# TRAVEL MODELING 101

Boston Region MPO
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## Introduction

This discussion is designed to give the layperson a sense of what a travel model is and how it is used. It is important to provide this description for those who are interested because travel modeling underlies much of the work done by the staff to the Boston Region Metropolitan Planning Organization (MPO).

Following this introduction, there is a brief section that describes the essence of the MPO´s set of travel models, and then another section that describes in more detail each step of the travel-modeling process. The final section discusses how the model set is maintained and applied in projects. The reader is invited to contact Scott Peterson, Director of Technical Services, (speterson@ctps.org), at the MPO´s Central Transportation Planning Staff (CTPS), for additional information.

A travel model set is nothing more than a tool, albeit a computationally complex tool. A travel model set predicts how many trips will be made by people in a given region on a typical day, where those trips will go, and what modes and routes those trips will utilize.

Travel models are built on the basis of the observed behavior of people. That behavior is typically measured from the results of a household travel survey. Statistical analysis of the survey data yields the models that describe this behavior. The models are then used to forecast future travel under certain assumed conditions: assumed population and employment patterns, assumed costs of the different travel modes, and an assumed transportation system.

Travel models exist to provide information about projects, programs, and policies for decision makers. In the context of projects, they are used to predict how many vehicles will use a new or modified roadway, or how many people will board a new or modified transit line. In the context of programs, such as the Long-Range Transportation Plan, they are used to predict total system-wide travel patterns. In a policy context, the travel model set has been used, for example, to inform MBTA decisions about new and modified fare policies.

The Boston Region MPO has always had a travel model set, and the staff, CTPS, maintains and applies (runs) it. The model set has undergone major improvements over the years: it was completely rebuilt in 2013 on the basis of a new household survey conducted in 2011. The model set is a so-called four-step model. It is so named because, historically, models of this sort were composed of four main models or model steps. The MPO´s travel-modeling process, as will be seen, is actually made up of six main steps.

## The Statewide Model

CTPS's regional model covers 164 communities in eastern Massachusetts. Ninety-seven of these communities are in the Boston Region MPO's planning area, and the other 67 communities are in adjacent MPOs. CTPS's model is nested within the statewide travel-demand forecasting model, which covers all of Massachusetts and Rhode Island, and the southeastern portion of New Hampshire.

The current version of the statewide model was built in January–March of 2017. This 2017 statewide model combines two models: 1) the 2016 statewide model, which did not have mode-choice capability; and 2) CTPS's four-step model. The 2017 statewide model was built by splicing the 164 communities in CTPS's regional model into the 2016 statewide model, effectively replacing the statewide model data for those communities with the most current data contained in the regional model. Consequently, all the inputs (population and employment data specifically), which were developed for the regional model, were incorporated into the statewide model.

## Essential Features of the Model Set

Currently, the model set represents weekday travel only. It is an aggregate model set, in application, in the sense that it represents and forecasts travel for groups of travelers, rather than for individual travelers. It is a planning-level tool, not an operations-analysis-level one.

The model set focuses on passenger travel within Massachusetts. There is, however, an adjunct commercial-vehicle model that is also run when necessary. Another adjunct model forecasts ground-access trips to Logan Airport made by air travelers. In addition, after the travel model set is run, the outputs from it are often entered into a model developed by CTPS that, with the use of emissions factors supplied by the US Environmental Protection Agency, computes emissions of pollutants from vehicles in the state. More information about these adjunct models can be obtained by contacting the Director of Technical Services at CTPS.

The model set is multimodal: it represents and forecasts travel by all of the state's transit modes, by all types of single-occupant and multiple-occupant vehicles, and by pedestrians. It represents travel for all purposes, including work, shopping, recreation, and personal business. The forecasts that it yields are for four different time periods during a weekday: morning peak, midday, afternoon peak, and evening/night. In the discussion that follows, trip purpose and time periods (along with many other model details and nuances) will be largely ignored for simplicity. The reader is reminded, however, that much of the process described below is followed for each of eight trip purposes and each of four time periods.

## Major Steps in the Travel-Modeling Process

The term four-step model refers to the third through sixth steps of the travel-modeling process described below, all of which deal with the demand side of the process. CTPS has added another step—a vehicle ownership model—and we also choose to refer to network and zone system development as a step, given its central role in the process. We therefore have six steps, as described below.

### *1—Network and Zone System Development*

Prior to evaluating the demand for travel in the region, the region´s supply of transportation must be represented by building a computer model of the region´s roadways and transit systems. Once built, this transportation network can be used to calculate the distances, times, and costs of traveling from one place to another in the region. These measurements are then used in the demand-modeling steps described below. In the final step, the modeled demand is loaded onto—or assigned to—the network to yield forecasts of traffic volumes on specific roads and transit ridership on specific lines. The network includes all transit lines in the region, all expressways and arterials, and many, but not all, collector and local streets.

This computerized representation of the region´s transportation network has to be anchored spatially: that is, it must be tied into some representation of real points on the ground so that the travel demand calculated in the steps below can be related to it. The way this is done is by dividing the region into so-called transportation analysis zones (TAZs). TAZs are sub-divisions of communities. These TAZs are loosely analogous to census tracts, but they are typically smaller (one square mile as opposed to about three for a census tract), and they are crafted to conform to the transportation network and natural features. Aggregate travel-demand forecasting models, such as the 2017 statewide model, require data at the TAZ level. Each TAZ is connected to the network so that the trips generated on the demand side of the model set can be loaded onto the network to obtain forecast traffic volumes and transit ridership.

The 2017 statewide model covers 446 communities (351 in Massachusetts, 39 in Rhode Island, and 56 in New Hampshire). There are 5,739 TAZs in the model (4,497 in Massachusetts, 812 in Rhode Island, and 430 in New Hampshire). There are also several loosely analogous points along the periphery of the statewide modeled area that allow simulated trips to pass into and out of it. The additional complexity these points impose on the modeling process will not be elaborated on here.

### *2—Vehicle Ownership Model*

The vehicle ownership model predicts how many vehicles households will own, based on various characteristics of the households. Vehicle ownership is important because it is associated with how many trips household members make and their probability of choosing transit. The household characteristics used to predict vehicle ownership are income, household size, and number of workers in the household.

In addition, household location has some influence on auto ownership. Therefore, the population and employment density surrounding the household´s location, as well as its accessibility to transit, are accounted for as well.

### *3—Trip Generation*

The trip generation step predicts how many trips, for each of several trip purposes, a household will make on a typical day. Along with vehicle ownership data, supplied by the vehicle ownership model just described, this model step uses household size and number of workers per household as inputs.  As can be imagined, all other factors being equal, households with more people, more workers, or more automobiles will make more trips. These relationships are all represented in the models. The generated trips are aggregated by TAZ.

While households produce trips, other places attract them. (Households themselves also attract trips, such as when a friend visits. For simplicity, this discussion ignores these trips.) Offices, schools and stores are examples of the many kinds of places that attract the trips that households produce. To forecast these "trip attractions," another set of equations is used. Each equation relates the number of employees, by employment type (basic, retail, or service), to the number of trips attracted to establishments of those types per day. All factors being equal, larger establishments of a given type have more employees and, therefore, attract more trips per day. Retail establishments generally attract more trips per employee than office establishments. As with the household ends of trips, these trips ends are aggregated by TAZ.

Some trips have neither end at a home, of course. A trip made from an office to a nearby deli at lunchtime is an example of such a trip. Separate equations forecast the numbers of these trips that go into and out of each TAZ.

### *4—Trip Distribution*

The trip generation step ascertains the number of trips that emanate from households in each TAZ and the number of trips attracted to the various places within each TAZ. It is not known where the trips produced by the households are going to, or where the trips attracted to the various places are coming from. In other words, trip generation tells us how many trips begin and end in each TAZ. What it does not tell us is how all the “trip ends” link to form whole trips from one TAZ to another.

The trip distribution step provides this linking function: it models trips from one place to another or from one TAZ to another. This is this accomplished by making two simplifying assumptions.  The first assumption is that trips produced by households in a given TAZ will be attracted to other TAZs in direct proportion to the relative sizes of those other TAZs.  This assumption is based on the Law of Gravitational Attraction, and for that reason trip distribution models of this sort are typically called gravity models.

The size of a TAZ, in this case, is measured by how many trips are attracted to it in total (as estimated in the trip generation step). So, all other factors being equal, in forecasting the number of trips produced by households in one TAZ that will be assigned to another TAZ, the larger the trip-attracting TAZ, the more trips will be assigned to it.

The second simplifying assumption is that trips produced in one TAZ will be attracted to other TAZs in inverse proportion to the travel time separating the two TAZs: when there are long travel times between TAZs, fewer trips will be attracted from the trip-producing TAZ. The travel times are computed from the transportation network, factoring both the time to drive and the time to take transit, if available, from one TAZ to another.

Of course, most TAZs produce some trips that are attracted to the origin TAZ, such as trips from home to the local elementary school. The trip distribution step estimates these trips in the same way that it estimates trips between TAZs.

### *5—Mode Choice*

From the previous two steps, the number of trips from every TAZ to every other TAZ is obtained. This information is organized into a matrix, often referred to by travel modelers as a trip table. In the case of the statewide model, a 5,379-by-5,379 matrix is produced, because in total there are 5,379 TAZs.

At this point the travel modes that will be used to make the trips from each TAZ to every other TAZ are unknown, and that is where the mode choice model comes into play. The mode choice model splits the trips in every TAZ-to-TAZ interchange by mode, based on the relative times and costs associated with each available mode. All else being equal, a given mode´s share of trips in a particular TAZ- to-TAZ interchange will increase as the time and/or cost of using that mode decreases relative to the other available modes. Other factors considered are travelers´ household size relative to household vehicle ownership, and TAZ population density (all else being equal, higher density indicates that more of the transit trips will be accessed by walking).

The modes considered are auto drive alone, auto shared-ride, walk-access transit, drive-access transit, and non-motorized (walk or bike) all the way. As with the trip distribution model step, the times and costs associated with each mode for each TAZ-to-TAZ interchange are computed using the transportation networks. In the case of the automobile modes, in addition to time spent driving on the road network, any time spent getting into and out of parking facilities is included. The costs include operating costs (fuel, oil, and maintenance), and tolls and parking charges, if any. The costs of owning a vehicle (insurance, depreciation, and interest) are not included, as they are considered "sunk" costs: they do not factor into the day-to-day decisions people make about whether to use their vehicles for a particular trip.

For the transit modes, in addition to time spent onboard the transit vehicle, we calculate time spent walking to and from stations and stops, time spent waiting for the initial transit vehicle and any other vehicles transferred to, and any time spent driving or being driven to a transit station. Costs include fares, of course, as well as auto-operating costs and parking lot charges if transit is accessed by automobile.

The non-motorized (walk) mode is free, and the time to walk from one TAZ to another is computed by applying 3.0 miles per hour to the distance between them.

## *6—Route Assignment*

The previous model step yields forecasts, for each TAZ-to-TAZ interchange, of the numbers of trips that will likely be made by each available mode. What is not determined by the mode choice step, however, is how many trips will be taken on particular routes through the network. Most zonal interchanges have more than one roadway routing connecting them, and many in the core part of the region also have more than one transit routing connecting them. In the route assignment step, therefore, the auto mode trips are assigned to different roadway routes, and the transit trips are assigned to the available transit routes. Walk trips are not generally assigned. Instead, their numbers and spatial patterns, as output from the mode choice step, are summarized and examined.

The route assignment process is somewhat analogous to mode choice. A particular routing along the roadway system will be assigned more of a zonal interchange´s trips if the trip cost is less expensive and the travel speeds are faster than other available routes. The same applies to transit routing. All of the time and cost components that are considered in trip distribution and mode choice are also considered here, the difference being that, in this step, the routes are considered as distinct from one another and are not grouped together into TAZ-to-TAZ measurements of time and cost as in the previous two steps.

Congestion is accounted for in this process. Roadways that are congested will be able to process a limited number of vehicles during a given period of time. The excess vehicles are assigned to other routes that have available capacity. On the transit part of the network, crowding on buses and trains is likewise accounted for, as are the capacities of station parking lots.

The result of this model step is a representation of the total trip making on the transportation network. Vehicle volumes on specific roads and transit boardings on specific bus and train lines are obtained from this model step and these data are used for evaluating projects.

## How Modeling Works in Practice

Travel-modeling practice at the Boston Region MPO can be divided into two major areas of effort: development and application. The staff is responsible for both areas.

## Model Development

Model development is an ongoing task. With a set of models and supporting routines as complex and data intensive as these are, there is always the need to update and improve them. To be precise, there are actually two parallel versions of the same model that are maintained. One represents current travel conditions. The other is the same essential model, but its inputs are for a future year that can be any time from one year to several decades away. For simplicity, this distinction will be ignored in this discussion, and the model set will be discussed here as if there is just a single one that represents both current and future conditions. Model development can be divided into three general subtasks as follows.

### *Minor Improvements*

Minor improvement tasks include updating the speeds on various roads in the network and making the computer routines that run the models more efficient. This is an ongoing activity.

### *Major Improvements and Revalidation*

The major improvements and revalidation tasks are more complicated. Periodically, some major factor in the model needs to be changed. Perhaps the MBTA has changed its fares, the MPO staff has obtained an updated set of traffic and transit boarding counts, or we have decided to adjust the form of one of the models slightly. When these adjustments occur, the model set must be revalidated. This simply means that, after the change is made or new counts are obtained, the model set must be run and adjusted until it replicates observed travel data: it must be shown to be valid in its representation of what we see around us before it can be used to forecast. (When the model set was first created, it was validated in this way before it was used.)

### *Rebuilding*

Rebuilding the model set from scratch is a major effort, and it only occurs every several years. The Boston Region MPO's model was last rebuilt in 2013, as has been mentioned. It occurred then because the MPO had conducted a new household travel survey in 2011. The data from such a survey allow modelers to completely rebuild models because the data, when analyzed statistically, yield the form and numerical contents of models. (This is formally known as model estimation.)

Examples of these parameters are the number of shopping trips that a household of three people with one worker make in a day, and the average time that a household member living in a particular part of the region takes to travel to work. Many of these parameters are fairly straightforward and easy to understand. Others are arcane to non-modelers. They exist, for example, in what are called utility equations in the mode choice models, where they measure the effect that changes in a particular mode´s travel times or costs would have on the probability of a household with certain characteristics choosing that mode. In all, there are scores of these straightforward and more arcane parameters in the model set.

It is extremely important to rebuild models periodically because the underlying behavior of travelers that models represent mathematically can change over time; without a new household survey modelers would not know about those changes, and the model forecasts could therefore be in error. After a major rebuilding the models are revalidated, as described above.

Regardless of what exactly has been done to the model set, once the changes have been made and it has been revalidated it is ready to be used in the next model-application project.

## Model Application

In any given project, several different future scenarios are typically analyzed. The scenarios may be, for example, variations of a planned transit line—say, scenarios oriented to bus, bus rapid transit, or rail alternatives. There are often variants of these main scenarios as well. The alternative scenarios may consist of different assumed forecasts of household and employment patterns. In some projects, the alternative scenarios consist of combinations of transportation and demographic possibilities.

In each case, the relevant characteristics of the transportation services or demographic assumptions are incorporated into the model set, and the model set is run. (When the demographics change, the work is not trivial: all of the demand models have to be rerun to produce new trip tables.) A variety of outputs will be obtained from the models, summarized, and reported. In addition to yielding traffic volumes and transit ridership on the region´s network, a host of other outputs are available. The possible outputs are too numerous to mention here, but they include mode shares by TAZ or collection of TAZs, through travel times from any point to any other point under congested conditions, and vehicle-hours traveled. As mentioned earlier, air quality impacts can be estimated by entering outputs into an adjunct model.

The travel model set is always run for the entire state, even if the analysis at hand only concerns a single corridor. In the latter case, there might be some detail added to the network and TAZ system in the corridor of interest, and there might be some refinement of the demographic assumptions in that corridor. Still the model set will be run for the entire state. That is done, in part, to capture travel impacts outside of the corridor that may result from changes within the corridor; this is particularly a concern in transit project analyses. Also, it is very time consuming to extract only the portion of the modeled area that is of immediate interest.

The travel model described herein is a planning-level tool. For projects requiring precise traffic forecasts that take into account all of the complex, underlying dynamics of traffic flow, and for precise transit-vehicle operations analyses, a different tool is required. In those cases, a micro-simulation tool would be used. CTPS has several such tools. More information can be obtained about them by contacting the Director of Technical Services at CTPS.