACTS

Travel demand modeling continues to be a core tool of transportation planning, yet its practice is widely criticized for failing to adopt advances from research, in essence for being 'frozen' in time *(6-8, 10)*. The State of California is in the midst of an aggressive program to remedy this situation. The Golden State has embarked on an ambitious effort to combat climate change and views travel demand modeling as an essential tool to assess whether planned land use and transportation policy interventions will achieve their greenhouse gas (GHG) reduction objectives. Therefore, a portion of California's groundbreaking climate change legislation explicitly aims to advance the travel demand modeling practiced at the state's eighteen metropolitan planning organizations (MPOs). In short, as part of its efforts to avert climate change, the state has raised the heat on the practice of travel demand modeling.

Since California is leading the nation in climate change legislation, the structure of these laws and the nature of their implementation are likely to influence policy in other states, as well as in the nation as a whole. This section examines the legislation and its early impact on changing the travel demand modeling practiced at California's MPOs. This analysis will inform efforts elsewhere to advance the critical, but innovation-resistant practice of travel demand modeling.

In 2006, California committed itself to significant reductions in GHG emissions through the passage of *Assembly Bill 32: The Global Warming Solutions Act*. Subsequent emission inventories and forecasts determined that transportation activities produce the largest share of GHGs and that policies to improve vehicular efficiency and reduce the carbon content of fuels were likely to fall short of the major long-run emissions reductions sought by the state.
Consequently, on September 30, 2008, California enacted *Senate Bill (SB) 375: The Sustainable Communities and Climate Protection Act.*

SB375 established planning requirements to use urban development policy -- specifically transportation and land use measures, such as transit-oriented development and urban infill -- to curb the vehicle-miles traveled (VMT) by automobiles and light trucks and thereby reduce the GHG emissions from the transportation sector. SB375 mandated that the California Air Resources Board (ARB) set GHG reduction targets for each MPO, that the MPOs develop new approaches called Sustainable Community Strategies (SCSs) as part of their Regional Transportation Plan (RTP) to achieve those reductions, and that ARB evaluate and approve the SCSs. Since improved travel demand models are necessary to better support each of these activities, SB375 also mandated the California Transportation Commission (CTC) revise its modeling guidelines *(9)*.

SB 732: Strategic Growth Council, a complementary law, was passed the same day to provide resources to assist MPOs in implementing SB375. SB732 created the Strategic Growth Council (SGC), a cabinet level group, to "recommend policies and investment strategies and priorities to the governor, the legislature, and to appropriate state agencies to encourage the development of sustainable communities." SB732 further authorized the SGC to distribute $90 million for "planning grants and planning incentives . . . to encourage the development of regional and local land use plans" *(94)*. This provision paved the way for state grants to improve travel demand models.

Table 1 identifies four processes created by the new legislation which have directly or indirectly worked to advance modeling. These include revising modeling guidelines, funding model improvements, setting GHG reduction targets, and preparing an SCS. This paper will address the first three processes, but omit the fourth which is still ongoing.

TABLE 1 Four Legislated Processes that Impact Travel Demand Modeling

Impact	Process	Legal Structure		Oversight Agency	Law	Date Achieved
Direct	Revising Modeling Guidelines	California Transportation Commission	CTC	CTC	SB 375	April 7, 2010
	Funding Modeling Improvements	Strategic Growth Council	SGC	Governor's Office	SB 732	Oct. 13, 2009
Indirect	Setting GHG Reduction Targets	Regional Targets Advisory Committee	RTAC	ARB	SB 375	Sept. 30, 2010
	Preparing an SCS	Sustainable Community Strategy	SCS	ARB	SB 375	Varies by MPO based on RTP schedule

8.1 Revising Modeling Guidelines

The revision of the CTC guidelines represents SB375's most explicit and direct attempt to advance metropolitan modeling practice. These guidelines determine acceptable models to be used in the development of RTPs and have been subject to periodic revision.

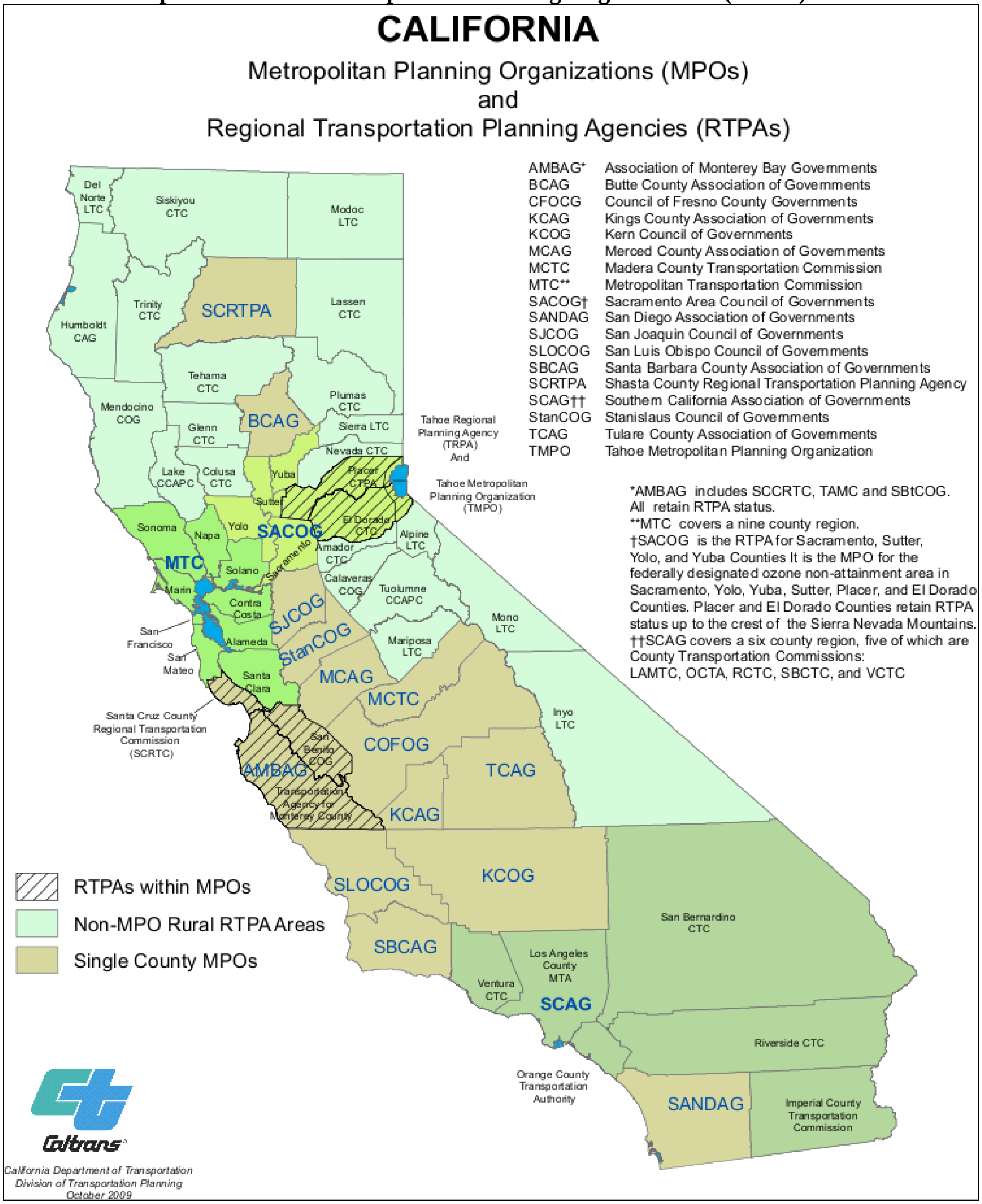
SB375 emphasized expanding the policy sensitivities of the models. The law did not mandate a specific modeling approach, but rather presented a normative position regarding desired, but not required, model functionality:

> current planning models and analytical techniques used for making transportation infrastructure decisions and for air quality planning should be able to assess the effects of policy choices, such as residential development patterns, expanded transit service and accessibility, the walkability of communities, and the use of economic incentives and disincentives *(9)*. (Underlining added)

This phrasing defines preferred model practice by the policies to be supported, not the type of model to be used; although the policies that are listed above are well addressed with advanced modeling techniques. This approach is in concert with SB375's commitment to bottom-up planning through which MPOs choose the methods that work best for them. Similarly, the use of the auxiliary verb 'should' rather than 'shall' implies these objectives are recommended rather than mandatory. By presenting the policies which models 'should' address, SB375 established a clear functional goal, even if it may be postponed to the future.

SB375 also set a minimum level of model functionality that the guidelines 'shall' ensure, namely accounting for the relationship between both density and transit service on vehicle ownership and use, the travel and land use impacts induced by new transport infrastructure, mode splits, and transit service characteristics. The legislation thus delineated the baseline performance threshold of the revised guidelines. However, SB375 provided wiggle room by making these required only "to the extent practicable, taking into account such factors as the size and available resources of the metropolitan planning organization" *(9)*.

FIGURE 1 Map of California Metropolitan Planning Organizations (MPOs)



SB375's language could be read to suggest that the modeling guideline revision process was relatively weak with the law merely encouraging rather than exacting change; however, from another perspective, what seemed problematic was actually rather pragmatic. The MPOs in California vary greatly in terms of population and consequently in terms of planning challenges and resources. SB375 sought to foster change that was tailored to the realities of the state's different regions while maintaining a performance baseline.

There was one area in which SB375 was firm. The legislation required that travel demand modeling practices be made more transparent and intelligible. The law stated that MPOs must make the "methodology, results, and key assumptions" of their travel models available and understandable to the public *(9)*. This daylighting was designed to make models a community asset and to bring in a new degree of public accountability. One issue that remained was whether making data available was inherent in the mandate. Without access to the data being used by the MPOs, the ability of outside groups to test alternatives would be limited.

On July 1, 2009, the CTC created an Advisory Committee to prepare amended guidelines for RTP preparation to account for the new requirements of SB375. The committee met slightly more frequently than monthly and maintained an active discussion on a dedicated listserv and through electronic mail. The revised *2010 Regional Transportation Plan Guidelines* were adopted by the CTC on April 7, 2010. The revisions were particularly focused on the practice of travel demand modeling. To accord with the injunction to create a system that was appropriate for the needs and resources of each MPO, the commission clustered the MPOs into five groups labeled A through E, each with its own travel demand modeling requirements *(95)*.

The guidelines *(95)* define the groups as follows:

A. Administrative units not qualifying for MPO status (not considered in this paper).
B. Regions with attainment AQ [air quality], slow to moderate growth, small population, and no urbanized area or transit having more than a minimal potential impact on VMT.
C. Regions with moderate to rapid growth, non-attainment AQ, or the potential for transit to significantly reduce VMT.
D. Regions that are nonattainment in ozone or CO [carbon monoxide], with a metropolitan planning area containing a population over 200,000.
E. The largest MPOs with rapid growth, large population centers and established transit systems.

Figure 1 presents a map of California MPOs and table 2 clusters these by model group. The groups roughly accord with total regional population. The exception is AMBAG, whose total population would suggest Group D, but remains in Group C because the coastal region lacks a single urbanized area with 200,000 people, the level at which an MPO becomes a transportation management area (TMA) under federal statutes.

The CTC guidelines only require modeling activities that are mandated by federal law. Therefore, Groups B and C share the same requirements and the TMA-designated Groups D and E share a stricter set of requirements. The real innovation of the revised CTC guidelines is therefore not its requirements, but its recommendations.

TABLE 2 California MPO Travel Model Groupings

Group	Metropolitan Planning Organization	Acronym	2009 Pop.	SCS Due	CTC Requirements	*CTC Recommendations*[a]
	Butte County Association of Governments	(BCAG)	220,748	Dec. 2012		
	Kings County Association of Governments	(KCAG)	154,743	July 2014		
	Madera County Transportation Commission	(MCTC)	152,331	Dec. 2013		
B	Merced County Association of Governments	(MCAG)	256,450	July 2014	B	*B*
	San Luis Obispo Council of Governments	(SLOCOG)	270,429	Dec. 2013		
	Shasta County Regional Transportation Planning Agency	(SCRTPA)	180,023	July 2015		
	Tahoe Metropolitan Planning Organization	(TMPO)	55,232[b]	Aug 2012		
	Association of Monterey Bay Governments	(AMBAG)	758,545	Nov. 2013		
C	Santa Barbara County Association of Governments	(SBCAG)	431,312	June 2013	B	*B + C*
	Tulare County Association of Governments	(TCAG)	441,481	Dec. 2013		
	Council of Fresno County Governments	(CFOCG)	942,298	Dec. 2013		
D	Kern Council of Governments	(KCOG)	827,173	July 2014	B + D	*B + C + D*
	San Joaquin Council of Governments	(SJCOG)	689,480	Dec. 2013		
	Stanislaus Council of Governments	(StanCOG)	526,383	Dec. 2013		
	Metropolitan Transportation Commission	(MTC)	7,375,678	April 2013		
E	Sacramento Area Council of Governments	(SACOG)	2,323,112	April 2012	B + D	*B + C + D + E*
	San Diego Association of Governments	(SANDAG)	3,173,407	Oct. 2011		
	Southern California Association of Governments	(SCAG)	18,761,139	April 2012		

(95, 96) [a] This table *italicizes* the CTC *recommendations* to better distinguish them from the requirements.
[b] The population for TMPO is for 2005 *(97)*. Not all of these residents live in California as this region straddles Nevada.

Table 3 summarizes the modeling guidelines. On the whole, the recommendations define a course of increasingly greater modeling complexity at an increasingly higher resolution. Along the way, the travel demand modeling becomes more nuanced and expands its purview to environmental and social equity concerns. The models increasingly gain feedback loops with the goal of having a fully integrated microeconomic-based land use model with an activity-based travel demand model that includes freight movements. To arrive at this endpoint, MPOs are to constantly upgrade their data resources, particularly the GIS layers of the natural and built environment, and their travel survey methodologies. In other words, the recommendations lay out a clear and structured path for advancing modeling practice at MPOs.

TABLE 3 CTC Guidelines for MPO Modeling: Requirements and *Recommendations* [a]

Requirements B ("MPOs shall . . .")	***Recommendations B ("MPOs should . . .")***	***Recommendations C ("MPOs should . . .")***
1. Model a range of alternatives for RTP	*1. Run 3-step models to converge at equilibrium*	*1. Follow all Recommendations B*
2. Forecast travel demand for 20 years ahead	*2. Model land use impacts on travel*	*2. Develop 4-step model*
3. Model criteria pollutants for conformity	*3. Augment models with post-processing*	*3. Run model to converge at equilibrium*
4. Quantify reduction in GHGs due to SCS	*4. Address changes in demographic patterns*	*4. Use simple land use models in short term*
5. Validate data used in model	*5. Develop GIS towards simple land use models*	*5. Develop market based land use models*
6. Forecast travel for people and goods	*6. Enter natural resource data into GIS*	*6. Develop parcel data and an existing layer*
	7. Develop parcel data and an existing layer	*7. Develop digital general plan layer*
	8. Augment model to measure impacts of SCS	*8. Develop and use simple freight model*
	9. Produce mode shares for all five main modes	*9. Use several employment types/ trip purposes*
	10. Calibrate data used in model	*10. Model peak and off-peak periods*
	11. Have a model improvement program	*11. Ensure model yields reasonable road speeds*
	12. Forecast bike/ped trips (if model has modes)	*12. Identify areas sensitive to land use impact*
	13. Input transit service characteristics to model	
	14. Represent entire transit network in model	
	15. Join CA Inter-Agency Modeling Forum	
	16. Secure funds to research advanced models	
Requirements D* ("MPOs shall . . .")	***Recommendations D ("MPOs should . . .")***	***Recommendations E ("MPOs should . . .")***
1. Follow all Requirements B	*1. Follow all Recommendations B+C*	*1. Follow all Recommendations B+C+D*
2. Meet all US conformity regulations	*2. Have 4-step models with full feedback across steps as well as some sort of land use model*	*2. Transition to activity-based travel models*
3. Validate outputs and check forecasts for reasonableness	*3. Add an auto-ownership step and make mode choice sensitive to land use variables*	*3. Build formal microeconomic land use models (these should be integrated with travel model)*
4. Document model assumptions	*4. Explicitly represent walk and bike modes*	*4. Include freight movement in travel demand*
5. Make land use/transport scenarios consistent	*5. Model parking cost and quantity; use small TAZs around rail stations and BRT corridors*	*5. Include commercial movements in a commodity flow model*
6. Use capacity sensitive assignment methods	*6. Include carpool and access-to-transit modes*	*6. Coordinate freight data collection with state*
7. Use reasonable travel impedances	*7. Use feedback loops (mode choice, speed, etc)*	*7. Make travel surveys activity based and accurately geo-coded; GPS sampling a plus*
8. Make models sensitive to travel costs	*8. Include simple land use models in next RTP*	*8. Perform stated preference surveys as necessary for use in location choice models*
9. Estimate traffic speeds based on road volume	*9. Implement freight models in short term and commodity flow models within a few years*	*9. Investigate microsimulation of households and firms – deploy if feasible*
10. Base VMT estimates on HPMS data	*10. Make simple environmental justice analyses*	
	11. Jointly model mode and destination choice	
*All of these requirements come directly out of the federal conformity regulations	*12. Monitor larger MPO use of advanced models*	
	13. Include activities/tours in next travel survey	
	14. Collect rent data for future land use model	
	15. Use assigned travel times to model mode split	

(95) [a] This table *italicizes* the CTC *recommendations* to better distinguish them from the requirements.

The impacts of the CTC guideline revisions on modeling do not come from the basic requirements, which are very low and easily met, but from the recommendations, which, for the first time in the state, outline an expected development path for MPO modeling practice. Because these expectations are embedded in RTP framework for receiving federal funding, the MPOs are taking them very seriously. The recommendations have encouraged smaller MPOs to plan for upgrading to more advanced techniques and have accelerated the transition to such methods by the larger MPOs.

While those larger MPOs had been developing activity-based models, the requirements furthered these efforts, particularly in the case of one large MPO whose modeling significantly lagged the other three major MPOs. One modeler noted that certainly the largest MPOs, those in modeling Group E, are viewing the CTC recommendations as required.

The graduated structure of the guidelines appears to also be very effective in advancing practice as agencies are facing discrete demands with clear and reasonable products. The expectations for each MPO are in line with their existing challenges and capacities. Therefore, in the short term, MPOs can have a very clear idea of what they need to do to improve their practice.

The graduated structure of the guidelines also appears to be useful in the longer term, particularly for the smaller MPOs. These agencies can now more easily anticipate future directions for their modeling efforts as it is assumed that, over time, the expectations will grow so that, for example, Group B will be expected to fulfill what is currently expected of Group C. One modeler at a smaller MPO noted that, with the revised guidelines in mind, he can more strategically monitor the experiences of his colleagues in higher modeling groups to “piggyback on the value” generated by the larger MPOs. He added, “The big boys are building a toolkit from which the smaller MPOs will then be able to cherry pick the tools that are most relevant for them.” As a result, the benefits of the experience of the MPOs in the higher modeling groups can cascade over time to those in the lower modeling groups.

Finally, the modeling group structure identifies clear peer MPOs across the state, at least for the purposes of travel demand modeling. While this point was not raised among the practitioners interviewed, it seems likely that such identification is advancing cooperation. Such cooperation was a major comment regarding some of the other processes, as discussed below.

8.2 Granting Funds for Planning

SB732, by creating the SGC and vesting it with the ability to grant funds for planning, also established a process designed to directly impact the practice of travel demand modeling.

The SGC is composed of the Director of State Planning and Research, the Secretary of the Resources Agency, the Secretary for Environmental Protection, the Secretary of Business, Transportation and Housing, the Secretary of California Health and Human Services, and one member of the public, appointed by the Governor. The council can offer grants from the $5.4 billion raised through the Proposition 84 passed by voters in 2006. These grants are meant to fund planning that is not funded by federal monies, particularly the demands of SB375. The law provides that

> To support the planning and development of sustainable communities, the council shall manage and award financial assistance to a council of governments, metropolitan planning organization, regional transportation planning agency, city, county, or joint powers authority, to develop, adopt or implement a regional plan or other planning instrument consistent with a regional plan that improves air and water quality, improves natural resource protection, increases the availability of affordable housing, improves transportation, meets the goals of the California Global Warming Solutions Act of 2006, and encourages sustainable land use. *(94)*

In 2009, the state budget bill allocated $12 million Proposition 84 dollars to the newly formed SGC for modeling grants. The SGC established multi-agency working groups to determine the evaluation criteria and possible distribution for these grants *(98)*. The affected MPOs were actively involved with the working groups and made certain that the criteria reflected the modeling practice of all MPOs, not just the largest and most advanced, and also determined a need-based allocation scheme *(99)*.

The SGC Modeling Incentive awards were designed “to expedite the development of regional transportation and land use modeling by supporting the data gathering and model development necessary to comply with SB375 and promote the objectives of the SGC." Those objectives explicitly included "a long-term view towards the development of fully functional regional integrated tour/activity-based models," but recognized the short term needs to comply with SB375. Five-sixths of this money was designated for MPOs, while the remaining sixth was for the statewide modeling efforts *(100)*.

The funding criteria prioritized "accelerating and implementing improved modeling capability." The criteria, which preceded the revised CTC guidelines by half a year, also offered a graduated approach to advancing modeling. Specifically, the SGC presented three steps of acceptable models. The lowest rung was a trip-based model with post-processing capabilities to consider smart growth. The middle rung was a tour based model with a smart growth post processor. The highest rung was "an inter-regional/regional integrated tour/activity-based transportation models with land use and economic modeling components that support a healthy way of life." This highest step envisions applying models that do not yet exist in practice to a much broader array of policy questions. The SGC criteria also required models to be sensitive to a range of factors, with a particular emphasis on land use *(100)*.

The SGC required applicants for grants to develop "a Model Improvement Plan (MIP) that describes the applicant's overall model enhancement approach, and/or data needs, to meet the goals of SB375 and promote the objectives of the SGC, including estimated milestones, costs, and timeframe for completion." This requirement forced MPOs to present a thoughtful and strategic vision of how they intended to advance their modeling practices *(100)*. This idea was drawn from early drafts of the Regional Targets Advisory Committee (RTAC) report, which will be discussed in the next section.

TABLE 4 SGC Modeling Incentive Grants by MPO and Population

Metropolitan Planning Organization	Group	SGC Grant ($)	$/Pop
Tahoe Metropolitan Planning Organization	B	352,000	6.37
Shasta County Regional Transportation Planning Agency	B	400,000	2.22
Butte County Association of Governments	B	400,000	1.81
San Luis Obispo Council of Governments	B	400,000	1.48
Santa Barbara County Association of Governments	C	400,000	0.93
Association of Monterrey Bay Governments	C	400,000	0.53
Sacramento Area Council of Governments	E	400,000	0.17
San Diego Association of Governments	E	400,000	0.13
Metropolitan Transportation Commission	E	800,000	0.11
Southern California Association of Governments	E	1,000,000	0.05
San Joaquin Valley MPOs*	B,C,D	2,500,000	0.63

(95, 101) with author calculations.
* Composed of Kings County Association of Governments, Madera County Transportation Commission, Merced County Association of Governments, Tulare County Association of Governments, Council of Fresno County Governments, Kern Council of Governments, San Joaquin Council of Governments, Stanislaus Council of Governments

Every California MPO submitted an application and received a grant according to the pre-arranged distribution. The grants were typically $400,000 although SCAG and MTC received at least double that amount *(101)*. The eight MPOs of the San Joaquin Valley made a joint proposal, based on their history of modeling collaboration, to construct a tour-based model for the whole valley *(102)*. Their application asked for and received $2.5 million *(101)*. Table 4 presents the modeling incentive grants received by MPOs and demonstrates how on a per capita basis, the smaller MPOs received relatively larger benefits from the program. This outcome reflects the concern among the working group that allocations be based on need and not on a per-capita basis *(99)*.

The SGC Modeling Incentive grants, which are only distributed to reimburse work completed, provide direct support to MPOs to advance their modeling practices. This support is particularly critical to the smaller MPOs whose pre-existing modeling programs were less developed. The broad participation of the MPOs in the Modeling Incentive Program created a process that was appropriate for the agencies involved. For example, early drafts of the criteria only recognized activity-based models, whose complexity is not entirely necessary for a smaller region. The MPO input altered the text to also value trip-based models, as long as they had a post-processor that enabled smart growth analysis *(99)*. Furthermore, by knowing what their allocation would be in advance, MPOs were able to propose very realistic work programs, rather than propose unrealistically ambitious programs in hopes of securing any funding.

The condition of setting a proposal within a broader Model Improvement Plan was also very helpful for encouraging MPOs to think strategically about their model development. That condition forced the MPOs to critically assess their current needs and actively map out their approach for advancing modeling in their region. Such planning appears not to be a consistent part of typical travel demand model management at MPOs.

Finally, the availability of funds was thought to encourage agencies to work together. The most overt example of such cooperation is the joint application of the San Joaquin Valley MPOs. The negotiation among MPOs regarding allocations demonstrated another example of integrated efforts. Furthermore, many of the actual modeling plans looked to leverage the resources of the statewide travel habit survey, particularly for interregional travel information.

8.3 Setting GHG Reduction Targets

SB375 is ultimately aimed at achieving set levels of greenhouse gas reduction. The process put forward in the legislation to establish these levels proved to be a potent, albeit indirect, force for advancing travel demand modeling.

SB375 called for the ARB to establish "greenhouse gas emission reduction targets for the automobile and light truck sector for 2020 and 2035, respectively" by September 30, 2010. The legislation also required that "no later than January 31, 2009, the state board shall appoint a Regional Targets Advisory Committee (RTAC) to recommend factors to be considered and methodologies to be used for setting greenhouse gas emission reduction targets for the affected regions" *(9)*. SB375 specified that the RTAC report consider a range of issues including

> data needs, modeling techniques, growth forecasts, the impact of regional jobs-housing balance on interregional travel and greenhouse gas emissions, economic and demographic trends, the magnitude of greenhouse gas reduction benefits from a variety of land use and transportation strategies, and appropriate methods to describe regional targets and to monitor performance in attaining those targets *(9)*.

All of these elements (with the exception of *modeling techniques*, which is explicitly about models themselves) are either inputs to or outputs from travel demand modeling. Therefore, the practice of modeling at MPOs in California was central to the activities of the RTAC work.

That committee itself was designed to be broad and to include

> representatives of the metropolitan planning organizations, affected air districts, the League of California Cities, the California State Association of Counties, local transportation agencies, and members of the public, including homebuilders, environmental organizations, planning organizations, environmental justice organizations, affordable housing organizations, and others, *(9)*

with the result that a broad pool of stakeholders was engaged in discussions of travel demand modeling.

SB 375 also required that the target setting process be consultative between the MPOs and ARB, with the MPOs able to propose a preferred target. ARB would issue draft targets on June 30, 2010 allowing for three months of further negotiation before the targets would be set *(9)*.

The RTAC committee was appointed at the end of January 2009 and held its first meeting on February 3, 2009 and published its recommendations for structuring the target setting process in September 2009. The 21-member committee included MPO directors and former directors, elected officials who had also served on regional boards, air quality experts, transportation consultants, environmentalists, and an academic. The committee met 14 times during its tenure and invited many experts to testify before the group or to submit comments *(103)*. Both the deliberations of the committee and the ensuing target setting process impacted modeling innovation among California's MPOs.

Modeling was a major topic of discussion immediately within the RTAC deliberations, particularly the wide variety of practice within the state *(104)*. RTAC decided to survey all the California MPOs regarding their current modeling capabilities and identifying areas that might need to be improved to implement SB375 *(105)*. ARB staff developed and conducted the survey which focused on two main questions: First, were models "reasonably sensitive to key factors and policy variables which are potentially of great interest for target-setting or implementation of SB375?" Second, is the level of that sensitivity consistent throughout the state *(106)*? The survey findings, presented to the RTAC in May 2009, included six different matrices that assessed MPO modeling capabilities across different attributes. These charts showed a wide range of modeling capabilities as well as a need for model improvements *(107)*. The findings also provided, for the first time, a clear view of modeling practice at all of the state's MPOs. This awareness facilitated communication among the different MPOs regarding modeling practices and set the baseline for the Model Improvement Plans required by the SGC *(100)*.

The RTAC report detailed the process for setting GHG emission targets, of which all the key elements touched upon modeling. The core of this process was the seven step collaboration between each MPOs and ARB regarding proposed targets. Essentially, MPOs were to use their travel demand models to estimate future GHG emission levels under current and proposed policies. ARB would then review these forecasts and ask for additional analysis until a reduction target could be mutually agreed upon *(103)*.

This approach recognized that travel demand models "are an essential, inextricable piece of the regional transportation planning process" and sought to build on that structure. At the same time, the committee recognized that the current state of modeling was lacking and improvements were needed:

> The use of travel demand models in conjunction with land use models provides the ability to estimate the aggregate impacts of implementing multiple land use and transportation policies and practices. Since the Committee assumes that these modeling systems will be used by all the MPOs throughout the SB375 implementation, regional and statewide model transparency consistency, and plans for improvement are a critical component of the Committee recommendations. This report also includes recommendations for improving the

> functionality and consistency of these models for the purposes of predicting and measuring the green house gas reductions attributable to actions pursuant to SB375 *(103)*.

RTAC modeling recommendations explicitly called for the adoption among California MPOs of a model post-processor capable of addressing land use interactions on travel. Such post-processors are not common practice as GHG analysis is not a part of federal modeling regulations. The RTAC also called for an on-going program of modeling self assessment, documentation, and strategic planning. Assessments were to include key validation statistics, results of sensitivity tests for measures of travel such as VMT and trips by mode, and results of planning scenario tests which would demonstrate model sensitivity to a variety of conditions and policies. The documentation was to review this testing and identify where the model may lack sensitivity for analyzing certain policies. This documentation was to be easily intelligible by the public to conform with the SB375 language for increasing model transparency. MPOs were to build on their assessments to create a strategic model improvement plan. The RTAC suggested that these plans focus on the costs and phasing of improvements for the initial target setting, the first SCS, and subsequent development *(103)*.

While these improvements were aimed at MPOs, the RTAC committee was also concerned about the ARB capacity to effectively assess the forecasts from the MPOs and to exact appropriate reductions. The report recommended "that ARB consult with land use and transportation modeling experts during its review of the MPOs' analyses. The Committee believes this input is critical to supplement ARB's existing technical capabilities" *(103)*. This provision ensured another high level review of modeling practices.

The target setting process proved to be a significant arena for advancing modeling at California's MPOs. These impacts come from the activities of the RTAC as well as the actual target setting according to the RTAC report.

The RTAC survey of modeling practices shined a very bright light on existing modeling capabilities throughout the state. The findings provided a clear understanding of current practice and provided the baseline for structuring improvements through the RTAC (and SGC) recommendation of a model improvement plan. Equally important, the survey revealed the MPO's modeling practices to each other. This act of laying their cards on the table encouraged MPOs to assess themselves in relationship to their peers. The MPOs that appeared deficient were more motivated to address these issues by advancing their practices. For example, SCAG has been particularly keen on improving its approaches as it so visibly trails its peers.

RTAC also provided a critical forum for MPOs to discuss modeling and analysis approaches. The committee meetings were designed to be highly accessible, with all the materials posted and the actual meetings broadcast online. Many MPO representatives and modelers, who were not officially on the committee, actively participated in the meetings, as they wanted to both understand and influence the target setting process. Indeed, many MPOs saw the target setting process and the analyses done to inform that process as a "dry run" for the SCS planning process to follow, and so wanted a voice in the process.

As people continued to show up at the RTAC meetings, they began to form alliances with their counterparts from other MPOs to work together to influence the process and to get their individual targets set at levels they could live with. For example, the four largest MPOs submitted a joint report on their target setting activities *(108)*. Those collaborations became institutionalized among the four largest MPOs and SJCOG, who now hold regular meetings at three different levels to figure out how they are going to comply with SB 375. While there had always been interaction between the big MPOs, it has never been this formalized or extended as deeply to the staff. Participants report this collaboration to be very useful for propagating new ideas and putting them into practice. These benefits extend to travel demand modeling. One expert described the new coordination as "SB375 seems to have alerted people to the idea that in modeling there are economies of scale with synergy opportunities." Another noted, "It's the first time that so many MPOs and state agencies are talking in detail about how to do policy analysis."

While much of the attention in the model review tasks focused on improving four-step models and transitioning to more advanced tour and activity-based approaches, simpler modeling approaches also played an important role in the target-setting process. For example, the MTC, which was in the midst of a major transition from a trip-based to an activity-based model and did not want to rely on the old model, yet was not ready to apply the new one, used off model, spreadsheet approaches to prepare their targets. In addition, many regions with trip based models, such as those in the San Joaquin Valley added smart growth post-processors to adjust the model results to account for the effects of infill and transit-oriented projects. Over the longer run, these regions are likely to step up efforts to improve the models so that sketch planning methods and post-processors will be supplements rather than the main tools used in GHG analyses.

While the target setting process established the baseline and created an impetus for modeling improvements at many MPOs, some of the smaller MPOs felt that the target setting process actually hindered their efforts to improve. Many of these regions have been using models that only focused on automobile travel and were looking to an ambitious GHG reduction target to force them to develop the capacity to analyze transit, to consider parking policies, and to have more resolution (smaller TAZ geometry). However, because ARB has set small MPO emissions targets low, there is little impetus for significant policy changes or investments in modeling improvements. One MPO staffer noted with frustration that ARB "has been walking on eggshells not wanting to offend local areas" and has essentially "given most small regions a pass" on air quality targets; yet "without a target, there is no real point" to SB375 compliance.

8.4 Discussion

SB375 represents an opportunity to make significant advances in modeling and planning capacity. This leap forward is one that many MPOs, particularly outside of the four major regions, have been putting off for some time. The director of one such MPO exclaimed "Thank goodness SB375 came along. Thank goodness Prop 84 [which funded model improvements] came along." In general, SB375 has raised the expectations of planning and "gave more hope to modelers throughout the state to do more things."

The California experience confirms the utility of all of the TRB *Special Report 288* *(8)* recommended strategies for advancing models and adds to them. The two key additions are instituting ongoing programs of model assessment and future planning and aiding in that future planning by providing a clear and graduated roadmap for expected advancement. However, the California experience also upends this framework to suggest that the critical precondition for model change is a legislative mandate to use models to achieve an ambitious planning agenda. Once the state committed to advancing modeling all these strategies naturally followed. It is not clear that without the renewed centrality of modeling, the proposed strategies, on their own, would make much difference. Therefore, it appears that the key ingredient for effecting modeling change is to pass policies which are predicated on advanced modeling features, otherwise there may not be sufficient incentive to innovate.

California's SB375, legislation mandating sustainable community strategies for greenhouse gas reduction, is changing the travel demand modeling practiced at the state's MPOs. Changes in modeling are coming about because the legislation mandates policy analyses that can only be done with advanced models or supplementary tools. As a result, state guidelines for modeling have had to change and so have MPO practices. Funding for model improvements of various sorts have helped MPOs advance their practices. In addition, preliminary analyses and model reviews done as part of the GHG reduction target setting process have made the limitations of some of the MPOs' models highly visible to the agencies themselves and to a broader group of interests. This exposure has led to the lagging MPOs making new efforts to improve their modeling. Finally, collaborations among MPOs that arose as a result of the target setting process have led to agreements on the kinds of longer term model improvements that are needed. The process has accelerated change at the large and medium MPOs, but may have undermined faster change among the smallest MPOs, who are not expected to deliver major GHG reductions.

The ultimate test of whether this process of legislatively mandated change in modeling is effective is still to come. Will the enhanced models allow planners to develop more sophisticated and more accurate analyses of the new sustainable community strategies the law requires? What specific modeling approaches will prove most useful? Will advanced models help the public better understand the consequences of alternative development patterns and transportation investments? Monitoring the role of modeling in the planning process and the ability of advanced models to improve planning and forecasting performance will be an important future step.

9 CONCLUSIONS AND DIRECTION FOR FUTURE RESEARCH

This research examines the implementation of innovation in travel demand modeling as practiced by regional planning agencies. The contention that this research embarks from is that these agencies resist change and ways must be found to encourage the embrace of new methods. My review of the history of modeling practiced at these agencies suggests on the contrary that innovations are implemented. The traditional modeling approach that originated in Detroit and Chicago in the mid-1950s has proven to be long lasting, but the leading MPOs have for many years complicated this modeling approach with disaggregate techniques, particularly for modal choice decisions. Most recently, many leading MPOs are investing in new activity based approaches, which are precisely the approaches that academics have long wanted to see implemented.

The relevant question therefore becomes how can the process of innovation be expedited and the benefits of new techniques disseminated across the nation's MPOs. To address this question, I use the framework of Everett Rogers *(11)*, who identifies innovations as novel technologies. In this framework, travel demand modeling represents a combination of technologies, which together yield forecasts of infrastructure use given different possible scenarios. Furthermore, Rogers distinguishes between the hardware of an innovation and the software of actually implementing it. This distinction is particularly relevant for travel demand modeling as the success of an implementation is strongly predicated on the knowledge of how to use the tool, knowledge which is not always well translated to users.

Rogers identifies traits which contribute to the ease of diffusion for a new technology. For example, technologies can be assessed according to their relative advantage over previous technologies. This trait is not entirely clear for innovation in travel demand modeling. While newer approaches have strong theoretical support, they may not fulfill the specific the implementing agency's need for reliable prediction. Without a demonstrated advantage, many MPOs have hesitated to invest scarce resources in changing their practices. This barrier will always exist for the first people to implement a technology that has not been tried elsewhere and given the innate conservatism of regional planning agencies may be a major barrier to innovation. An effective way to address this concern, which is being conducted by several MPOs with much interest from the federal level, is comparing the model results from traditional and more advanced models. As more information becomes available, the relative advantage or lack thereof should become more apparent. The problem is that such comparisons take time and resources and many MPOs lack the bandwidth to do model assessments while fulfilling their needs for production.

Two solutions seem reasonable. The first is for expanded federal support for comparing models to ascertain whether new methods indeed bring the expected benefits. The second is for users of advanced models to widely disseminate their experiences. This approach, which has been conducted by the San Francisco County Transportation Authority, has been highly influential in demonstrating the possible uses and therefore advantages of new modeling approaches. Among my case studies, both the MTC and SACOG were impressed about the advantages of new modeling approaches by tracking their peer organizations' experiences. This finding is consistent with the literature about how organizations learn *(109).*

Rogers also assesses whether an innovation is compatible with the expectations of possible adopters. Here again, modeling innovations are a difficult sell. New approaches tend to present information on travel in novel ways. For example, the MTC investment in the innovative MTCFCAST model of the 1970s, despite extensive upfront work by the consultant to establish expectations with the client, did not deliver. The consultant was proud of the way their approach had added theoretical rigor as well as new functionality within the existing UTPS framework. However, the MTC found the system too cumbersome and did not feel that it provided promised advantages.

The MTC responded by shying away from modeling innovations for a generation after that experience.

This example touches on another of Rogers' factors affecting the diffusion of innovations, namely the complexity of a new technology. MTCFCAST was too difficult for the practicing planners to use. The model's designers conceded that instead of building such a complex model, they would have been better off ensuring that the MTC could use the model. The complexity issue is significant as these models incorporate so many variables. The knowledge of how to operate a model, the software element in Rogers' terminology, is a key limiting factor for a successful implementation. SACOG, for example, worked very closely with its consultants on its activity based model to ensure that it could be used. One of the consultant modelers even moved over to SACOG permanently. At the MTC, where they are currently implementing their activity based model, the head modeler noted that it used to be possible for a modeler to understand and control all elements of the modeling system, but that is no longer the case. The MTC is trying to manage the complexity of the new system by leveraging experience and software developed for the Atlanta MPO. The modelers from these two agencies have weekly conference calls with the consultant to address issues. The complexity of modeling also suggests a need for more comprehensive training for practitioners. This training has historically been provided on the job, but that may not prepare candidates sufficiently with the requisite skills in computer programming and the knowledge of city planning. It appears that the modelers who are successful with embracing the complexity of new modeling approaches have math and programming backgrounds that they brought to planning graduate programs, not that they learned there. The planning academic community needs to possibly reconsider the level of formal training for successful practice.

Rogers notes two other traits that affect the ease of diffusion of new technologies, namely its trialability and its observability. The trialability component has proven difficult for advanced models as it is tough to casually try one out without first investing many resources. This difficulty is likely the result of new model approaches not being well developed in standardized software. As software makers see a market for activity based models or as open source approaches foster access to such software, there are likely to be improvements in trialability. Currently, however, the situation is that MPOs feel they need to make a major one time investment to shift to a new modeling approach. This may not entirely be the case. The Chicago and Atlanta MPOs received praise from experts for pursuing a 'go slow' approach where they had a long time frame for trying out activity based models on a piecemeal basis to see if they would work for them. The luxury of investing slowly likely requires a chief modeler who has strong opinion leadership at the MPO and can muster sustained resources without necessarily returning a clear product. Alternatively, such investment approaches may serve other needs such as thwarting lawsuits and therefore be appealing to MPO boards.

As noted earlier, the ability to observe peer institutions having success with activity based models, or even their willingness to commit resources to them, has a strong influence on the willingness to consider innovative modeling approaches. The role of the federal government in sponsoring venues for such observability is crucial. At a more regional level, the state of California is having much success in advancing modeling through fostering interagency communication. Somewhat surprisingly, these linkages did not exist between MPOs despite their addressing very similar challenges. The SB375 implementation convened many opportunities for agencies to see what their peers were up to and to encourage them in transitioning to new methods.

Rogers sees the communication of innovations as a critical portion of their diffusion. This observation has been highly confirmed by my research. Experts often cited their peer interactions at conferences as central to their willingness to consider new modeling technologies. This follows Rogers' framework of homo/heterophily where people are receptive to peers who have largely the same knowledge, but differ in an important way, such as the application of a new modeling technique. I would push this further to note that peer agencies are competitive with each other.

When the modeling practices in California were cataloged as part of the target setting efforts of SB375, some MPOs felt they were behind and needed to catch up. This desire can overcome a historical resistance to implementing new approaches. This peer competition can take several forms. For example, during the BATSC process, the Bay Area modelers very much sought to advance practice with their work. They wanted to build on the knowledge gained elsewhere to do a better job of modeling. However, at the same time, the resource constraints, mainly time, made the fulfillment of that objective not entirely possible. BATSC was explicitly motivated by its position relative to its peers. This same thinking was even more apparent with the MTC effort to implement discrete choice models. The agency wanted to be the innovator and that desire motivated the investment in a new modeling approach. The federal government, through the Travel Model Improvement Program, has been successful at harnessing positive peer pressure. Both of my case study MPOs embarked on significant modeling changes after participating in such a TMIP-sponsored peer review.

Another relationship that proved significant for contributing to innovation in travel demand modeling was the linkage of the MPO with a local university interested in modeling. In the Bay Area, it was the exposure to Daniel McFadden's Nobel Prize winning efforts that provided the support to embrace discrete choice methods. In Sacramento, it was the engagement of Robert Johnston in the discussions surrounding land use planning that lead to a commitment to an integrated land use and transportation model. In both of these examples, the university provided a trial run for employing a new technology and essentially gave "cover" to the MPO to follow suit.

Another interesting finding is that the peer pressure to innovate may come from partner agencies who are not traditional peers. In Sacramento, the regional transit agency's frustration with what it perceived as the limitations of existing modeling practice is what kick-started SACOG's drive to model innovation. Similarly, the MTC engagement with the modeling being practiced at the county level in San Francisco strongly influenced the larger agency's willingness to invest in an activity based model. In fact, the MTC initially planned to copy the SFCTA model wholesale. SACOG emphasized how important their interactions with partner agencies were for determining which modeling approaches to prioritize both for SACMET 94 and for SACSIM. This communal engagement with modeling seems to help not only build a constituency for innovation, but to ensure that the innovation best reflects local needs.

The history and the case studies also demonstrate how critical communal voices are for driving a policy concern that requires better modeling approaches. The CATS model was initiated due to concerns from different levels of government regarding highway construction. The Portland Metro activity based model grew out of earlier work that was led by a local environmental group who wanted to see alternatives to planning as usual. The SACOG modeling resources have developed largely to support the Blueprint process that was initiated through lawsuits from environmental advocates. Although SACOG had investigated the transition to an activity based model earlier, it was the communal consensus that regional land use planning was critical for improving transportation that provided the actual push to invest in SACSIM. The SB375 legislation has done an excellent job of formalizing the input of a diverse range of stakeholders into modeling decisions. For example, the RTAC committee was made up of representatives from 21 different agencies and groups who felt they needed to learn about modeling practice in the state to properly establish a procedure for GHG target setting. The different concerns of the stakeholder groups led to a broader range of recommendations which in turn required more advanced modeling capabilities.

The public support for model change is also seen directly in the SB375 legislation. This law makes it a state priority to provide a new level of functionality for land use and transportation decision making. The public support for the law also led to the release of public funds to make the necessary changes. The law showed that modeling capacity can be seen as a state responsibility and that California's commitment to averting climate change entails a concomitant commitment to advancing modeling practice. SB375 demonstrates the important role that legislation has in fostering modeling innovation. Just as the 1962 Highway Act resulted in the widespread development of the initial models, legislative mandates that require certain planning functionalities can drive interest in innovation. These findings confirm the insight of Guttenberg *(14)* that innovations occur when there is a mismatch between the planning problem and the tools for addressing it. Guttenberg emphasizes the importance of a planning issue to be 'hot' to ensure sustained interest and resources. In California, the strong concern for global warming provides such interest.

SB 375 further succeeds by structuring that innovation in a clear way. The planning guidelines provide a roadmap for model development. Furthermore, the MPOs need to plan their model improvements to be eligible for state financial support for those improvements. The result is that all the MPOs in the state have a clear direction for how to advance their practice and established funding sources to invest. The modeling guidelines remove the uncertainty that has long plagued model improvement decisions. No longer do MPOs need to worry about what to do, the course is clear, now they need to worry about how to do it. It should be noted that establishing these goalposts affect all MPOs, even the most advanced as there is a structured expectation for each type of MPO. Future federal legislation might emulate this structured approach to defining MPO modeling functionality.

While legislative mandates can be very useful for ensuring that all MPOs achieve a certain modeling standard, other factors will continue to drive the most innovative MPOs. This research has suggested that the combination of a policy of interest that requires analysis with an activist internal interest in continually improving modeling methodologies have driven model innovators. These are regions in which the modelers have a strong professional concern for doing the best work possible as well as an ability to articulate the importance of modeling improvements to the rest of the MPO staff and the board. These features are well represented in SACOG which has actively looked to upgrade its modeling over the last two decades. Interviews at SACOG suggested that because the MPO was interested in improving its approaches, it was able to effectively take advantage of funding opportunities that arose to keep pushing the ball forward on model improvements. That approach can be encouraged by legislation, but is likely to still come from personnel.

Many experts noted concerns about maintaining those talented people in MPOs as salaries are low compared to other avenues to use the same skills. Nonetheless, it appears that many modelers see their craft as a calling and are not entirely motivated by financial rewards. The modelers that do leave often become consultants who then translate the innovations to other regions.

The role of consultants, I feel is central, to advancing practice. In the Rogers framework, I see the consultants as the change agents, the people that advocate for innovation. Their ability to translate experience from one MPO to another is a key component to initiating innovation. Consultants have an economic incentive to encourage potential clients to try new things. Furthermore, consultants may be willing to partially finance innovations if they feel a loss on one project will be made up later. Consultants can essentially pool money from different clients to fund the development of a new approach. This feature is quite apparent with the CT-RAMP modeling system of Parsons Brinckerhoff. The consulting firm has been able to leverage different contracts to develop the software and was able to absorb losses on early projects in the hope of future gains.

Similarly, the companies that make modeling software provide a key role in facilitating innovation at MPOs. MPOs feel security in knowing that their efforts will be supported by the software providers. Currently, many of the innovative approaches are customizations that rest on top of existing software, but as those base programs incorporate new options, it will facilitate the diffusion of new ideas in practice. As a result, software providers have an interest in encouraging implementation of modeling innovations at the MPO level. At the same time, software developers can inhibit innovation if they do not create new features for their programs.

Historically, software has a mixed role in promoting innovation at MPOs. The software that was promoted by the Bureau of Public Roads and later the Department of Transportation facilitated the spread of modeling throughout the country. Conversely, the reliance on these programs limited the market for new competitors to bring in new ideas. More recently, several private companies have come to dominate the travel demand software market. Meanwhile the government has shifted to experimenting with sponsoring open source software rather than publicly funding the development of privately distributed software.

Based on my expert interviews and the two cases, a critical factor for innovation is bringing the community into the planning process. This feature can be seen very clearly with the Blueprint visioning exercise in Sacramento that engaged the entire community in regional planning. When people are reviewing planning practices, practitioners are motivated to do better. Part of the success of SB375 has been bringing in outside perspectives on modeling. These viewpoints prevent modeling from being the purview of a few people cloistered in a regional agency. Instead, when modeling is daylighted, modelers are more responsive. The MTC will even negotiate with public groups to conduct a series of model runs. That exposure makes modeling relevant and forces MPOs to keep it current.

We are now at an inflection point in the history of modeling as the major MPOs embrace the activity based approach. Serious questions will need to be answered regarding the success of these new methods in meeting the needs of an MPO. Already, these new modeling approaches are changing the way in which planners consider and present information. Instead of a matrix of one-way trips between zones, models can now present a list of people and the actual trips they make throughout the day. It is possible to consider impacts at a much finer grain, for example by race or income group. But at the same time, these new possibilities will need to be tested and validated. There is an opportunity to reshape the relationship between planners and modelers within an MPO, who in many cases are in separate administrative units, and these new relationships will determine whether advanced modeling practices result in better planning. It is important to not just have an innovation, but it must be used. Rogers talks about ‘reinvention. ’ how an adopting unit will make an innovation its own and use it in new ways. The next decade will see tremendous reinvention of modeling, particularly in the activity based paradigm. Researchers will need to study this process to ensure that implementing modeling innovations leads to tangible benefits. Innovation is not sufficient for its own sake. Travel demand modeling needs to serve the needs of metropolitan region. Models may be imperfect, but they must be useful.

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11 APPENDIX

Interview Guide for Interviews with Modeling Leaders (Academics and Other Experts)

A	**Background**
Q1	Thank you for meeting with me. Let's get started with a discussion of your thinking on modeling in general. What is your view is of travel demand modeling and its role in transportation planning and decisionmaking? (Open ended question intended to elicit first thoughts on the status and role of modeling).
Q2	What do you consider to be the milestones in travel demand modeling, i.e, the major advances since travel demand models were first widely introduced in the 1960s?
Q3	In your view, what constitutes the state of the art in travel demand modeling, i.e., the most advanced approaches?
Q4	What in your view are the most serious deficiencies in modeling as it is currently practiced ?
B	**Role in planning and decision making**
Q5	In your experience, how are models used in transport planning and decision making?
Q6	In your view, what role could or should models play ?
Q7	Can you illustrate this point with any examples?
C	**Innovation**
Q8	What have been the key innovations/changes in modeling practice?
Q2	Thinking about leadership in modeling innovation, who comes to mind? What specifically were their roles (probe for both agencies and individuals)?
D	**Knowledge of Case Studies (for those who were involved or otherwise would know about these cases.) I am studying modeling in the San Francisco Bay Area and Sacramento.**
Q1	The San Francisco Bay Area's Metropolitan Transportation Commission (MTC) was the first MPO to implement disaggregate,travel demand forecasting models, e.g, logit mode choice models. Are you familiar with these models? Do you agree that they were a major innovation (why or why not) Can you tell me your recollections of how these modeling approaches came about? ?
Q2	FOR SACOG: SACOG has, by many reports, been a leader in testing land use transportation integrated models. Are you familiar with these models? Do you consider them to be innovative? Can you tell me how that came about?

Interview Guide for MPO Planners/Policymakers

A	Background
Q1	Thank you for meeting with me. Let's get started with a little background of the MPO. Specifically, what are the key issues the MPO is currently dealing with? (Probe re: • Global warming and GHG reduction • Land use and transportation coordination (e.g. TOD) • Transit and effects of service cuts and fare increases • Congestion management (ITS, pricing, HOT lanes, etc.))
Q2	Can you tell me how the MPO has changed its approach to these issues over time? • What has been learned? • What strategies have been dropped? • What strategies remain important?
B	**Impact of Global Warming Concerns**
Q1	How has concern about global warming and bills such as AB 32 and SB 375 changed things? How is the MPO addressing these issues? • How interested are the elected board members in these issues? • Are there board policies on these matters? Tell me about them. • Are there differences of opinion on which strategies to pursue?
Q2	I'd like to hear more about the planning approach. How does the MPO investigate these climate change issues? • Is this work done in house or with the help of consultants? • Are the full travel demand models routinely used or are simpler methods employed? • How do other related agencies participate in these analyses?

Interview Guide for MPO Modelers

A	**Background**
Q1	Thank you for meeting with me. Let's get started with a little background onthe MPO. Specifically, what are the key issues the MPO is currently using models to investigate? • Global warming and GHG reduction • Land use and transportation coordination (e.g. TOD) • Transit and effects of service cuts and fare increases • Congestion management (ITS, pricing, HOT lanes, etc.)
Q2	I would like to know more about your regional modeling tools that you apply to these issues [from Q1]. What modeling approaches are you using? • What is the role of the formal travel demand model? What are some of the strengths and weaknesses of this approach? If not used, why not? • What other modeling tools are employed? Spreadsheet, sketch planning, elasticity analysis? What are their benefits and drawbacks? • Is this work done in house or through consultants, or a bit of both? When does it make sense to do one or the other?
B	**The Models**
Q1	I am particularly interested in when and why MPOs decide to change their models. First let me ask if there are any contemplated improvements to the full regional model or the alternative modeling techniques? Can you tell me how these came about? • What precipitated this new concern? • Was it internally (staff, board, elected officials) or externally motivated (interest groups, university research, EPA or other oversight agency)? • Who decided the model needed to be changed within the MPO? How did they marshal resources to advance this issue? (probe on costs, time involved)
Q2	Now, looking backwards at the same idea. What have been the major changes to these models in the past? • First let me ask what elements constitute for you a major model change?(new model specification, reestimation of a model specification on an new dataset, , new software,…. • How did these changes get implemented (who was involved, internal or external help, costs, time, etc.)
Q3	Can we look at each change one at a time? Can you tell me how these earlier changes came about? • What precipitated these changes? • Was it internally (staff, board, elected officials) or externally motivated (interest groups, university research, EPA or other oversight agency)? • Who decided the model needed to be changed within the MPO? How did they marshal resources and support to advance this issue? • Who actually made the changes to the model? In house work or consultants? • What monies funded these changes to the model? • How long did it take to make each change? I am asking from when the MPO decided to invest in change until the model innovation was in use. • What were the proponents/impediments to change? Consultant slow, institutional issues, retraining needs, etc. • What were the strengths and weaknesses of each change? • How have the changes to the model affected the planning processes at the MPO? New areas of focus, new staff, new problems
Q4	Finally, I want to ask about the role of modeling within the planning and policy making deliberations of your MPO. • How important is that role? • Does modeling precede policy or follow policy or a little of both? • How, if at all, would you like to see that role changed? • Currently, what are the main strengths of the model system at your MPO? Weaknesses?
Bonus	**If not addressed earlier**
Q	One of the issues that a lot of MPOs have struggled with is the land use connection to travel demand. Could you tell me a little bit about how your MPO has dealt with this issue? (congestion pricing, transit investment and development, etc)

	• How have you changed your model to better address this question?

CPHS Approval Letter

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COMMITTEE FOR PROTECTION OF HUMAN SUBJECTS
OFFICE FOR THE PROTECTION OF HUMAN SUBJECTS
University of California, Berkeley
2150 Shattuck Avenue, Suite 313
Berkeley, CA 94704 -5940

(510) 642-7461
Fax: (510) 643-6272
Website: http://cphs.berkeley.edu
FWA#00006252

NOTICE OF APPROVAL FOR HUMAN RESEARCH

DATE:	*December 07, 2010*
TO:	*Elizabeth A DEAKIN, City and Regional Planning*
	Gregory Louis Newmark, City and Regional Planning
CPHS PROTOCOL NUMBER:	*2010-02-808*
CPHS PROTOCOL TITLE:	*Travel Demand Model Review*
FUNDING SOURCE(S):	*NONE*

A *new* application was submitted for the above-referenced protocol. The Committee for Protection of Human Subjects (CPHS) or Office for the Protection of Human Subjects (OPHS) has reviewed and approved the application by *expedited* review procedures.

Effective Date: December 06, 2010
Expiration Date: December 05, 2011

This approval is issued under University of California, Berkeley Federalwide Assurance #00006252.

If you have any questions about the above, please contact the Office for the Protection of Human Subjects staff at Tel (510) 642-7461; Fax (510) 643-6272; or Email ophs@berkeley.edu .

Thank you for your cooperation and your commitment to the protection of human subjects in research.

Sincerely,

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COMMITTEE FOR PROTECTION OF HUMAN SUBJECTS
OFFICE FOR THE PROTECTION OF HUMAN SUBJECTS
University of California, Berkeley
2150 Shattuck Avenue, Suite 313
Berkeley, CA 94704 -5940

(510) 642-7461
Fax: (510) 643-6272
Website: http://cphs.berkeley.edu
FWA#00006252

William Jagust
Committee for Protection of Human Subjects