**Planning of Managed Lanes for
Reconstruction of a Major Urban Freeway**

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Many urban area freeways were designed and built in the early years of the Interstate highway program, which originated with the Federal-Aid Highway Act of 1956. Several suburban freeway sections in northeastern Illinois even predate the Interstate program. Segments of the Kingery and Bishop Ford (originally the Calumet) Expressways were completed in 1950 and the Edens Expressway followed in 1951. A 2.5 mile portion of the Eisenhower (Congress) Expressway in the near western suburbs opened in 1955 (*1*). All radial expressways leading to the Chicago central area were in operation by 1964 when the Stevenson (Southwest) Expressway was finished. The map in Figure 1 shows the opening years for the inner ring of radial expressways.

Figure 1. Opening Dates of Chicago Area Expressways

The region's older expressways have since gone through one or more cycles of resurfacing or pavement replacement. The Kennedy, Dan Ryan, and Stevenson Expressways have undergone more extensive reconstruction. The Kennedy was largely rebuilt during 1992-1994 and an eastern segment of the Stevenson in the period 1999-2000. The northern elevated bridge on the Dan Ryan was renovated during 1988-1989, and the remainder of this expressway underwent nearly complete reconstruction throughout 2006-2007.

The remaining aging expressways are mostly beyond the point where their useful lives can be extended by resurfacing existing pavement. This raises the question of how much reconstruction to undertake. Should the expressway be rebuilt maintaining the same access, geometrics and cross-section, or should the facility be more substantially improved and redesigned to improve safety and reduce congestion?

However, there are a number of issues with the rehabilitation and reconstruction of freeways in congested travel corridors. Limited rights-of-way, the desire to maintain traffic operations during construction, environmental considerations, funding, and local community interests all factor into the planning process that precedes any facility modernization. Planners also must consider more complex approaches to reduce congestion than adding general purpose lanes. Providing managed lanes that control usage by vehicle occupancy or differential pricing, as well as intermodal solutions to reduce congestion, are now typically part of urban freeway corridor planning.

This paper reviews the modeling work to forecast traffic and ridership undertaken as part of the reconstruction planning for a seven-mile urban portion of the I-290 corridor in the western suburbs. The project considers pricing and managed lane alternatives that greatly increase the scope and complexity of the traffic/ridership forecasting and modeling. An overview of the project's travel models and evaluation methods is provided, and then the paper discusses modeling of the managed lane alternatives. Several specialized combinations of route and mode choice models were implemented to evaluate high occupancy vehicle (HOV) lanes, high occupancy toll (HOT) lanes, and different methods for toll collection.

Alternatives Modeled

There is a website for the Eisenhower Expressway (I-290) reconstruction (**2**) that provides an overview of the project and the planning process. The map in Figure 2 was taken from the website and shows the project study area from Mannheim Road to Cicero Avenue. This section of the Eisenhower is three lanes in each direction. At the western end of the study area the Eisenhower was rebuilt to reduce congestion in an area popularly termed the "Hillside Strangler." At the east end of the study area, from Austin Avenue eastward, the Eisenhower expands to four lanes in each direction. Westbound traffic frequently faces heavily congested conditions due to the reduction in lanes at Austin Boulevard, where the inner lane ends at a left hand exit ramp on Austin.

Figure 2. I-290 Reconstruction Study Area
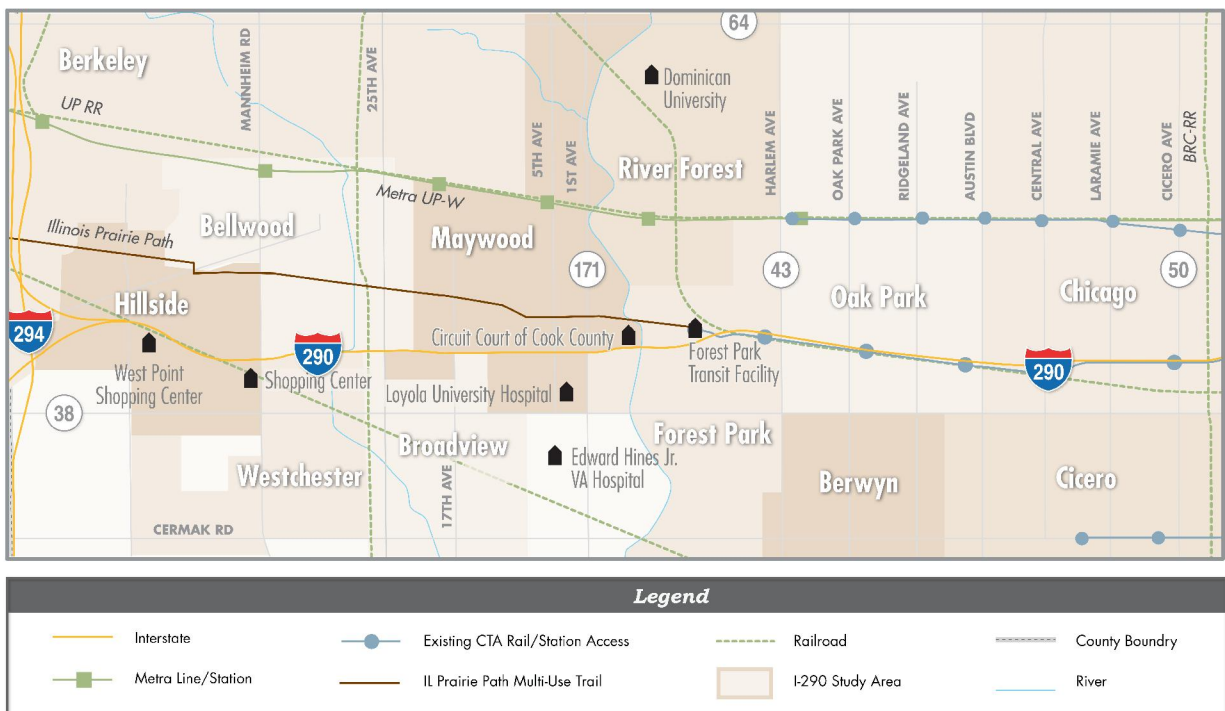
Two rounds of modeling have been completed. In round one each alternative is either a single mode highway oriented or transit oriented improvement. Alternatives from the first round that passed an initial screening are paired into combined highway-transit alternatives for the second round of model runs.

The website includes detailed descriptions of the alternatives considered in both rounds of model runs and there is no reason to detail them in this paper. However, the general types of highway alternatives evaluated include:

1. Add general purpose lane

2. Add two or more person HOV lane

3. Add three or more person HOV lane

4. Add toll lane with tolls roughly equal to current Illinois Tollway tolls

5. Several pricing levels for an additional HOT lane that does not charge three or more person vehicles

6. Tolling of existing and added general purpose lanes

In addition to considering these highway options within the project's study area, several more alternatives were generated by extending general purpose, HOV, or HOT lanes east to the Chicago central area or west into DuPage County.

Transit alternatives were more limited. All transit alternatives include westward addition of service from the Forest Park Blue Line CTA station. An extension of the Blue Line rail transit or corridor bus rapid transit to Mannheim or Oak Brook were considered, as well as expanded express bus service from Forest Park into eastern DuPage County.

Model Sequence

The logic of the I-290 model flow is depicted in Figure 3. It is essentially the Chicago Metropolitan Agency for Planning (CMAP) sequence of trip based models (*3*) with some minor customizing for the I-290 project. The CMAP study area (covering all or parts of twenty-one counties in Illinois, Indiana, and Wisconsin) and CMAP regional zone system are retained for the I-290 modeling.

Core CMAP models and procedures are in the shaded boxes. The initialization step or iteration 0 is followed by four full model iterations of trip distribution, mode choice, time of day allocation, and traffic assignment. During initialization, highway travel times are computed assuming totally uncongested traffic conditions. In subsequent model iterations, estimated traffic from earlier iterations determines highway travel times. All iterations start with a fixed forecast of the number of daily person trip ends by vehicular means generated in zones, either the base year 2010 or future 2040.

For the project, the models are applied as follows:

1. Trip Distribution. Trip distribution links the trip ends into vehicular person trip movements between zones. Four tables of movements are modeled: (1) home-work by low income (below the regional median) workers; (2) home-work by high income (above the median) workers; (3) all other home based trips, and; (4) all non-home based trips.

Figure 3. I-290 Reconstruction Project Model Flowchart
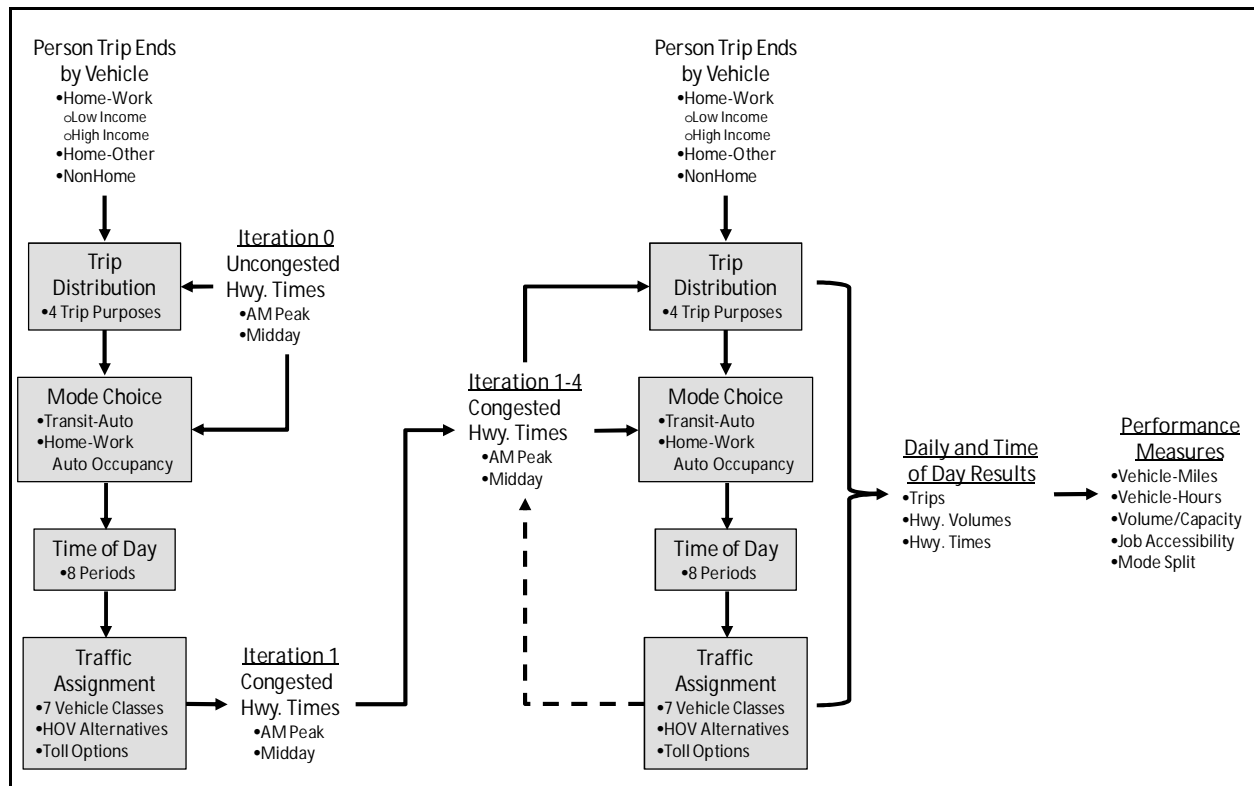
Zone to zone travel times largely determine the linking of trip ends in trip distribution. In applying the model, AM peak period travel times are used to distribute home-work trips while the remaining two trip purposes are paired with midday times.

2. Mode Choice. The mode choice model allocates the four vehicular person trip tables from trip distribution to modes. There is a primary modeled choice between auto and transit modes, which takes place for all trip purposes, and a secondary choice of auto occupancy (single occupant, two person, and three or more person vehicles) for home-work trips only. The pairing of trip purposes and travel times in the mode choice model is the same as in trip distribution, but the specific times for work trip mode choice depend on whether there is a managed lane in the highway alternative and modeled vehicle occupancy level.

3. Time of Day. This is not truly a model component but a series of matrix calculations to factor the auto trip tables from mode choice into eight daily time periods for traffic assignment. After mode choice, there are six auto person home-work trip tables (two income categories for each of three auto occupancy levels) and two non-work purpose tables. The daily time periods are: am pre-peak (one hour), am peak (two hour), am post-peak (one hour), midday (four hour), pm pre-peak (two hour), pm peak(two hour), pm post-peak (two hour), and overnight.

Non-work trips are also factored into auto occupancy levels at this point based on observed levels. All person trips by auto are then converted to auto trips. Truck trips (four categories in passenger car equivalences), trips with one or more trip ends outside the region, and air passenger trips are also factored into time periods and combined with auto trips. At completion of the calculations, there are seven vehicle trip tables for each time period, SOV, HOV two person, and HOV three or more person auto trip tables, plus B-plate, light, medium, and heavy truck trips.

4. Traffic Assignment. Traffic assignment employs the multi-vehicle class assignment algorithm in the EMME travel demand modeling software (*4*). In this approach, a link in the coded highway network has eligible vehicle classes that may use the link. For the purposes of the project, links are coded with up to three active vehicle classes, H-high occupancy vehicle, S-single occupant vehicle, and T-truck. All links are coded with an H since high occupancy vehicles can typically move anywhere in the network. Links coded with an S define the sub-network over which single occupant vehicles may travel, generally every link in the network except those reserved for high occupancy vehicles. Links coded with a T allow the four truck classes. Trucks are prohibited from the HOV lanes and other roadways with truck restrictions.

Modeling HOV Lanes

Figure 4 Illustrates how HOV lanes are coded as separate links from the general purpose links and connected via short links that allow movements between the general purpose and HOV lanes. Zone to zone SOV and HOV times are determined by tracing minimum time paths through the respective assignment sub-networks.

Figure 4. Coding of HOV Lanes
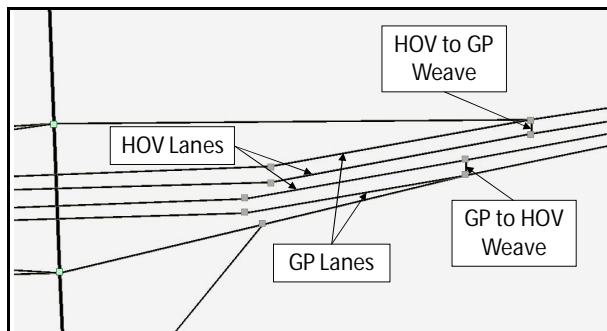
High occupancy vehicle lane alternatives are modeled through mode choice and traffic assignment. In the project the HOV lane alternatives are both two or more and three or more person restricted facilities. Table 1 summarizes how these two variants are dealt with in mode choice and assignment.

Table 1. Sub-Network for Mode Choice Travel Times and Traffic Assignment

HOV Lane Requirement	Auto Occupancy Trip Table		
	SOV	Two Person	Three or More Person
Two or More	S	S	H
Three or More	S	H	H

The mode choice model always estimates three auto occupancies for home-work travel regardless of the minimum occupancy level for an HOV lane. An input keyword determines whether the travel cost for the two person vehicle occupancy choice depends upon zone to zone times estimated with the SOV sub-network or the HOV sub-network. If no network links are restricted to HOV vehicles then the same

zone to zone times are used for SOV, HOV two, and HOV three or more person travel costs.

In traffic assignment the vehicle class sub-networks are similarly matched with the appropriate vehicle occupancy level trip table or tables. If the HOV lane is only restricted to two or more person vehicles, then the two person trip table is assigned to the HOV sub-network. When HOVs are required to have three or more persons, the two person trip table is assigned to the SOV sub-network.

The mode choice model was originally developed for the first HOV Lane Feasibility Study for the I-290 corridor completed in 1998 (*5*). It combines the original transit-auto binary choice model developed at the Chicago Area Transportation Study (CATS) with the auto sub-mode portion of the mode choice model developed for the Maryland National Capital Parks and Planning Commission (M-NCPPC) in the late 1980s (*6*). While dated, the M-NCPPC model is a rarity in that it was estimated to observed route choices that included a significant HOV lane option, the Shirley Highway in northern Virginia. Both models were recalibrated to current conditions with 2005-2009 American Community Survey (ACS) summary file data (*7*).
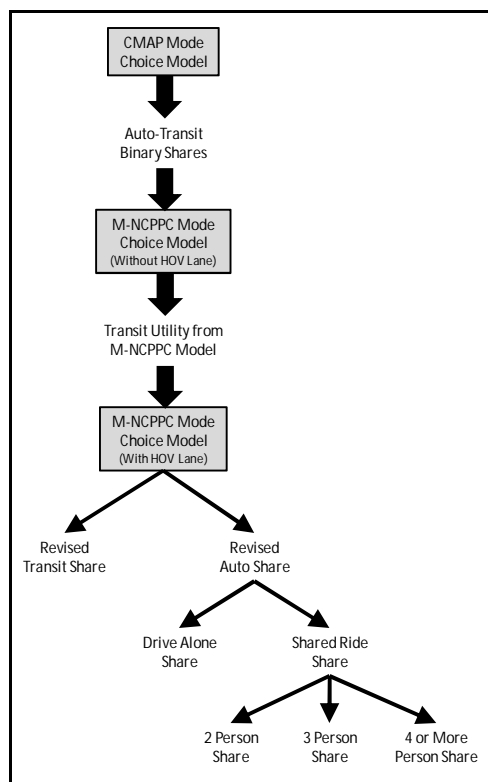
Figure 5. I-290 Project Mode Choice

Figure 5 shows how this combined mode choice model operates to estimate home-work vehicle occupancy choices. The CMAP/CATS model is applied first and produces mode shares for transit and auto without an available HOV lane. The procedure next moves to the M-NCPPC model, again without an HOV lane in the network. Mode choice estimating equations in the M-NCPPC model are evaluated holding the binary mode shares fixed to the CMAP/CATS values. This yields an estimate of the utility or cost of using transit in the M-NCPPC model consistent with the transit cost in the CMAP/CATS model.

The M-NCPPC model is again applied but with the HOV lane coded in the network. Only the auto part of the model is evaluated since the transit side utility was previously determined and is unaffected by the presence of the HOV lane. The occupancy mode shares are then determined, starting with the two plus person auto occupancy choices under shared ride in the M-NCPPC model. Two or more of these choices will have access to the HOV facility and their utilities will reflect its availability. The calculations proceed upward with the shared ride choice benefiting from the increased utility of the three lower multiple occupancy choices. New auto-transit mode shares are finally calculated reflecting the improved utility of the options under the auto choice due to the availability of the HOV lane.

Modeling Link-Based Tolls in Traffic Assignment

Tolls have usually been incorporated into regional traffic assignments by converting a toll cost into equivalent minutes of link delay using an average value of time derived from regional wage rates or mode choice models. Links where tolls are collected then have their travel times increased by an amount equaling the toll conversion. In contrast, the link toll models in the I-290 project use a continuous function to adjust the value of time with increasing toll link volume instead of discrete values of time.

This approach was originally developed by CATS (*8*) and was calibrated to new census data for the I-290 work. The maximum traffic volumes that would pass through toll links without charging any toll are first estimated by a separate assignment without tolls. The equivalent delay for a toll can then be estimated as a function of the maximum link volumes when the distribution of time values for these vehicles is assumed. This is a relationship identical to a link volume-delay function, an equation that estimates the travel time on a link as a function of link traffic and capacity.

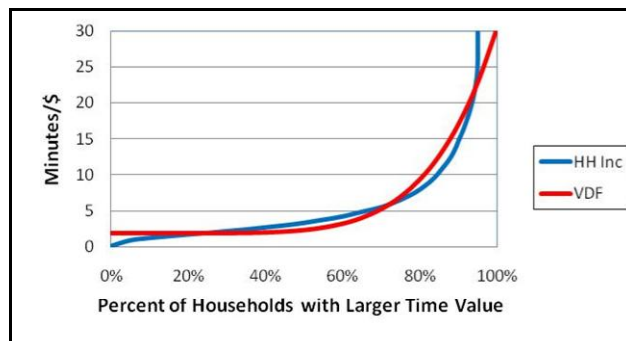**Figure 6. Toll Volume-Delay Functions**

Figure 6 shows household income derived values of time from the 2005-2009 ACS Public Use Microdata Set (*9*) and the toll link volume-delay function estimated from these values. The toll link volume-delay function was estimated by fitting a function to two-thirds the income based time value of the household expressed in minutes per dollar. Income is discounted because travel time is considered less valuable than work time.

The Y-axis is the value of time expressed in minutes per dollar. The X-axis is the cumulative percent of households with an income based value of time greater than the value shown on the Y-axis. For example, seventy percent of all households in the region have an income based value of time less than five minutes per dollar, equating to an annual household income of around $40,000 in 2009. In application, the Y-axis equals the toll traffic volume divided by the previously assigned traffic without tolls.

While the justification for basing the value of time on household income is questionable, the distribution of time values can shift somewhat without greatly affecting the assignment results. The values of time implied by the toll volume-delay function range between $30 per hour (two minutes per dollar) and $1.90 per hour (thirty-two minutes per dollar) when the assigned volume equals the maximum volume without tolls.

Two forms of toll collection are considered In the I-290 work, barrier and vehicle-mile collection. Barrier collection occurs when the tolls are collected at a specific point, a toll gate or open road collection via transponders. Short links are coded into the network at toll collection locations with minimal uncongested travel time, the amount of toll collected, and a code signifying that the toll link volume-delay is to be used to compute congested travel times.

Vehicle-mile tolling is dealt with through another toll volume-delay function. This is a more complex function that combines the relationship between travel time and traffic on the link with the toll volume-delay function. A per mile toll is also part of the function. As is the case for barrier toll collection, links that are vehicle-mile tolled are assigned a specific code that links them to vehicle-mile toll volume-delay function.

Modeling High Occupancy Toll Lanes in Traffic Assignment

High occupancy toll lanes function in the following manner. Vehicles with the requisite number of occupants are allowed into the HOT lane without charge, while vehicles with fewer occupants may use the HOT lane but pay a toll. Tolls can be dynamic and vary with the lane's traffic allowing congestion tolling.

Figure 7. Coding for HOT Lanes

HOT Lanes
(H,S Vehicle Classes)

GP to HOT Link
(H Vehicle Class)

Toll Barrier Link
(S Vehicle Class)
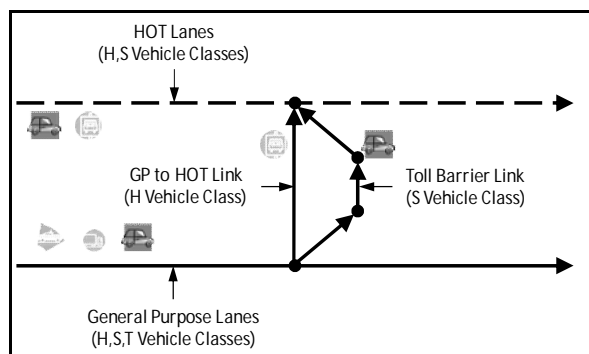
General Purpose Lanes
(H,S,T Vehicle Classes)

Figure 7 shows how example network coding for the modeling of HOT lanes. This is a portion of the network with an eastbound HOT lane paralleling general purpose lanes. The connecting links in the middle of the figure allow traffic to move from the general purpose to the HOT lane. There is one direct link that allows three or more person HOVs to move from the general purpose to the HOT lane without crossing the toll barrier link. All SOV traffic weaving from the general purpose to HOT lane must pass through the toll barrier and pay the toll, which is charged in equivalent minutes. All truck traffic is prohibited from entering the HOT lane.

Tolls and Mode Choice

This section discusses the introduction of tolls into the mode choice model for the I-290 reconstruction project. As outlined above, the effect of tolls on driver behavior was modeled through traffic assignment or route choice. A limitation of this approach is that auto users' ability to shift modes in response to toll charges is not addressed by the models.

An incremental mode choice adjustment was incorporated into the model sequence to allow trips remaining on toll routes to shift to transit. The approach is incremental in that additional auto costs due to tolls are determined. Mode choice calculations are then replicated in a series of matrix operations that predict the marginal shifts of trips among auto sub-modes, total auto, and transit. These calculations are carried out for the eight daily time periods and the five iterations of the full model.

In effect, the model sequence depicted in Figure 1 is altered by deleting the trip distribution and mode choice model steps and replacing them with revised vehicular person trip tables built through this incremental adjustment of the full model run. The matrix operations that revise the trip tables are:

1. The procedure starts with a completed model run as shown in Figure 3. The highway paths through the network are saved for all model iterations and all vehicle classes. Note that the ability to retain the full paths is a fairly recent option in the EMME software.

2. Repeat this and the following steps for each iteration. Retrace the AM peak period and midday paths and determine the person trips that are tolled and the amounts charged. Person trips on paths without tolls do not concern us, since these travelers' mode choices will remain unchanged when tolls are considered.

3. Using the M-NCPPC model coefficients, calculate the change in auto utility for: (1) two and three or more person occupancy vehicles; (2) ride sharing incorporating the utility of the multiple occupancy vehicles; (3) single occupant vehicles, and (4) auto incorporating the utility of driving alone and ride sharing.

4. Estimate the change in mode shares due to tolls for the four trip purposes. This is a pivot-point calculation with the general form:

ΔMode Share due to Toll = ΔUtility due to Toll*(1-Non-Toll Mode Share)*Non-Toll Mode Share.

5. A final step adjusts the person trip tables previously estimated in mode choice to account for the new mode choices of persons formally on toll path routes.

The procedure was repeated for alternatives that include tolls on the managed lane, with and without managed lane tolls. This allows the effect of the managed lane tolls to be isolated from other regional toll facilities.

Implications for Future Model Development

Two points stand out in the authors' minds after applying the models in the I-290 project. First, there is the issue of how to deal with the value of time without resorting to average values. The use of the toll volume-delay function attempts to deal with the fact that values of time depend on trip purposes, household/person characteristics, vehicle occupancies, and a number of other factors. Average values of time were applied in the mode choice calculations.

Second, is the large amount of data required to apply trip-based models. The EMME database after a model run with toll adjustment of mode choices contains nearly 200 zone to zone tables, and there are many other temporary tables in use during the model sequence. Since each table contains almost 4,000,000 entries, there are several hundred variables in these tables for each resident in the study area.

CMAP is in the process of developing a set of advanced models (*10*). These models, which deal with individual household and person travel behavior, appear far more complex at first glance than trip-based models. But it is unlikely that they require substantially more effort to apply than the I-290 trip-based models. The I-290 modeling work only reinforces the need for models that can better deal with increasingly complex corridor alternatives involving pricing, auto occupancy choices, and mode shifts.

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