The rapid movement of people and goods is essential to economic growth in the United States and in every one of its urban areas. Funds for building and operating highway and transit systems are a major portion of expenditures for local, state, and federal governments. Traffic congestion is one of the most important issues facing local elected officials everywhere. Suburbs fight for more highway funds, while central cities push for transit improvements. Within all large urban regions, city, suburban, and rural jurisdictions must cooperate in regional transportation planning exercises every 3 years.

Urban transportation planning in the United States began with the development of travel demand models in the 1950s and then became formalized in the 1960s with the U.S. Department of Transportation (U.S. DOT) codifying practice and software. Travel models begin by making 20-year projections of future land uses in small zones throughout the region. These land use projections (residential, commercial, industrial) are then used to project, for each small area, the number per zone of households, which generate trips, and the number of employees, which attract trips. With computer software, the trips are assigned to a network of roads that connects the zones. As more trips are loaded onto the network in the modeling process, travel speeds slow down and some trips are assigned to faster sets of links in the network. After many iterations where all trips try all possible routes, total traveler time is minimized. Then travel speeds on the links are analyzed to see where congestion is the worst. These congested areas are where additional investment will be needed, to increase road or transit capacity.

I begin this chapter with a review of the history of regional transportation planning in the United States and then identify recent federal laws that have placed additional requirements on transportation modeling and planning. Next, I review the steps in travel modeling, outlining improvements that the larger metropolitan agencies are undertaking and the variety of policy analysis capabilities that regional transportation planning agencies are now pursuing to address the needs of citizen groups and local governments. These “bottom-up” needs, which come from the constituent groups,
are in addition to the "top-down" requirements from the federal laws. After this review I outline an ambitious model improvement program in one region to bring all of these pieces together. Finally, I describe foreseeable future modeling advances to indicate the nature of planning practice during the next decade.

**HISTORY OF REGIONAL TRANSPORTATION PLANNING**

Federal law requires regional transportation planning for medium-sized and large urban areas in order to qualify for federal highway and transit funding. Many states also have similar requirements to get state funding. Transportation is the only remaining type of infrastructure funding for which Congress still requires regional planning. Such planning was formerly necessary to apply for federal funding for hospitals, sewage treatment plants, and water supply systems, but these regulations were dropped in the 1970s. Understanding regional transportation planning is vital because it is the only regional planning process undertaken regularly in most regions and because changes in transportation systems affect many aspects of urban life, including traffic congestion, air quality, transit availability for lower income households, and land development patterns.

Before World War II, transportation planning did not include travel modeling. After the war, rapid increases in automobile ownership, widespread suburbanization, and a vast increase in federal spending for transportation investments led to the need for regional modeling of travel behavior. Early studies were done in Detroit and Chicago, followed by studies in other eastern cities. Many of the early methods were developed by the Chicago Area Transportation Study. The Federal Highway Act of 1963 required urban areas to use a "continuing, comprehensive, and cooperative" transportation planning process (the 3C process) to qualify for federal funding. Urban areas were defined as regions, and so regional modeling became the standard procedure. The Bureau of Public Roads (which later became the Federal Highway Administration [FHWA]) sponsored research to develop standardized methods and published manuals describing travel modeling methods so that transportation modeling and planning practice became standardized nationwide. Specifically, these methods became codified in the Urban Transportation Modeling System (UTMS), or Urban Transportation Planning System (UTPS), which was a standardized set of methods for "four-step" travel modeling. The four steps are (1) trip generation, which predicts the number of daily household trips; (2) trip distribution, which predicts where each trip goes; (3) mode choice, which predicts which travel mode is chosen; and (4) route assignment, which predicts travelers' routes on roads, rail lines, or bus lines. Many regions used the software disseminated by the U.S. DOT for use on mainframe computers.

Travel models play a central part in transportation planning. How are they designed? First, the Metropolitan Planning Organization (MPO) divides the urban region into 100–2,000 zones, generally composed of census block groups and census tracts. The MPO develops a set of networks in the travel model software that represent all the major roads and all transit lines. Then the MPO performs a household travel survey, where a few thousand randomly selected households are surveyed on a random midweek day, in order to identify all trips made by time, mode, route, destination, and purpose on that day. These data are then used to estimate several submodels, also known as the "travel model steps."

An ideal travel model would represent all behaviors affected by changes in the transportation system. The model would be estimated on large data sets and the equations in the various submodels would have high explanatory value, statistically. Furthermore, the models would include explanatory variables relevant to all major policy issues, such
as road tolls, new road capacity, or compact growth.

The MPO begins with the first of the four main submodels, the trip generation model, in which household characteristics (e.g., income and size) determine the number of trips the household makes per weekday. Second, a trip distribution model is estimated, where trips are generated by households and attracted by employment. The trips are linked randomly from one zone to another and then a proportionate fitting program rematches origin and destination zones, to get a distribution of trip time lengths which matches that in the survey data. This is done separately for each trip purpose (home-based work, home-based other, and non-home-based are the minimum set). Then, the agency estimates a mode choice model, where the travel mode chosen is a function of the modes available to the household, household income, and the cost of the mode for each trip taken (time cost plus auto mileage costs or transit fares). Finally, in the assignment submodel, trips are assigned to the network, to get from the origin zone to the destination zone. As links become loaded with travelers, the vehicle speeds slow down. This results in some trips being assigned to other routes, until no trip can be made more quickly.

The whole model set is run on the base year data, and traffic volumes are calibrated to actual traffic counts in certain parts of the region. Various adjustments are made in the submodel parameters until the modeled traffic volumes match the observed volumes fairly well. This calibration is also done for transit line ridership for all transit lines and for regional mode shares and number of trips. After the model is calibrated, it is run for those future years of interest, based on the amount and location of projected population and employment. Generally, models are run on a 20-year horizon for facility planning and are also run on the intermediate years for which there is a vehicle emissions reduction deadline. Figure 5.1 shows the steps in this modeling process.

![Figure 5.1](image)


In the 1960s, opposition to freeways in central cities resulted in a statutory requirement for a local freeway agreement to be signed by all cities and counties where the right-of-way would be acquired. Rising environmental concerns led to the adoption of the National Environmental Policy Act (NEPA), in 1969, which requires a detailed environmental assessment of all federally funded projects. In 1975, the U.S. DOT adopted regulations requiring not only a long-range (20-year) plan, but also a short-term element, focusing on low-cost Transportation Systems Management (TSM) policies, such as carpool lanes, ramp metering, and limiting parking. These measures were intended to reduce peak travel demand and to manage peak flows better; they represented the first federal objectives for demand management, instead of simply
providing more capacity on roads and transit lines. Also, public participation requirements were strengthened and paying attention to the transportation needs of the elderly and the poor was mandated.

In the early 1980s, the federal agencies reduced their oversight of regional planning somewhat, but the basic planning requirements stayed in place. Federal funding for new freeway and highway capacity began to decline steadily as the Interstate Highway System was almost completed. Greater suburban travel and higher auto ownership in general led to continuing rapid increases in vehicle miles of travel (VMT), a broad measure of travel demand within urban regions. Although tailpipe controls on vehicles continued to improve, the vast majority of larger urban regions did not meet all federal air quality standards. Many urban regions adopted plans with light rail systems, and, in general, there was an increased interest in transit improvements, some of which was directed to urban renewal objectives for central cities.

In the 1950s and 1960s, travel modeling addressed mainly the simple issue of where to provide new freeways and highways. Solving this problem merely requires the agency to determine the most congested corridors in the road system. Only the trip distribution model step (where trips originate and where they go) and the route assignment model step have to be roughly right to determine relative congestion levels on roads. Trip generation and mode choice do not have to be very accurate. Models were generally daily models, in that they represented all daily travel. Vehicle speeds were poorly simulated. Travel models were generally accurate enough for ranking network links by congestion level, however.

In the 1970s and 1980s, travel modeling practice advanced statistically, with the use of disaggregate discrete choice models, mainly for mode choice, advocated at the Williamsburg Urban Transportation Modeling Conference, held by the U.S. DOT in the early 1970s. There have been international travel modeling conferences every few years since then, focusing on making travel models more behavioral and accurate. Many consulting firms are competent in discrete choice model development. Smaller urban areas with, say, less than 200,000 people, still generally do not use mode choice models, but regions above this population level do, as they have significant bus and rail systems, or wish to plan for them.

Let us now review the recent federal laws that have greatly increased the requirements placed on travel modeling and on transportation planning. Agencies are still trying to adjust to these new mandates. The key point is that whereas in the 1960s, 1970s, and 1980s the federal government was primarily concerned about congestion reduction from transportation investments, in the 1990s air quality concerns became equally important.

**RECENT FEDERAL PLANNING REQUIREMENTS**

The Clean Air Act of 1970 required all states to adopt a State Implementation Plan (SIP) that includes an emissions inventory for each region in the state and a plan for attainment of all ambient federal air quality standards. The Clean Air Act Amendments of 1977 and the subsequent Highway Act both required all regional transportation plans to show attainment of the vehicle emissions reductions specified in the SIP, through the modeling of travel and emissions from on-road vehicles. The emissions modeling is governed by the U.S. Environmental Protection Agency (U.S. EPA) and most states use the EPA emissions modeling software. This program takes daily VMT (in each vehicle speed class) data for the region (taken from the travel model) and other data, such as number of trips, and produces emissions projections. It also relies on vehicle fleets specified by the EPA for all future years (number of vehicles by model and year). Under the 1977 amendments, a re-
tion that did not do a transportation plan could have its federal funds for transportation improvements denied (the "funding sanction").

The Clean Air Act of 1990 is the most important policy advance in transportation planning in recent decades. It greatly strengthens the previous requirement for air quality attainment by providing that federal transportation funds can be withheld from regions that adopt transportation plans but cannot show attainment (through modeled emissions reductions) by the deadlines for each pollutant. This was the first time the funding sanction had been tied to actual attainment, and therefore represents a much stronger incentive for regions to reduce emissions. The Clean Air Act of 1990 also strengthens the role of demand-side policies, by requiring that Transportation Control Measures (TCMs) be studied in nonattainment regions, and lists the TCMs that must be studied for each level of nonattainment (moderate, serious, severe, and extreme). The TCM lists include much stronger demand reduction policies than had appeared on the earlier lists of TSM policies. TCMs, for example, include peak-period road tolls.

The Surface Transportation Act of 1991 reinforced the policies in the Clean Air Act of 1990 and emphasized multimodal planning (for all modes, in a connected system). It also strengthened the requirements for public participation and interagency consultation and required that MPOs with more than 200,000 people have their planning procedures recertified by the U.S. DOT every 3 years. In sum, the objectives of transportation planning have evolved from adding road and transit capacity to also managing travel demand, connecting modes, and reducing emissions.

The Clean Air Act air quality conformity rule (40 CFR 93.122[b][1]), adopted pursuant to the act, requires that all regions with "serious" or worse ozone or carbon monoxide nonattainment status run models that are equilibrated across all model steps to fully represent the effects of changes in accessibility on travel demand. This rule was adopted because academics and environmental groups have long contended that adding road capacity speeds up travel and leads to longer trips. There is considerable evidence that increased accessibility on roads leads to increased travel (Cervero and Hansen, 2000, 2002; Transportation Research Board, 1995). Most larger MPOs have now begun to run their travel models in this fashion. Equilibrated, or "full feedback," modeling means that the speeds in the assignment submodel step are fed back to the other submodel steps.

The conformity rule (40 CFR 93.122[b][1]) also requires that the land development effects of regional transportation plans be accounted for, in the "serious" and worse ("severe" and "extreme") air quality regions. It says that the land use patterns and facility plans must be "consistent" in each alternative. This is a much more contentious rule, as it requires MPOs to adopt some sort of land use forecasting committee or model. Because of a lawsuit in the Chicago region in the mid-1990s and this rule, most large MPOs are now developing land use models to run in combination with their travel models. Medium-sized MPOs with "serious" or worse air quality are beginning to do the same. MPOs do not regulate land use, and so they must gain the cooperation of their member cities and counties to allow alternative land use projections to be run with each regional transportation (facility) plan.

More fundamentally, the Clean Air Act of 1990 requires the MPO modeling in these regions to be much more accurate than it has been, so that emissions will not only be ranked correctly across alternative plans, but also be projected accurately absolutely, in order to judge the performance of any plan against emission reduction budgets developed for each nonattainment region. This means that travel must be projected by time of day (peak and off-peak periods), to forecast congestion, vehicle speeds, and emis-
sions in more detail. Travel speeds must also be much more accurate than in the past. Most large, and some medium-sized, MPOs now use speed postprocessors (extra models) to project vehicle speeds more accurately. These models are calibrated against observed vehicle speeds in the base year model. Since MPOs must demonstrate air quality conformity every 3 years, this new level of modeling accuracy is very difficult for MPOs to achieve.

In addition, the Clean Air Act of 1990 requires that all MPOs be able to model the effects of TCMs such as peak-period tolls, parking charges, fuel taxes, flextime, paratransit, transit, land use intensification near to rail stations, bike and pedestrian facilities, park-and-ride lots for transit and for carpooling, ramp metering, and carpool lanes. This requirement means that the travel model must be sensitive to a much greater variety of policies and travel behaviors than in the past. Models need to represent all transit, walk, and bike modes, for example. They also must include prices for travel (time cost, distance cost, transit fares, tolls, and parking charges) for all modes, in all model steps. The more advanced large MPOs’ models do include all of these variables to make them sensitive to such policies, but the medium-sized MPOs need to catch up by adopting substantial model improvement programs.

The Civil Rights Act of 1964 has resulted in a series of transportation discrimination cases that are making MPOs consider the equity effects of their plans more seriously. A very important settlement in Los Angeles County in the 1990s, for example, requires much greater investment in bus system improvements, because poor people ride buses, not rail (see Deka, Chapter 12, this volume). The MPO for that region now includes simple equity measures in its regional plans. The 1998 EPA guidelines on environmental justice are being implemented by all federal transportation agencies (U.S. EPA, 1998). Some states also have adopted their own statutes requiring the analysis of such equity issues. It is worth noting that, to get theoretically complete economic equity measures, you have to run economic models within your travel model or land use model. This is the least understood and least developed area of MPO practice, even though such models are in widespread use in other developed countries.

In some regions, NEPA is increasingly being enforced (through lawsuits) regarding the growth-inducing impacts of highways. The MPOs will need to model induced travel (VMT) and induced land development (type and location) for major road and passenger rail improvements. Since cities and counties control land use planning, MPOs often treat these projections of land development as “impact evaluations,” not land use plans.

One useful way to think of all of these requirements for modeling is to list all of the behaviors we wish to simulate. In conventional travel models these behaviors are only crudely represented:

1. Trip generation is represented poorly. Nonmotorized modes are omitted, only a few trip purposes are identified, and there are no land use and accessibility explanatory variables. This means, for example, that the effects of land use density on trip generation are not modeled and the effects of land use policies on walking and biking are also omitted.

2. Trip distribution (specifying the number of trips from each residence zone to each workplace zone) is rudimentary. Trips are not linked in sequences, but are all modeled separately. Workers from households are not matched to job types by income. The monetary costs of travel are not represented. The whole model set is not run to equilibrium, and so the effects of vehicle speeds on trip lengths is neglected. Equilibrium modeling takes the link speeds from the assignment
step and feeds them back to the trip distribution and mode choice steps and the whole model set is run (iterated) until speeds no longer change. All model steps now have the same link speeds.

3. Mode choice, at least in the larger MPOs, is done fairly well with disaggregate models. Nonmotorized modes are missing in most models, however. Small MPOs omit this step.

4. Travel assignment is quite inaccurate, as road capacities are often inaccurate and the relation between vehicle flows (road volumes) and speeds are poorly represented. Generally, quite inaccurate speeds result, especially in daily models. As a consequence, projected congestion levels are unreliable. Emissions estimates are therefore inaccurate.

Behaviors that are generally missing completely (for which new submodels must be created) include:

1. Auto ownership (autos per household), which strongly affects trip generation and mode choice.

2. Trip chaining, which increases as congestion gets worse (drivers link more trips together). Chaining also reduces the number of cold engine starts, which are a critical input to an emissions model.

3. Time of travel, which is affected by congestion. Peak spreading occurs as congestion worsens, and this affects speeds and emissions (more people travel at shoulder times and off-peak times).

4. Location of land development, which is affected by congestion levels in sub-areas in the region.

5. Location of firms. As congestion levels change, firms move around in the existing building stock, to be close to their workers, suppliers, and customers.

6. Location of households. As congestion changes, households move around in the available dwellings, in order to have access to employment, shopping, and schools.

To summarize, MPOs are now required to greatly improve their capabilities for modeling travel and land development as well as the effects of the resultant travel and land use patterns on the economy, environment, and social equity. Box 5.1 summarizes the many federal requirements that now affect modeling.

We can see that MPOs are under great pressure to improve their travel models. We will identify improvements that can be made on all of these submodels, below. To do this, we review all of the steps in the overall transportation planning process. We will propose improvements in this process, as well as for the travel models, which are a major part of the planning process.

**OVERVIEW OF TRAVEL MODELS AND LAND USE MODELS**

Following Pas (1995), we will divide the planning process into three phases and describe past practice. Drawing from Beimborn, Kennedy, and Schaefer (1996), Deaken, Harvey, and Skabardonis (1993), and the recent model development programs for Oregon and the Sacramento region, we outline at the end of each section the improvements generally agreed on for medium-sized and large MPOs. We will not discuss goods movement, owing to limited space. Other good sources include U.S. Department of Transportation (1994c) and Johnston and Rodier (1994). The best recent set of recommendations for travel models and land use models is Miller, Kriger, and Hunt (1999).

**Preanalysis Phase**

The preanalysis phase consists of (1) problem identification, (2) formulation of objectives, (3) data collection and analysis, (4) model implementation and calibration, and (5) model validation.
BOX 5.1. Summary of Federal Legal Requirements Affecting Travel Modeling

Clean Air Act of 1990

Serious and Worse Air Quality Regions:

- MPO must show attainment by deadlines
- Run network-based regional travel demand model
- Run model to equilibrium (to show induced travel)
- Land development patterns must be consistent with facility plans
- Peak and off-peak time periods
- Travel costs must be included in all model steps

All Other Areas:

Must use any of the above methods, if the MPO has them available

Surface Transportation Act of 1991

- Agencies must plan for all travel modes
- MPOs must consult with other agencies and interest groups on scenarios, modeling methods, and indicators
- Planning process must be recertified every 3 years

Civil Rights Act of 1964

- Agencies cannot discriminate against minorities in transit services
- Agencies must consider the effects of all projects and plans on minorities and on lower income households (Executive Order on Environmental Justice)

National Environmental Policy Act

- MPOs must consider the growth-inducing impacts of projects (including the land development effects of major projects)

The generation of alternatives is another especially weak step in transportation planning. Most MPOs initially analyze several roadway and transit investment schemes, but do this in-house, not in published documents. In the official plan, the MPOs usually analyze only the “Preferred Plan” and the “No Action Alternative,” which is required by NEPA. The preferred plan, in many instances, seems to be the maximum investment in roads where the plan can just meet the future emissions requirements. Transit is added to reduce emissions, as nec-
essay, and to satisfy interest groups advocating for transit and for lower income households in general. MPOs almost never identify and evaluate all-transit alternatives (the author has reviewed most of the plans from the largest 15 MPOs). The main reason for this appears to be that transit investments will generally focus on the central cities in a region and so will not meet the chief political test of MPO decision making, which is geographic equity (i.e., spreading the money around all areas within the urban region). Each MPO board member is an elected local government official and so he or she wants to bring the dollars into his or her jurisdiction. In some states, such as California, transportation funds are legally allocated by population, and so outlying counties get their “share” of funds. These funding rules make transportation planning more a process of spreading projects around than of seeking to meet regional objectives for economic efficiency, equity, or even congestion reduction. This is a good example of how “planning is politics.” Nevertheless, it is important for MPOs to examine several alternative plans, including ones that focus on transit and land use in central cities, as well as on typical freeway widenings, to see the results. Several MPOs have engaged in visioning processes over the last 20 years, in which they examined broadly different alternatives, projected for 40 or 50 years. This is an essential part of transportation planning and should be done every 10 years or so by MPOs, outside of the regular planning cycle. These broad analyses may affect the funding process in ways that benefit the whole region.

The third weakness in this phase is inadequate plan evaluation criteria. The outputs from travel models are measures of congestion, such as level-of-service (A–F) on each network link and person-hours of travel delay. They also send their VMT-by-speed-class projections to emissions models that estimate the number of tons of each pollutant produced per weekday. MPOs, however, seldom evaluate equity outcomes well and they seldom evaluate aggregate economic welfare at all. These measures are urged, but not required by, the Surface Transportation Act of 1991. They are, however, essential to an informed and accountable planning process. Easily applied measures of comparative aggregate economic welfare (net benefits to travelers) do exist. These measures can come directly from the mode choice model or, for smaller MPOs without such models, from travel costs calculated off-model using travel times and distances from the travel model. These measures can also be calculated for travelers by income class and so can give a vertical equity measure (i.e., economic welfare by household income class).

Since few MPOs in the United States use these measures, economic welfare and social equity are not given much weight in plan evaluation. Such measures are used in most developed countries and in many developing ones; multilateral banks require them for major transportation investments.

Last, ongoing data collection is fundamental to accurate travel modeling. All MPOs should perform a household travel survey every decade, coordinated with the national census. In addition to travel questions asked of a random sample of the whole region’s population, surveys can be done on the same households over time (panel surveys), and surveys can be used to support land use modeling by asking questions about household and firm location behavior. One should also survey firms to determine goods movements by commodity type. MPOs need to perform a survey of employment to supplement national sources such as InfoUSA. If an MPO is going to develop a land use model, then it must also gather land use data. Most MPOs now have geographic information system (GIS) capabilities and so can use parcel data sets, if all of their constituent counties have these data (see Nyerges, Chapter 7, this volume). Parcel data, supplemented with air photos and satellite data, are the only way to get spatially accurate land use maps. All of these data-gathering efforts are expensive and time-consuming, and so each MPO needs to have a model development process that makes the most of the data available.
gram where the data gathering and data cleaning is part of an ongoing process.

In general, these issues of narrow objectives, narrow range of alternatives, inadequate evaluation criteria, and insufficient data gathering are a consequence of inadequate MPO budgets for transportation planning. MPOs that spend $1 billion per year on transportation projects will spend only a few million dollars on transportation planning, which is a few tenths of a percent of the budget. Private firms spend a much greater proportion of their overall costs on planning. Federal funding rules permit the use of several categories of funds for MPO planning, but most MPOs prefer to spend those funds primarily on facilities. This generalization, that MPOs don’t spend enough on planning in the preanalysis phase, applies to the next two phases of planning, as well. Figure 5.2 outlines the three phases of transportation planning.

**Technical Analysis Phase**

The next phase of transportation planning is the technical analysis phase, which is primarily travel modeling but may also include a land use model. I noted earlier that complete set of models would represent all behaviors in the urban system that are affected by changes in the transportation system. Now we will define an ideal model in more detail from the perspective of urban modeling, where all urban systems are represented. According to Wegener (1994), urban models should represent all subsystems. He defines these systems by the speed with which they change. *Slow change systems* include transportation networks and land uses (permitted economic activities). *Medium-speed change systems* include workplaces and housing, by which he means the construction of buildings. *Fast change systems* include employment and population, meaning the movement of workers and households among existing buildings. *Immediate change systems* include goods transport and personal travel. It is widely accepted that changes in the transport networks will affect travel and goods movement and, subsequently, employment and population locations, and, finally, the construction of workplaces and housing. This broader urban modeling perspective is now becoming accepted in transportation planning and modeling. When the U.S. DOT had four teams of consultants develop outlines of advanced travel forecasting models in the early 1990s, three of the proposals included land use models as part of the package to ensure accuracy of travel forecasts (U.S. Department of Transportation, 1994a).

With this broader perspective, let us now review again the typical MPO travel modeling process, derived from the 1960s and still in use today, called the “four-step” modeling process. This typical process does not include a land use model.

In recent years, several conferences and publications have called for improved travel models and for the addition of land use

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models to MPO practice. A compilation of recommendations from peer reviews of travel models, done during MPO recertifications, was published in 1994 (Peer Review Panel Functions and Organization, 1994). This report lists desirable modeling characteristics for observed data, demographic and economic forecasts, model system design, general forecasting issues, trip generation, trip distribution, mode share, assignment, and other details. The U.S. DOT published Short-Term Travel Model Improvements in 1994 (U.S. Department of Transportation, 1994b). Good papers from this period were by Stopher (1993a, 1993b) and Deakin, Harvey, and Skabardonis, Inc. (1993). Hundreds of papers have been published and presented at the Transportation Research Board annual meetings over the last 20 years on how to improve travel models.

Activity Forecasts

These forecasts are done before the four-step model is run. The MPO needs data on the location of different types of households and employment for the base year and for the forecast years. Base-year data are gotten from the decennial census and from the MPO’s household travel survey and other local surveys and GIS data sets (from the census: households, number of workers per household, persons per household, household income, number of autos per household, all by zone; from other data sources: number of employees by type of employment by zone). Then, population and employment forecasts for the counties in the region are taken from a state agency. These are usually derived from national and state input–output and econometric models of the national and state economies. We will not concern ourselves with the accuracy of these projections, since they are exogenous, except to note that the error is, on average, at least 1% for each year of the forecast, meaning that the typical 20-year projections can be high or low by 20% or more. In addition, the MPO must get or make forecasts for household income and size, the other most important variables in the travel model. Many states provide these forecasts for counties. Errors in demographic inputs to travel models are unavoidable. This is one reason that MPOs are required to redo their transportation plans every 3 years.

The MPO then must allocate the firms and households to zones. This is usually done for a few hundred to 2,000 travel analysis zones (TAZs), which are generally the base-year block groups or census tracts. Only a few large MPOs use some sort of land use model to allocate households and firms to zones in future years. The vast majority of MPOs use a judgmental process in which the staff examines vacant lands in each county and what the land use designations are for them in each county’s land use plan. By hand, or using a simple GIS system, the MPO staff assigns future households by density class and income (income correlates with density and with existing incomes). Future household auto ownership level is also generally correlated with existing auto ownership, which comes from census data. Types of firms (generally manufacturing, retail, other, for small MPOs, with more categories for larger MPOs) are allocated by land use categories in local plans.

Most local land use plans, however, are for a 20-year period and are redone about every 12 years. This means that the average plan is about 6 years old and so may have as little as 14 years of land remaining in it designated for urban land uses. So the MPO staff will run out of land for some land use types in many cities and counties in the region when doing 20-year projections. As a result, the MPO staff must project where lands will be designated for future growth by interviewing local planners. The local planners often will not commit to any specific areas, so the MPO staff must do this on their own.

Jobs/housing balance also presents a problem to the MPO staff. Most localities want more employment than housing, because
housing units pay only property taxes whereas retail uses pay property and sales taxes. So if the MPO staff uses the local projections in the land use plans, or uses the local land use maps literally, they will get far more employment than there will be workers in households for all future years. That is, local governments project and plan for too much employment, to keep such lands in oversupply, which makes these lands less costly, to attract firms. The MPO, however, cannot run a travel model with excessive employment, as the model must balance jobs with workers. So the MPO staff must reduce employment projections for many of its jurisdictions, and they do so by negotiating with the local planners. This procedure is inaccurate since employment can still be projected in zones where firms would probably not locate, in terms of access to markets, workers, and related firms.

MPOs should match forecasted land use patterns to each facility scenario to be accurate because land development is affected by changes in accessibility. This can be done by using a land use model or an expert panel. These projections must be approved by all the member cities and counties because they control land uses in the region. This process really just formalizes the currently poorly documented procedures, where projections do not conform to local land use plans. The difference is that the MPO would use different land use patterns for each of its transportation alternatives.

Demographic trends must also be accurately forecasted. Average household incomes, for each income class, should not be simply forecasted to stay the same in real dollars. This masks the changes that have occurred in the past two decades, where in most parts of the United States the lower income groups have experienced a large drop in real income. In some parts of the country, the middle-income groups have also lost income. The MPO must project these trends, in order to capture their strong effects on auto ownership, trip generation, and mode choice.

In the four model steps below, it is important to observe that the first three submodels are estimated on data for individuals and households. This gives the maximum statistical power to the models, as all variation in the data are available. After the equations are estimated for each household and employment type, however, the model is applied in an aggregate fashion, on categories of households and employment in each zone. The four-step model is sometimes called an “aggregate travel model” because of the zonal averages used in application, but the submodels are estimated in a disaggregate fashion.

Trip Generation

This is the first step of the four-step travel modeling process. This simple statistical model (a cross-classification table or regression model) projects the number of weekday trips a household will produce, based on household income, number of autos owned, number of workers, and household size. It is insensitive to the level of road congestion in the region and is also insensitive to transit accessibility. This is theoretically incorrect, as regions with good transit and congested roads would tend to get a higher transit mode share and lower auto ownership for each household type. It is also insensitive to land use density in the residence zone, which is known to be inversely related to trip generation. The model also projects trip attractions, which are the destinations for the trips. Attractions are determined by the number and types of employees in each zone, again using simple models. There are standard books with trip attraction data for each type of employee. Trip productions (from households) and attractions (to employment) must be equal, and to do this the travel model iterates to convergence on tables of all trips, by origin and destination zones. Usually, the model is set to make attractions match productions, as agencies feel that their local data for trip generation are reasonable.
An auto ownership step should be added to the model set, so that household number of autos is dependent on accessibility for auto travel and to land use variables in the home zone, such as density and mix. Trip generation should be made sensitive to auto ownership and to origin (home) zone land use density and mix and to parking costs in the home zone and employment zone. The pedestrian and bike modes need to be added, as these are the subject of much policymaking. Trip purposes need to be elaborated to include at least home-based shop trips, home-based school trips, and work-related trips. More trip purposes results in more accurate estimates for trip generation, trip distribution, and mode choice, as these submarkets behave differently.

**Trip Distribution**

The second step matches trip origins at households (by zone) to trip destinations at firms (by zone). All trips are considered to be separate, even though in reality trips are linked in tours (e.g., home, to work, to shop, then to home). Trip distribution is done separately by trip purpose, with the simplest models having home-based work, home-based other, and non-home-based trip purposes. The trips are distributed across the production/attraction pairs (now called origins and destinations) according to a gravity-type model, in which the number of trips falls off as a function of trip time length, raised to a power greater than 1. The gravity model captures the fact that trips are more likely to be short than they are to be long. The other determinant of the number of trips placed in each cell in the zonal trip distribution table is the number of trips produced in each zone and the number of trips attracted in each zone, which is taken from the previous model step. To summarize, all trips are considered separately and are assigned to origin and destination zone pairs in a large table, according to the time length of the trips, using an iterative fitting algorithm to get all trips distributed.

The main issue with this model step is whether trip distances are fixed in the model or not. If an MPO runs through the four model steps just once, one can have different vehicle speeds and road volumes in the trip distribution step, the mode choice step, and the network assignment step. This is, of course, illogical and inaccurate. The very earliest UTPS manuals from the U.S. DOT warned against this practice, but it became routine in MPOs, ostensibly because of (mainframe) computer runtimes and costs. If all of the model steps are run through iteratively until all steps have the same travel speeds or volumes on a sample of links, or the trip distribution table does not change significantly, then one has an equilibrated model. This is the only logical and legally defensible method, and it is the method recommended in all academic textbooks and articles. It is called “full-feedback” modeling. Several academic articles discuss methods for this procedure, as does a U.S. DOT-commissioned report on methods for model equilibration (COMSIS, Inc., 1996).

Not iterating the whole model set is not only inaccurate, it is biased toward adding road capacity. With a properly equilibrated model, when you widen roads, travel speeds go up and people make trips of longer distances in about the same amount of time as before. This is based on the observation that the household travel time budget (daily total travel times) is very stable over time and so can be treated as almost fixed in any given model year. With travel time budgets that are almost constant, if road travel becomes faster, people will travel longer distances on average, and if road travel slows, they will make shorter distance trips. So, in a properly functioning model with full feedback, the No Action Alternative will show high levels of congestion in future years, but this congestion will result in shorter distance trips and so the congestion will be reduced somewhat by this behavioral change. In a model set with a “fixed trip table” (the model steps are only run
through once), there is no such feedback to reduce trip lengths, VMT, and congestion, and so congestion levels are overprojected. Exaggerated congestion levels make road expansion projects appear more urgent than they really are. Several lawsuits have attacked this practice.

This same bias applies to the Proposed Plan alternative, in which a properly equilibrated model will show that adding to road capacity speeds up travel, leading to longer distance trips, which then adds to VMT, which in turn leads to greater congestion. So the benefits of adding road capacity in reducing travel times is diminished somewhat in the model, as the extra travel adds to congestion. A model run with a fixed trip table, however, does not represent this important behavior and shows greater congestion reductions than will really occur. This makes the plan alternative look better than it will be.

This issue of “induced travel” has been the subject of dozens of papers in the last few years, and there is now a strong consensus that adding capacity speeds up travel, inducing longer distance trips (Cervero & Hansen, 2000, 2002; Noland & Lem, 2000). One of the critical improvements MPOs can make to their travel models is to run them to full equilibration. The air quality conformity rule requires this for “serious” and worse air quality regions. This method is necessary, however, to pass even a threshold test of basic scientific soundness in any lawsuit that questions an MPO’s modeling. Virtually all MPOs run their models on desktops or workstations and so computer runtime costs are irrelevant. Most travel modeling systems software (the management shell that runs all the submodels [model steps] in sequence) have the ability to equilibrate the model steps, and so this is a small effort, except in the largest MPOs that have very complex models. These MPOs, however, have the resources to write the code to iterate the model steps.

Large MPOs now equilibrate their model sets. More recently, they have also gone to a more accurate type of trip distribution model, at least for the home-based work trip, which is associated with the peak travel period, where congestion is the worst. This is the destination choice model, which is a discrete choice model where the destination zones are the choice set. Some large MPOs have joint mode-destination choice models for work trips, where both are chosen simultaneously. This is the theoretically best model type, but it is more difficult to estimate. In principle, all trips should be distributed using destination choice models, as they are based in microeconomics (traveler utility), whereas the current economics of trip distribution by iterative fitting of the trip table is ad hoc.

**Mode Choice**

In this model step, the trips in the trip distribution table are allocated to modes with a statistical model that includes trip cost (distance cost, time cost, fares, tolls, and parking charges), household income, household auto ownership (number of cars), and accessibility. The whole model set must be run to get the travel times, which then are fed back to the mode choice step. Small MPOs generally do not have a mode choice step, and so run what are called “traffic models” (only auto travel is represented). Some medium-sized MPOs use diversion curves (or mode split curves) or run simple mode split models that are sensitive only to auto travel times, where slower times create more demand for transit. Often, they are manipulated by hand, that is, mode percentages are changed judgmentally. Most medium-sized and all large MPOs use discrete choice models, which are much more accurate than mode split models and, more importantly, are behaviorally based. They also are more policy-sensitive. That is, they can project changes in mode choice that result from the construction of a new passenger rail line or the widening of a freeway.
The mode choice model is the strongest submodel in terms of its behavior, which is firmly based in microeconomic theory. A major weakness of many mode choice models, however, is that they do not include nonmotorized modes, such as walk and bike. The walk mode share is much larger than the transit share in most medium-sized urban regions, for example, and so must be modeled, in order to forecast shares for other modes accurately. Also, improving transit generally shifts some travelers from the walk and bike modes to transit, so they must be represented. Most large MPOs have recently included the walk and bike modes in their models. Another weakness is that mode choice models are not sensitive to land use policies, such as increased densities and land use mix, which are expected to reduce auto mode shares. So, many larger MPOs have recently added land use variables in their mode choice models, usually for the transit, walk, and bike modes. Medium-sized MPOs need to also make these two types of model improvements in order to be able to evaluate transit options.

**Assignment or Route Choice**

The fourth step involves assigning the vehicles to the network of roads and the transit passengers to the rail and bus lines. Most MPOs use capacity-restrained assignment, where a computer program assigns vehicles to the shortest distance routes for each origin-destination pair of zones. The trips are loaded onto the network and the travel speeds are then calculated from the traffic volumes, related to the capacity of each link. For each volume/capacity ratio, there is a related speed in a table. This permits the creation of a trip time table (time lengths of trips). As vehicles on links slow down, the model assigns some vehicles to other faster pathways to link the origin zone to the destination zone, until such new assignments cannot decrease travel times in the system.

In most MPOs, the road and transit network files need to be "cleaned" (i.e., checked for errors) thoroughly to reduce errors in link capacities and to fix non-connected links and nodes in the spatial graph. Link capacities should be carefully recalculated with additional data on road geometry (e.g., width, slope, sight lines). Carpool lanes must be a separate link type, as speeds will be higher in them. Transit access links (from parking lots and streets) should also be coded, especially for rail stations.

Intersection delays need to be represented in the networks, and delays for links and intersections must be calibrated to local data. Postprocessing of speeds is also becoming a common practice. In this procedure, modeled vehicle speeds are made to match observed speeds. Time-of-day must be represented, at least as peak and off-peak periods. Even more time periods (peak, shoulder, off-peak, nighttime) will make the model more accurate in projecting speeds and emissions.

Advanced practice for the large MPOs is to develop tour-based models that incorporate time-of-day explicitly in trip generation. Portland, Oregon, and San Francisco adopted such models in 2001. Trip chaining in tours also permits more accurate estimates of the number of cold, warm, and hot vehicle starts, which is important to emissions analysis. Very advanced models will also represent changes in household "activity allocation," such as working at home or deferring an out-of-home activity. Household travel surveys must be improved to match these new modeling requirements, and so multiday activity and travel diaries are coming into use.

**Emissions Modeling**

After the four-step model is run, the MPO then calculates the on-road vehicle emissions. As noted above, a standard emissions model is used in all states, except California, which has its own model. We will not go
into the details of these models, except to say that the past emissions factors for each vehicle type and age were much lower than were the empirically observed emissions, and so the most recently revised emissions models have higher emissions for any given fleet with any given regionwide VMT. This change will make it more difficult for many MPOs to show air quality attainment in regional transportation plans completed after 2002. The new emissions models also show higher emissions at high speeds (over 55 miles per hour), which will make building more freeway lanes produce more emissions in the models. Last, we note that new ambient air quality standards for small particulates and for ozone have been adopted by the U.S. EPA recently, and the new standards will cause many regions that are now in attainment to go out of attainment for these new standards.

A very important change required by the air quality conformity rules is that travel speed in the base-year models must be calibrated (matched) to actual measured speeds in the base year. This means MPOs cannot continue their past practice of capping highway speeds in the model at 55 miles per hour, which resulted in large underestimates of emissions on highways. Models now should include speed categories up to 75 miles per hour, since substantial proportions of vehicles travel at over 65 miles per hour in most regions.

Postanalysis Phase

This phase includes plan evaluation, plan implementation, and monitoring of the results. We will only discuss evaluation here because of limited space.

Plan evaluation should be comprehensive, that is, it should include all major impact categories. These many measures can be summarized as economic, equity, and environmental issues. Regarding economic issues, MPOs generally evaluate congestion levels with level-of-service on links and also with person-hours of delay for all travelers. These are narrow measures, as they depict only road congestion and do not include the overall economic utility of the travelers. A utility measure can be derived from most mode choice models, so that a complete measure is readily available for large MPOs and for the medium-sized ones that have mode choice models. Smaller MPOs can get a similar measure, based on travel costs derived from their model runs. Social equity can be measured in many ways, but the most complete measure is traveler utility by household income class, which is measured by using the logsums from the logit mode choice model. All mode choice models require that households be categorized by at least three income classes so that one can perform this equity analysis (Rodier & Johnston, 1998).

For environmental measures, MPOs give the on-road emissions of several pollutants and can project energy use by vehicles. It is fairly simple also to project the emissions of greenhouse gases, using published research that relates fuel use to greenhouse gases. NEPA requires that the MPO also evaluate runoff from all roads in the plan, but most MPOs do not do this adequately. Recent legal cases and changes in EPA rules require local governments to evaluate and treat nonpoint runoff (water pollution), that is, runoff from impervious surfaces in the region. A recent Clean Water Act case in Southern California, for instance, requires California DOT and U.S. DOT to treat all runoff from federally funded and state-funded roads. MPOs need to improve practice in this area of analysis. Many runoff models are available.

Habitat damage is a big issue in the southeastern, southwestern, and Pacific Coast states, where large numbers of listed species occur, and in all wetlands and riparian lands in the United States. With recent advances in mapping habitat types and in GIS methods in general, the analysis of habitat impacts of transportation plans is much
LAND USE MODELING

Land use modeling has a long history in the United States. Early academic models were developed in the 1950s and 1960s by researchers such as Lowry and Alonso. The federal government was supportive of these models as they could be used in both transportation planning and in urban redevelopment. A U.S. DOT request for proposals in 1971 states:

The following issues have been of concern to transportation planning agencies:

BOX 5.2. Summary of Good Modeling Practice for Medium-Sized and Large MPOs

**Time Representation**
- Peak and off-peak periods

**Data Gathering**
- Household travel survey every decade with tours
- Vehicle speed surveys
- Data for urban model

**Activity Forecasts**
- GIS land use model or economic urban model

**Auto Ownership**
- Discrete choice model, dependent on land use, parking costs, and accessibility by mode

**Trip Generation**
- Walk and bike modes
- More trip purposes
- Dependent on auto ownership
- Three or more time periods

**Trip Distribution**
- Full model equilibration
- Composite costs used (all modes, all costs)
- All-day trip tours represented

**Mode Choice**
- Discrete choice models used
- Land use variables in transit, walk, and bike models

**Goods Movement**
- Fixed trip tables

**Assignment**
- Capacity-restrained
- Cleaned-up link capacities
- Speeds calibrated
- Three or more time periods
1. In urban areas, it is necessary to achieve a balance between the need for mobility and the preservation of environmental quality and social stability. How can this process be incorporated into the transportation/land use planning program beginning with plan development?

2. To what extent can transportation system planning and facility capacity planning be used to influence land development? What are the available controls for accomplishing this, and how can they be applied effectively?

3. Providing too high a level of service of the auto-highway system in urban areas might result in travel demand exceeding the supply that can feasibly be provided. What should determine the minimum or maximum level of service (speed), which should be used as a criterion for planning transportation facilities in specific parts of the urban area?

4. What would be the consequence of controlling transportation facility capacities as a means of directing land-use development even though such controls could mean congestion with more pollution and higher travel costs?

This study should determine the feasibility of the balanced development of land use and transportation facilities. It should also determine whether or not land development and travel can be brought into a satisfactory balance such that any transportation improvements made can provide a continuing high level of service over time. (Putman, 1983, pp. 39–40)

This U.S. DOT contract led to the development of the earliest integrated urban model in the United States, ITLUP (Integrated Transportation and Land Use Planning), by Putman in the early 1970s, which has since been used by about two dozen MPOs in the United States. This is a Lowry-type model with land use types dependent on accessibility and past demand for land, but without the use of land (or floor space) prices as a feedback. This type of model requires the MPO to gather data only on land consumption (acres of each land use type) by firms and households in each traffic analysis zone or district. All the other data are already in use for travel modeling in each region.

Echenique developed a more complete urban modeling system in the late 1960s and 1970s, one that included the supply and demand for floor space, mediated by price (Hunt & Simmonds, 1993). Again, the U.S. DOT supported the development of the generalized software package for this model (Echenique, M. H. & Partners, and Voorhees, A. M., & Associates, 1980, in Echenique et al., 1990). This package later became MEPLAN (Marcial Echenique and Partners Planning Model), which has been applied in more than 50 urban regions in the world. The U.S. DOT software was apparently never used by any region in the United States. This class of models requires floor space lease value data and floor space consumption data, and it is more difficult to implement than the simpler type of land use model. Calibration of urban models is quite difficult, but new software that substantially automates this process is now becoming available (Abraham & Hunt, 2000).

There is a long-established trend of improved travel modeling and land use modeling, both in the United States and abroad. The Federal Highway Administration (FHWA) has a website that reviews the various types of urban models (fhwa.dot.gov/planning/toolbox/land_develop_forecasting.htm). Dissemination of these methods into agency practice has been quite slow, however, but new legal mandates are putting pressure on MPOs to advance their models. In addition, these agencies are now expected to evaluate a great range of land use and transportation policies that require land use models and much better travel models.

Modeling the induced land development effects of transport improvements can change VMT projections substantially (Rodier, Abraham, Johnston, & Hunt, in press). We compared a future No Build scenario with a future Maximum Freeway Ex-
pansion scenario, using both a travel model and an urban model. We found that the land use effects added about 15% to the VMT difference between the scenarios. In another paper, we found that using a land use model along with a travel model changed the direction of change in emissions (future Build case minus future No Build case) and in travel speeds for highway scenarios, compared to running a travel model only (Rodier, Johnston, & Abraham, 2002).

Planners in the Portland, Oregon MPO compared an analysis of their 20-year transportation plan with their new integrated urban model (travel and land use models, run in sequence) with their previous typical analysis, using only their travel model and found: (1) using the land use model makes the travel model results more reasonable, in terms of economic theory and common sense; and (2) when both models were used, congestion levels on some roads were significantly lower because firms moved outward to take advantage of less-congested conditions in the countercommute (Conder & Lawton, 2002). In other words, not using a land use model can result in exaggerated projections of congestion, because the effects of congestion on land development are not represented.

A National Academy of Sciences review panel concluded that both induced travel and induced land development are real behaviors (Transportation Research Board, 1995). This work was partly based on much more detailed research previously done by a national panel in the United Kingdom. Many published papers show the induced travel effect, using historical data; for a review, see Noland and Lem (2000), and for a detailed empirical study see Cervero and Hansen (2000, 2002). A review of textbook sections on model equilibration is in Purvis (1991). This area is fairly settled now, given the recent papers with strong statistics. A few recent papers show the land development effect (Boarnet & Haughwout, 2000; Cervero, 2003; Nelson & Moody, 2000).

The FHWA disseminates several travel models and impact models that include provisions for entering induced travel factors.

State governments also recognize that added road capacity affects travel and land use. The National Governors Association (NGA) policy position NR–13 states that "the impact that highway decisions have on growth patterns and, in turn, on the environmental health of communities must also be appropriately analyzed in advance” (2001, p. 1). A report by the NGA also says that "rapid suburbanization and urban decay are mirror images of the same phenomenon” (National Governors Association, 2000). The latter statement recognizes the "hollowing out effect" that sprawl induces, where central city business and residential properties are abandoned when growth moves outward.

Federal agencies are encouraging the use of land use models by supporting research on them. The U.S. Environmental Protection Agency has published a reference work on land use models (U.S. EPA, 2000). The National Center for Geographic Information and Analysis has a review of GIS-based land development models on their website at nogia.ucsb.edu/conf/landuse97/summary.html. A review of a great variety of land use forecasting methods was done for the FHWA and covers both simple and complex models (Parsons Brinckerhoff Quade & Douglas, Inc., 1999). A detailed review of integrated urban models was done for the Transit Cooperative Research Program (Miller, Kriger, & Hunt, 1998). The U.S. DOT has published recommendations for improving urban models (U.S. Department of Transportation, 1995).

Many MPOs have been using land use models of various sorts for many years, but not in iteration with their travel model. That is, they use the models for their base case demographic forecasts, which are then used for all transportation scenarios (Porter, Meleney, & Deakin, 1995; SAI International, 1997). A more recent survey shows a few MPOs using land use models for pro-
jecting different scenarios (MAG, 2000). Full microeconomic urban models were recently developed for Honolulu, Salt Lake City, Eugene (Oregon), Sacramento, New York City, and the state of Oregon. Similar models are being developed for Calgary, Edmonton, the state of Ohio, and the Seattle and Chicago regions. The San Diego, Atlanta, and San Francisco regions have had zonally aggregate urban models for many years.

Having now reviewed the recent “top-down” federal laws requiring better modeling methods and having also gone through the steps in a modeling process and identified best practices for each step, we now review the “bottom-up” policy analysis capabilities being espoused by citizens groups and local governments. MPOs should respond to these needs too.

NEW POLICY ANALYSIS NEEDS

It is important to emphasize that, regardless of federal laws, lawsuits, and political pressures for more elaborate modeling, the increased policy analysis demands being placed on MPOs by their constituent local governments and by citizens groups also require better modeling. Recent recertification reviews, ongoing MPO experience with the strong consultation requirements, and agency surveys during model design programs reveal a growing list of policy concerns expressed by local member jurisdictions and citizens groups.

For example, the Sacramento region MPO surveyed the staffs of local agencies in 2001 and held several public workshops to get feedback on policy concerns. The survey revealed that the following issues were hot (in order of popularity): (1) land use and smart growth; (2) pricing of parking and roads; (3) automated traveler information systems; (4) paratransit, bus rapid transit; (5) environmental justice, social equity; (6) induced land development; (7) induced and suppressed travel; (8) peak spreading, departure time choice; (9) effects of land use and design on travel; (10) sidewalks, bike lanes; (11) air quality conformity, NEPA documents, traffic impact studies, land use planning; (12) models useful for subregion and subarea studies (fine spatial detail); (13) models useable by other agencies, standard modules, GIS; (14) making all assumptions explicit; (15) interregional travel; (16) open space planning and habitat protection; (17) useful for sensitivity analyses of policies; (18) including lots of understandable performance measures; (19) representing all travel behaviors; (20) representing nonmotorized modes and telecommuting; (21) representing land markets, not just local land use plans; (22) representing multimodal trips in tours, by time of day; and (23) useful for broad scenario testing. This is a long and demanding list. Most of these needs came from local transportation and land use planning staffs. So we can see that the higher standards for MPO modeling are coming from both external legal mandates and also from internal needs among member cities and counties.

There is great variation in MPO modeling practice, even among large MPOs. While many MPOs use models from the 1960s that are no longer scientifically defensible, many other MPOs regularly improve their capabilities and engage in good practice, even as expectations continue to increase. Some large and medium-sized MPOs recently have gone to full feedback in their travel models, an inexpensive improvement. Many have added mode choice models, some with walk and bike represented. Many MPOs have developed peak and off-peak time periods in their travel models. Most recently, some MPOs are developing land development models of various kinds. The great variation in quality of modeling, even among large MPOs, seems to reflect a lack of detailed guidance from the federal agencies and from professional organizations.

Another interesting aspect of this issue is that a few MPOs, even small ones, have developed good methods that are quite inex-
pensive. The Anchorage MPO, for example, has walk and bike modes, equilibrates their model set, and has a spreadsheet land use allocation model that includes accessibility from the base-year network as an attraction. Whereas this MPO currently uses the land use model to project only one land use pattern and then uses this pattern as input for all transportation plans, it could easily adapt this model to be used for projecting land uses appropriate for each future scenario, simply by using the future networks to get accessibility.

Another example is the Merced County Association of Governments in California (population 211,000 in 2000), which is running a simple GIS-based land use allocation model to design land use alternatives and then taking those land uses into the travel model. Many MPOs have developed similar GIS-based land use allocation models.

To show how agencies are trying to respond to both the “top-down” legal mandates and the “bottom-up” needs being expressed within their regions, we will review one agency’s model improvement program.

AN EXAMPLE MODEL IMPROVEMENT PROGRAM

The Sacramento region (population 1.9 million in year 2000) has a high growth rate and many important resources in need of protection, including prime agricultural lands, valley and foothill riparian corridors, native grasslands, and oak woodlands. It is an interesting region for model development as it includes heavy passenger rail, light rail, and several bus systems. Lower income households in this region have seen drops in their real incomes over the last 30 years, and so the need for transit services is increasing.

The region is in nonattainment for ozone, and the regional transportation plan may have difficulty showing conformity with the State (air quality) Implementation Plan (SIP) for future years. California has recently adopted a new emissions model that will likely make it more difficult for this region to demonstrate conformity after 2002. Because of these concerns about air quality and concerns about sprawl and loss of agricultural lands and of habitats, rising traffic congestion, lack of transit service for many lower income people in the central cities, and a public dislike for homogeneous (monotonous) segregated land use patterns, the MPO recently decided to improve its modeling capabilities and to design and evaluate broad regional scenarios.

The current model improvement program in this region is starting from a strong base, owing to past model upgrades. In the early 1990s, the Portland, Oregon MPO upgraded its travel model and the Sacramento agency adopted the same improvements in the mid-1990s. The 1994 model was developed with a 1991 household travel survey conducted in the Sacramento region. The resulting SACMET (Sacramento Metropolitan Travel Model) is based on the four-step modeling framework but has the following improvements:

1. Full model feedback (trip lengthening is represented);
2. Auto ownership and trip generation steps with accessibility variables (more road capacity results in more autos and more auto trips);
3. A joint destination-mode choice model for work trips (more accurate work trip mode choice and distribution);
4. A mode choice model with separate walk and bike modes, walk and drive transit access modes, and two carpool modes (more accurate mode share projections and better sensitivity to land use policies);
5. Land use, travel time and monetary costs, and household attribute variables included in the mode choice models (can evaluate land use policies and road tolls, fuel taxes, and parking charges);
6. All mode choice equations in disaggregate form (more accurate mode shares); and
7. A trip assignment step that assigns separate A.M. peak, P.M. peak, and off-peak periods (more accurate volumes, speeds, and emissions).

The SACMET model has considerable detail in the description of conditions, with 11,159 roadway links and 8,403 roadway lane miles. The zone system is also finely detailed, with 1,077 transportation analysis zones. There is an explicit representation of truck movements in the model with a fixed trip table for heavy trucks. Heavy-duty trucks constitute a small proportion of urban trips, but their size and slow acceleration gives them a significant effect on congestion. Land use is a fixed exogenous input in SACMET, however.

This travel model meets all the conditions in the air quality conformity rule, except the requirement for “consistent” land use and facility scenarios. This model set also does not permit the evaluation of the growth-inducing effects of expanded highways on land development, as required by NEPA. This travel model, however, presumably produces more accurate vehicle speeds and emissions for each time period, as speeds are now calibrated in the base-year model. The model is also sensitive to land use intensification policies, which are a major issue in this region.

More recently, the MPO has come under increasing pressure to model the land use effects of its transportation plans. The agency has been sued once and, as we saw above, land use impacts are a concern to its member governments and to citizens groups. During the mid-1990s, the author led a project that implemented and compared three land use models in the region (Hunt et al., 2001). We went on to implement an improved version of the MEPLAN land use model in this region, funded by the U.S. DOT, the California DOT, the U.S. EPA, and the California Energy Commission. This model was then, and still is, the easiest-to-apply full urban model with land markets represented. With a team from the University of Calgary, we implemented a model with floor space explicitly represented, in quantity and price. Several policy analyses were completed with these models, and the results were broadly reasonable (Rodier et al., in press; Rodier, Johnston, & Abraham, 2002). The cost to the MPO of developing and applying this 60-zone model would have been between $100,000 and $200,000 for consultants and about $100,000 for internal staff time. These estimates would apply to other large MPOs that have fairly complete land use data.

Under pressure for more accurate travel modeling and better policy analysis capabilities, the MPO designed a staged model improvement program in 2001. In 2002, it adopted our 60-zone version of MEPLAN and updated the base-year data sets from 1990 to 2000. It is run in 5-year steps. In 2004, the MPO will implement the PECAS (Production, Exchange, and Consumption Allocation Model), recently developed by Oregon DOT. This is a model similar to MEPLAN, but it includes a more detailed representation of goods exchange and so gives a valid measure of economic welfare, called “producer surplus” for firms and households. This is the most comprehensive measure of urban economic welfare, as rents and travel and goods movement costs comprise about 40% of an urban economy. This state-of-the-practice model will be run in 1-year steps on 600 zones.

During 2003, the MPO will engage in a scenario testing process with citizens and interest groups. Using PLACES, a public-license (free) GIS software package, the MPO will generate 50-year land use maps in real time in workshops, according to interest group and citizen wishes. This will be done for each city and county in the region and for the whole region. The staff will summarize these scenarios into a few for further analysis. They will also add in relevant transportation facilities. These general-
ized land use scenarios will then be taken into PECAS as changes in the local land use designations, which control potential land use types and densities. PECAS will then be run to give market-based projections for the 600 zones. Then PLACES will be used to disaggregate the zonal land use projections to parcels. The SACMET travel model will be run on these data, to get travel, emissions, congestion, and other transportation measures. In addition, several GIS-based impact models will be run on the land use data, to assess effects on habitats, flood damage, local service costs, and soil erosion.

Concurrently, in this near-term period, the SACMET travel model will be improved by adding trip tours, using 15-minute time periods, and simulating all travelers individually. Modeling tours allows a more accurate representation of trip chaining. Travelers will possess many demographic characteristics, and so equity analyses can be done by income, race, and the like, and by zone. Implementing the initial PECAS model in 2003 will cost about $600,000. Other regions implementing PECAS include the State of Ohio and Calgary.

In the 2004–2005 period, the MPO intends to improve the land use model further by using parts of the Oregon Generation 2 model, which uses the PECAS economic structure but requires the microsimulation of all firms and households, located by street address. The model will be run in 1-year steps. Matching of workers to jobs will be improved with more data on individuals’ educational status and job experience. Goods movement will be represented by individual shipments of commodities. The travel model is integrated into this structure by using microsimulation of all households and individuals in them, by address. Household activity allocation will be represented, followed by trip tours. Time of travel will be represented in smaller increments and departure time choice represented with more variables. The cost of going to the improved, more-disaggregate models will be between $1 and $2 million, depending on the extent of the disaggregation of firms. All of this disaggregation in time and space should result in more accurate projections of travel and emissions. These disaggregate models also permit detailed equity analysis, because each traveler and locator has a rich set of characteristics attached to it.

The Sacramento MPO’s plan for model development is ambitious and it will keep the agency at the forefront, with state-of-the-practice models. This will help insulate the MPO from lawsuits, as well as permit it to address the policy issues listed above. Because of the more detailed representation of travelers, trip tours, types of firms, and households, the models will be more accurate, as well as more policy-sensitive. Last, because the models will include theoretically sound indicators for economic welfare, social equity, and environmental impacts, all important evaluation issues can be represented. This comprehensive modeling will then allow the MPO and its constituencies to evaluate the trade-offs among the scenarios being examined. The 50-year time horizon in the scenario process is necessary in order to see significant effects from land use policies and from transit-building policies too. The fact that MPOs do 20-year plans biases them against such policies. The Sacramento region’s model improvement program is similar to those in many large MPOs now, but it is more comprehensive. Its scenario testing is also exemplary; only a few other regions have done 40-year or 50-year scenario exercises.

Now that we have reviewed travel models and land use models in some detail and seen the improvements that are being made, we will look a bit further ahead to see what future developments will include.

THE FUTURE OF MODELING
TRAVEL AND LAND USE

In general, modeling is moving toward the microsimulation of travel, goods shipments, households, and firms with land, develop-
ers, and floorspace demand all represented. Firms and households will be simulated by point locations. Large MPOs are progressing to disaggregate travel modeling, including tour-based joint mode-destination choice models initially and eventually microeconomic models of household activity allocation. Household vehicle holdings are represented. These models are discrete in time and space with households represented by address and firms by block or tract. The travel model will be based in GIS for data management and display (see Nyerges, Chapter 7, this volume). The goods movement model will represent shipments of commodities by truck type and time of day, with terminal costs included. Many of these methods recently have been applied in Portland, Oregon, the State of Oregon, and San Francisco. A household travel survey that asks about trip tours is needed, and several MPOs are currently doing these.

For land use modeling in the future, large MPOs will develop similarly disaggregate land use models, where households are represented by address and firms by block or tract. Floorspace quantity and price will be represented. Developer decisions will be represented with a discrete choice model, based on historical parcel data. Reuse of buildings and redevelopment of parcels are included, as are the production and consumption of all goods and services. The land use model is based in GIS for data management and display. All local services and regulations are represented.

Data are handled in a data library, which all submodels address directly. The travel and land use models are closely linked, so that person and goods movements are derived directly from the spatial flows between sectors for persons and goods in the land use model. The models will be run with time periods appropriate to each behavior (minutes, hours, days, months). UrbanSim has been developed around these concepts and recently applied to the Eugene–Springfield, Oregon, region, the Salt Lake region, and the Honolulu area. UrbanSim is an open-code model, available on the World Wide Web for download, and was supported by the National Science Foundation, the Oregon DOT, and the U.S. DOT (www.urbansim.org). Digital census data are available for 1990 and 2000, making the estimation and calibration of urban models more tractable than in the past. Also, parcel data are increasingly being used by MPOs for various other purposes. MPOs do need to gather data on the locations of firms, number of employees, and floorspace lease values. Some of these data are available from national vendors.

In general, MPOs need to budget for continuous model improvements over each decade. Some data sets take a year or two to gather, clean, and assemble, before a new model can be estimated and calibrated. As member jurisdictions make more demands on the MPO models for various types of policy analysis, the models will have to keep pace. Many MPOs are making the models available to all of their member agencies and better user interfaces are being developed for these local staff people. A good framework for seeing how models can evolve over time is presented in Miller, Kriger, and Hunt (1999). It is also important to understand that the interagency consultation process required by the surface transportation act intends for the partner agencies to influence the evaluation and choice of models to be used by MPOs. Local governments and partner state and local agencies can use this joint decision-making process to require better modeling practices by MPOs.

REFERENCES


Oakland, CA: Metropolitan Transportation Commission.