Transportation Planning

1. Mode Choice

Mode choice is the third step in the four-step modeling process. In models where the unit of travel is vehicle trips, only automobile travel is modeled, and therefore there is no need for a mode choice step. (Hence, these models are sometimes referred to as “three-step models.”).
Mode choice is required in models where the unit of travel is person trips by all modes, or by all motorized modes. The mode choice model splits the trip tables developed in trip distribution into trips for each mode analyzed in the model. These tables are segmented by trip purpose and in some cases further segmented by income or number of vehicles. If the unit is person trips by motorized modes, these modal alternatives include auto and transit modes. If the unit is person trips by all modes including nonmotorized modes, then the modal alternatives may also include walking and bicycling, although sometimes nonmotorized trips are factored out prior to mode choice.

2. Model Function

Modal Alternatives

The first step in mode choice is determining which modal alternatives are to be modeled. Generally, alternatives can be classified as auto, transit, and nonmotorized modes. The simplest models may model just these three main modes (or two, if nonmotorized travel is not included in the model).
Auto modes are generally classified by automobile occupancy level (e.g., drive alone, two-person carpool, and threeor- more-person carpool). Sometimes autos using toll roads are modeled as separate alternatives, often also classified by auto occupancy level.
Transit modes apply to complete (linked) trips from origin to destination, including any walk or auto access or egress as well as transfers. These may be classified by access (and sometimes egress) mode and by type of service. Because such variables as walk time and parking cost are important elements in mode choice, walk access and auto access transit modes should be modeled separately, unless there is little demand for transit where people drive or are driven to the transit stop. Service types that may be modeled separately are often defined by local (e.g., local bus) versus premium (e.g., commuter rail) service. Among the modes that have been included in mode choice models in the United States are local bus, express bus, light rail, heavy rail (e.g.,subway), and commuter rail. Some models include a generic “premium transit” mode.

There are advantages and disadvantages to having a large number of modal alternatives defined by service type. An advantage is that differences in level of service can be considered more readily, and many travelers view various transit types very differently (for example, some travelers who use commuter rail might not consider using local bus). A disadvantage is that having more modes makes the model more complex, and therefore harder to estimate and more time consuming to apply, and the complexity may result in complicated nesting structures that are hard to estimate and difficult to find transferable parameters for. Another issue is how to classify "mixed mode" trips, for example, a trip where a traveler uses both local bus and heavy rail. There is no ideal method to classify such trips; methods such as classifying trips as the "more premium" of the modes used would be inappropriate for trips that are primarily on a less premium mode, and most modeling software does not provide a way of identifying the percentage of each submode between an origin and destination.

Nonmotorized modes are sometimes separated into two modes, walk and bicycle, but are often treated as a single modal alternative. (Note that a walk or bicycle access segment of a transit trip is not considered a separate trip; it is considered part of the transit trip.)
Mode choice is applied by first estimating the probability of choosing each modal alternative for each traveler or segment of travelers. The probability is based on a set of explanatory variables that include characteristics of the modal level of service, traveler characteristics, and features of the areas where the travel takes place. In four-step models, the probabilities are applied as shares of the market segments to which they apply; that is, if a mode has a 75 percent probability of being chosen by a market segment (e.g., work trips for an origin destination zone pair), 75 percent of the travelers in that segment are allocated to that mode.

Most mode choice models use the logit formulation. In a logit mode choice model, the alternatives represent the modes. The utility is a function of the explanatory variables.

These variables may include the following:

• Modal level of service—Auto in-vehicle time, transit in-vehicle time, wait time, walk access/egress time, auto access time, transit fare, parking cost, number of transfers;
• Traveler characteristics—Vehicle availability (sometimes relative to other potential drivers), household income, gender, age, worker/student status; and
• Area characteristics—Development density, pedestrian environment.

At a minimum, mode choice models need to include level-of-service variables so that the effects of changes in level of service (e.g., run time improvements, fare increases, parking costs) can be analyzed. Transportation investment and policy alternatives usually change the level of service for one or more modes relative to the others, and so the effects on modal usage need to be estimated. The inclusion of traveler characteristics allows the model to be sensitive to changing demographics. Including area characteristics allows the model to consider the effects of land use changes, which may be part of policy alternatives the model is being used to help analyze.

The values for the modal level-of-service variables must be obtained for every origin-destination zone pair. These values are obtained through the process of skimming the networks. A separate skim matrix is needed for each modal alternative (and each time period, if time of- day modeling, discussed in Section 4.9, is employed). This requirement implies that a network is needed for each mode. These individual modal networks are developed from the basic two networks–highway and transit–and by adjusting parameters to match the assumed use of the mode. For example, skims for a local bus mode could be obtained by allowing travel only on local bus routes in the transit network. For transit auto access modes, provision must be made for allowing auto portions of these trips to be made along the highway network. For nonmotorized modes, the usual practice is to revise the highway network by eliminating links on which only motorized vehicles are allowed (freeways, ramps, etc.) and skimming the network using minimum distance paths.

While the foregoing description of obtaining the mode specific paths may appear to be relatively simple, great caremust be used in the process to ensure that the paths and skims obtained are consistent with the mode choice model. This may be difficult when obtaining paths for "higher-level" modes.
For example, while drive-alone paths could be obtained by turning off HOV links in the path-building process, it might be necessary to "encourage" the use of HOV links (or discourage the use of drive-alone links) in order to obtain reason able HOV paths and skims for the mode choice model. At the same time, this encouragement should be performed in such a way that preserves the relationships between parameters used in the path-building process and mode choice coefficients. This is especially true for transit path-building.
If the mode choice model coefficients show that out-of-vehicle time is twice as onerous as in-vehicle travel time (i.e., the ratio of the coefficients is two to one), it is improper to use a different relationship between out-of-vehicle time and in-vehicle time in the path-building process.

3. Best Practices

As is the case with trip distribution models, mode choice model accuracy can be enhanced by segmenting the model by income or vehicle availability level. When there are more than two modal alternatives, as is common in mode choice models, the multinomial logit model can introduce inaccuracies in the way it estimates how people choose among alternatives.
One way of dealing with this issue is the use of a nested logit model . A major advantage of nested structures for mode choice is that similar modes, such as transit with auto access and transit with walk access, can be grouped as a subset, all branching from a common "composite mode."

The "nesting coefficient" must be between zero and one and should be statistically significantly different from zero and one. In the literature review of transferability studies (see Appendix B), no research was found into the transferability of nesting coefficients from one area to another. In models around the United States, nesting coefficients are often asserted with values ranging from about 0.2 to 0.8, nearly the entire valid range.

اضافة logit model

The IIA assumption can be problematic in mode choice models with more than two alternatives. For example, if car, bus, and rail are the alternatives and they all had equal utilities, the probability of choosing a transit mode would be greater than that of choosing the car mode. The modeler would need to decide if this were a correct formulation (i.e., although rail and bus may not be perfect substitutes, such a formulation may still be problematic). A nested logit formulation of this choice set would help address this issue by subordinating the somewhat related bus versus rail choice beneath a car versus transit choice.

3. Basis for Data Development

Logit mode choice model parameters are estimated using statistical techniques and specialized software designed to estimate this type of model. As in the estimation of a linear regression model, the data required are individual trip observations that include the trip origin and destination, the necessary traveler characteristics, and of course the chosen mode for the trip. Information on the level of service by each available mode can be added to the estimation data set from the network skims; information on area characteristics based on the origin and destination can also be added.

The only data source likely to provide a set of travel observations that include all modal alternatives is a household survey data set. Unfortunately, except in areas with high transit use (or very large survey sample sizes), the number of observations in a household survey for transit modes is likely to be too small to estimate statistically significant model parameters. Therefore, the household survey data set is often supplemented with data from a transit rider survey.

Even with typical household survey sample sizes and large transit rider survey data sets, it is often difficult to estimate mode choice model parameters that are both statistically significant and of reasonable sign and magnitude. As a result, the model development process often includes "constraining" some model parameters (utility coefficients) to specific values, often relative to one another. For example, parameters for transit out-of-vehicle time (wait time, walk time, etc.) might be constrained to be a multiple of the coefficient for in-vehicle time, say two or three, to reflect the fact that travelers find walking or waiting more onerous than riding.

Because of the difficulty in model estimation and in obtaining sufficient estimation data sets, mode choice is the model component most often characterized by parameters that are not estimated from local data, even in urban areas where parameters for other model components are estimated in that way. This practice of transferring parameters from other models has resulted, ironically, in a relative lack of recent models available for consideration as the estimation context.
Many recently estimated models include at least some constrained coefficients.

4. Model Parameters

Even for applications with similar circumstances, unless models have identical specifications, the values for specific coefficients may differ significantly between models. The alternative definitions, nesting structures, and presence or absence of other variables in a model can affect the coefficients of any variable. So it is much more valid to transfer individual models rather than composites of models with different variables or structures.
With that in mind, the best guidance for an MPO without sufficient local data for model estimation (the application context) is to transfer a complete model from another area (the estimation context), preferably from an area of similar demographic, geographic, and transportation system characteristics.

Model parameters can then be calibrated to ensure reasonable results in the application context, preferably retaining the relationships (i.e., ratios) between coefficients that have been estimated elsewhere. Care should be taken to note whether any of the model parameters in the estimation context were transferred themselves from elsewhere or otherwise constrained.

It is, of course, impractical to present in this report every mode choice model that might be considered in the estimation context. Analysts are encouraged to research specific models from likely estimation contexts and obtain information from sources such as direct contact of MPOs or on-line model documentation.

If this is not feasible, information is presented in Tables 1 through 9 in simplified form for some of the models in the MPO Documentation Database for the classic three trip purposes.

Table 1. Characteristics of home-based work mode choice models from the MPO Documentation Database.

Model	Population Range	Nested Logit?	Include Nonmotorized?	Auto Submodes	Transit Submodes
A	< 1 million	Yes	No	DA/SR	Local/Premium
B	> 1 million	No	No	DA/SR	None
C	> 1 million	No	No	DA/SR	None
D	> 1 million	No	No	None	None
E	> 1 million	Yes	No	DA/SR	Local/Premium
F	> 1 million	Yes	No	DA/SR	Local/Premium/Rail
G	> 1 million	Yes	No	DA/SR	None
H	> 1 million	Yes	Yes	DA/SR	None
I	> 1 million	Yes	Yes	DA/SR	None

DA = drive alone, SR = shared ride.

Table 2. Coefficients from home-based work mode choice models in the MPO Documentation Database.

Model	In-Vehicle Time	Out-of-Vehicle Time	Walk Time	First Wait Time	Transfer Wait Time	Cost
A	−0.021		−0.054	−0.098[a]	−0.098	−0.0031
B	−0.030	−0.075				−0.0043
C	−0.036	−0.053				−0.0077
D	−0.019		−0.058	−0.081	−0.040	−0.0072
E	−0.025	−0.050				−0.0025
F	−0.044	−0.088				−0.0067
G	−0.028	−0.065				−0.0055
H	−0.033		−0.093	−0.038	−0.038	−0.0021
I	−0.025	−0.050				−0.0050[b]

The units of time variables are in minutes; cost variables are cents.

[a] Model A uses a first wait time stratified by the first 7 minutes and beyond. The coefficient shown is for the first 7 minutes; the coefficient for beyond 7 minutes is –0.023.

[b] Model I has a separate coefficient for auto parking cost, which is –0.0025; the coefficient shown is for all other auto operating and transit costs.

Table 3. Relationships between coefficients from home-based work mode choice models in the MPO Documentation Database.

Model	Out-of-Vehicle Time/ In-Vehicle Time	Walk/ In-Vehicle Time	First Wait/ In-Vehicle Time	Value of In-Vehicle Time
A		2.6	4.7	$4.06 per hour
B	2.5			$4.19 per hour
C	1.5			$2.81 per hour
D		3.1	4.3	$1.58 per hour
E	2.0			$6.00 per hour
F	2.0			$3.94 per hour
G	2.3			$3.05 per hour
H		2.8	1.2	$9.43 per hour
I	2.0			$3.00 per hour

Table 4. Characteristics of home-based nonwork mode choice models from the MPO Documentation Database.

Model	Population Range	Nested Logit?	Include Nonmotorized?	Auto Submodes	Transit Submodes
A	< 1 million	No	No	None	None
D	> 1 million	No	No	None	None
E	> 1 million	Yes	No	DA/SR	Local/Premium
G	> 1 million	No	No	DA/SR	None
I	> 1 million	Yes	Yes	DA/SR	None
J	> 1 million	No	No	None	None
K	> 1 million	Yes	No	DA/SR	Local/Premium
L	< 1 million	No	Yes	DA/SR	None

DA = drive alone, SR = shared ride.

Table 5. Coefficients from home-based non work mode choice models in the MPO Documentation Database.

Model	In-Vehicle Time	Out-of Vehicle Time	Walk Time	First Wait Time	Transfer Wait Time	Cost	Auto Operating Cost	Parking Cost	Transit Cost (Fare)
A	−0.007	−0.017[a]				−0.005			
D	−0.011		−0.066	−0.061	−0.059	−0.033			
E	−0.020	−0.060				−0.003			
G	−0.010	−0.046				−0.029			
I	−0.008	−0.025					−0.010	−0.025	−0.010
J	−0.025		−0.075	−0.050[a]	−0.050		−0.170	−0.085	−0.250
K[b]	−0.022	−0.066				−0.009			
L	−0.007	−0.017[a]				−0.009			

The units of time variables are minutes, cost variables are cents.

[a] Models A, J, and L use a first wait time stratified by the first 7 minutes and beyond. The coefficient shown is for the first 7 minutes; the coefficient for beyond 7 minutes is −0.007 for Model A, −0.025 for Model J, and −0.007 for Model L.

[b] Model K has an additional variable for "transfer penalty," which has a coefficient of −0.154. This coefficient is seven times the in-vehicle time coefficient, which implies that a transit transfer has the same effect on utility as an increase in travel time of 7 minutes.

Table 6. Relationships between coefficients from home-based nonwork mode choice models in the MPO Documentation Database.

Model	Out-of-Vehicle Time/ In-Vehicle Time	Walk/ In-Vehicle Time	First Wait/ In-Vehicle Time	Value of In-Vehicle Time
A	2.4			$0.48 per hour
D		6.0	5.6	$0.21 per hour
E	3.0			$3.69 per hour
G	4.6			$0.21 per hour
I	3.1			$0.48 per hour
J		3.0	2.0	$0.09 per hour
K	3.0			$1.40 per hour
L	2.4			$0.80 per hour

Table 7. Characteristics of nonhome-based mode choice models from the MPO Documentation Database.

Model	Population Range	Nested Logit?	Include Nonmotorized?	Auto Submodes	Transit Submodes
A	< 1 million	No	No	DA/SR	None
D	> 1 million	No	No	DA/SR	None
E	> 1 million	Yes	No	DA/SR	Local/Premium
F	> 1 million	Yes	No	DA/SR	Local/Premium/Rail
G	> 1 million	No	No	DA/SR	None
I	> 1 million	Yes	No	None	None
J	> 1 million	No	No	None	None
L	< 1 million	No	No	None	None
M	> 1 million	No	Yes	DA/SR	None
N	> 1 million	Yes	No	DA/SR	None
O	< 1 million	No	Yes	DA/SR	None

DA = drive alone, SR = shared ride.

Table 8. Coefficients from nonhome-based mode choice models in the MPO Documentation Database.

Model	In-Vehicle Time	Out-of-Vehicle Time	Walk Time	First Wait Time	Transfer Wait Time	Cost	Auto Operating Cost	Parking Cost	Transit Cost (Fare)
A	−0.026		−0.065	−0.065[a]	−0.065	−0.008			
D	−0.011		−0.066	−0.061	−0.059	−0.033			
E	−0.020	−0.060				−0.002			
F	−0.022	−0.044				−0.003			
G	−0.006	−0.068				−0.008			
I	−0.020	−0.050					−0.006	−0.016	−0.006
J	−0.025		−0.075	−0.050[a]	−0.050		−0.179	−0.090	−0.250
L	−0.026		−0.065	−0.065[a]	−0.065	−0.013			
M[b]	−0.013		−0.032	−0.032[a]	−0.050	−0.002			
N[b]	−0.030		−0.053	−0.083	−0.083	−0.182			
O	−0.035	−0.082				−0.011			

The units of time variables are minutes, cost variables are cents.

[a] Models A, J, L, and M use a first wait time stratified by the first 7 minutes and beyond. The coefficient shown is for the first 7 minutes; the coefficient for beyond 7 minutes is −0.026 for Model A, −0.025 for Model J, −0.026 for Model L, and −0.025 for Model M.

[b] Models M and N have an additional variable for "transfer penalty," which has a coefficient of −0.306 in Model M and −0.030 in Model N.

Table 9. Relationships between coefficients from nonhome-based mode choice models in MPO Documentation Database.

Model	Out-of-Vehicle Time/ In-Vehicle Time	Walk/ In-Vehicle Time	First Wait/ In-Vehicle Time	Value of In-Vehicle Time
A	2.5			$2.01 per hour
D		5.8	5.4	$0.21 per hour
E	3.0			$5.45 per hour
F	2.0			$4.04 per hour
G	11.3			$0.46 per hour
I	2.5			$2.00 per hour
J		3.0	2.0	$0.08 per hour
L	2.5			$1.20 per hour
M	2.5			$5.08 per hour
N		1.7	2.8	$0.10 per hour
O	2.3			$1.86 per hour

The information from the MPO Documentation Database includes parameters for the level-of-service variables likely to be used in mode choice models in areas to which mode choice models are likely to be transferred.

The MPO Documentation Database includes mode choice model parameters for about 30 MPO models. All of these models are located in urban areas with populations over 500,000 and most are in areas with populations over 1 million. For some of the models in the MPO Documentation Database, information on the mode choice models is incomplete, and some models have unusual or complex variable or modal alternative definitions that would make transferring parameters difficult. These models were excluded from the tables below, and so the number of models for which information on transferable parameters is available is less than 30.

Table 1 presents the characteristics of nine mode choice models for home-based work trips from the MPO Documentation Database. These models can be summarized as follows:

• Eight models from areas with populations over 1 million, and one model from the 500,000 to 1 million population range;
• Six nested logit and three multinomial logit models;
• Two models that include nonmotorized trip modes, and seven that do not; and
• Two models that have transit modes separated into local and premium submodes; one that separates transit into local, premium (e.g., express bus), and rail submodes; and six that use generic modes representing all transit. All nine models have separate modes for walk and auto access to each transit submode.

The nesting structures for the nested models in this group include separate nests for auto, transit, and nonmotorized modes.

Table 2 presents the coefficients of the variables in the nine models described in Table 1. Note that six models use a generic out-of-vehicle time variable while the others have separate components for some types of out-of-vehicle time.
All of these coefficients are "generic," meaning they do not differ by modal alternative although some of the variables do not pertain to all modes (for example, wait time is not included in the utilities for auto modes). Table 3 presents some of the relationships between pairs of coefficients for these models.

There are some notable similarities among the parameters shown in Table 2 and the relationships shown in Table 3. The in-vehicle time coefficients range from -0.019 to -0.044, indicating similar sensitivity to travel time. It should be noted that the FTA guidance for New Starts forecasts indicates that compelling evidence is needed if the in-vehicle time coefficient does not fall between -0.020 and -0.030 (Federal Transit Administration, 2006), and most are close to this range. All of the models have out-of-vehicle time coefficients that are greater in absolute value than the in-vehicle time coefficients, with the ratios ranging from 1.5 to 4.7. FTA guidance for New Starts forecasts also indicates that compelling evidence is needed if the ratio does not fall between 2.0 and 3.0, and most are within this range.

The value of time is computed as the ratio of the in-vehicle time and cost coefficients, converted to dollars per hour. It represents the tradeoff in utility between in-vehicle time and cost; for example, in Model E an average traveler would be indifferent between a travel time increase of 6 minutes and a transit fare increase of 60 cents. There is some variability in the implied values of time, with model D on the low end.

The guidance for choosing a model from Tables 1 through 3 is to look for a model with similar modal alternatives to those that the analyst wishes to model in the application context. For example, if nonmotorized modes are to be included, Models H and I can be considered. Other considerations include whether a nested logit model is desired or required (A, E, F, G, H, or I), perhaps the population of the area (although most of the models in the tables are for large urban areas), the variables the analyst wishes to include, the prevalence of existing transportation modes, and the analyst's assessment of the reasonableness of the parameters and relationships given his or her knowledge of the region.

Tables 4, 5, and 6 show the model characteristics, parameters, and relationships, respectively, for eight models from the MPO Documentation Database for home-based nonwork trips. Tables 7, 8, and 9 show the model characteristics, parameters, and relationships, respectively, for 11 models from the MPO Documentation Database for nonhome-based trips. The information in these tables is presented and used the same way as the information in Tables 1, 2, and 3 for home-based work trips. Note that most of the models are simpler than for work trips, with fewer submode alternatives and fewer nested

logit models. Note that the parameters are a bit more variable for nonwork trips than for work trips, and the values of time are lower for nonwork travel, as expected.
The coefficients shown in Tables 2, 5, and 8 are used in the utility function for each mode (see Equation below). For example, the utility for transit with auto access for Model B in Table 2 is given by:

$$V_{tw} = \beta_{tw0} - 0.030 \text{ (in-vehicle time)}$$
$$- 0.075 \text{ (out-of-vehicle time)} - 0.0043 \text{ (cost)}$$

The utilities are then used to compute the choice probabilities. The logit model utility and probability computations are performed the same way as in the vehicle availability logit model.

5. Automobile Occupancy

The highway assignment step, requires tables of vehicle trips while the output of early model steps is in person trips. (As mentioned earlier, some models use auto vehicle trips as the unit of travel. Since such models have no mode choice step, and the outputs of trip distribution will already be in vehicle trips, the auto occupancy step is not needed in these models.) A process to convert person trips made by auto to vehicle trips is therefore required. This conversion typically is based on a set of factors, called auto occupancy factors, which are applied to the various automobile passenger trip tables produced by the mode choice step. Because the auto occupancy factors vary considerably by trip purpose, it is recommended that the categorization of passenger trips by purpose used through the preceding steps be retained.

Sometimes mode choice models include multiple auto modes that are defined based on automobile occupancy levels (e.g., drive alone, two-person carpool, and three-or more-person carpool). In such models, much of the conversion process from auto person trips to auto vehicle trips takes place in the mode choice model:
There is one vehicle trip per drive-alone auto person trip and one vehicle trip per two-person carpool person trip (i.e., the conversion factors for these modes are 1.0 and 2.0, respectively). For three-or-more-person carpool trips, a conversion factor equivalent to the average vehicle occupancy for vehicles with three or more occupants is used. These factors, which may vary by trip purposes, are generally derived from local household survey data or transferred from comparable MPO models.

6. Model Function

Auto occupancy factors are scalar factors which are applied to the passenger automobile tables. In some cases the auto occupancy factor is adjusted based on Travel Demand Management policies, but the choice to ride in a shared-ride automobile mode is more properly a mode choice decision. It has already been stated that the automobile occupancy is expected to vary based on trip purpose; for example, the auto occupancy of a work trip is typically much lower than the automobile occupancy for a recreational trip. Other considerations that may affect automobile occupancy are metropolitan size and density, transit availability, automobile ownership, and income.

There is also support to suggest that automobile occupancy may vary by time of day. For example, work trips with lower auto occupancy may predominate during the peak hours.
This possibility suggests that disaggregating passenger trips by time of day might be more appropriately done before applying auto occupancy factors.
When the calculations are done in this order, the time-of-day effect on trip purpose and the associated auto occupancies by purpose will result in lower auto occupancies during peak hours.

The scalar formula for converting auto passenger trips into auto vehicle trips is:

$$Auto_{ij}^{p} = T_{ijauto}^{p} * AOC^{p}$$

$Auto_{ij}^{p}$ = Auto vehicle trips between zone i and zone j for purpose p;
T_{ijauto}^{p} = Auto person trips between zone i and zone j for purpose p; and

AOC^{p} = Auto occupancy factor (persons, including driver, per auto) for purpose p.

7. Best Practices

If the model will be used to analyze changes in auto occupancy levels due to changes in transportation level of service, policy changes, or specific implementations designed to affect carpooling (such as HOV lanes), then it is necessary to include in the mode choice model separate modal alternatives related to auto occupancy levels (i.e., drive alone, shared ride with two occupants, etc.) with level-of-service variables that are specific to the various alternatives.
If the model is not to be used for these types of analyses, and person trips are the unit of travel, then using auto occupancy factors by trip purpose to convert auto vehicle trips to auto person trips using Equation above may be considered best practice.

8. Basis for Data Development

When sufficient local data are available, best practice for obtaining automobile occupancy rates is to estimate them by trip purpose from household activity/travel survey data.
This type of data source would also be used in estimating the parameters of mode choice models related to the choice between auto modes defined by occupancy level.
To provide information for areas without local data, the 2009 NHTS data set was used to develop vehicle occupancy factors by trip purpose and urban area population shown in Table 10.

Table 10. Average daily vehicle occupancy by trip purpose by time period.

Vehicle Occupancy—Time Period	Trip Purpose					
	Home-Based Work	Home-Based Nonwork	Home-Based School	Home-Based Other (Excluding School)	Nonhome Based	All Trips
All Auto Modes—daily	1.10	1.72	1.14	1.75	1.66	1.55
Carpool 2 Plus Only—daily	2.42	2.71	2.35	2.71	2.75	2.72
Carpool 3 Plus Only—daily	3.60	3.81	3.46	3.81	3.79	3.80
All Auto Modes—a.m. peak	1.09	1.66	[a]	[a]	1.43	1.34
Carpool 2 Plus Only—a.m. peak	2.36	2.65	[a]	[a]	2.65	2.61
Carpool 3 Plus Only—a.m. peak	3.42	3.57	[a]	[a]	3.68	3.64
All Auto Modes—p.m. peak	1.11	1.66	[a]	[a]	1.65	1.50
Carpool 2 Plus Only—p.m. peak	2.45	2.62	[a]	[a]	2.72	2.65
Carpool 3 Plus Only—p.m. peak	3.63	3.66	[a]	[a]	3.75	3.70

[a] Use daily parameters; NHTS data insufficient to estimate.
Source: 2009 NHTS.

9. Model Parameters

The time-of-day distributions by hour for each trip purpose, by direction for home-based trips derived from 2009 NHTS data for weekdays are presented in Table C.11 in Appendix C shows these time-of-day distributions–for all modes and individually for auto, transit, and nonmotorized modes–for use in areas where time-of-day factors are applied after mode choice. There does not seem to be a relationship between time of day and urban area population, and so the results are not stratified by population range.
The numbers shown in Table C.11 can be used to develop factors by trip purpose for any time periods defined as beginning and ending on the hour. However, while the factors are fairly consistent across urban area size categories, there can be considerable variation between different urban areas. Peaking conditions can vary greatly based on many factors. The type of economic activity that predominates in an area can affect peaking–for example, an area with large manufacturing plants might have peaks defined mainly by shift change times while an area with a large tourism industry may see later peaks.
Another factor has to do with regional geography and dispersion of residential and commercial activities. Areas where commuters may travel long distances may see earlier

starts and later ends to peak periods. Levels of congestion can also affect peaking, as peak spreading may cause travel to increase in "shoulder periods."

Table C.11. Time-of-day distributions by trip purpose and direction.

	Home-Based Work		Home-Based Nonwork		Home-Based School		Home-Based Other			
Hour Ending	From Home	To Home	From Home	To Home	From Home	To Home	From Home	To Home	Nonhome-Based	All Trips
1:00 AM	0.1%	0.5%	0.0%	0.3%	0.0%	0.0%	0.0%	0.3%	0.2%	0.3%
2:00 AM	0.0%	0.2%	0.0%	0.2%	0.0%	0.0%	0.0%	0.2%	0.1%	0.1%
3:00 AM	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%
4:00 AM	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
5:00 AM	1.4%	0.0%	0.2%	0.0%	0.0%	0.0%	0.2%	0.0%	0.3%	0.4%
6:00 AM	5.2%	0.0%	0.6%	0.1%	0.2%	0.0%	0.7%	0.1%	0.5%	1.3%
7:00 AM	11.5%	0.1%	2.3%	0.3%	6.4%	0.0%	1.8%	0.3%	1.7%	3.6%
8:00 AM	14.3%	0.1%	7.0%	1.0%	28.2%	0.1%	4.2%	1.0%	4.9%	7.9%
9:00 AM	7.7%	0.1%	4.8%	1.3%	12.6%	0.2%	3.9%	1.3%	5.1%	6.1%
10:00 AM	2.8%	0.3%	3.4%	1.4%	1.7%	0.2%	3.6%	1.4%	5.1%	4.6%
11:00 AM	1.3%	0.3%	3.1%	1.9%	0.8%	0.4%	3.4%	1.9%	6.4%	4.9%
Noon	1.1%	1.0%	2.5%	2.4%	0.6%	1.1%	2.8%	2.4%	9.2%	5.8%
1:00 PM	1.6%	1.8%	2.3%	2.9%	0.7%	2.0%	2.5%	2.9%	11.1%	6.8%
2:00 PM	1.7%	1.4%	2.5%	2.7%	0.3%	2.0%	2.8%	2.7%	8.8%	6.0%
3:00 PM	1.7%	2.7%	2.7%	4.7%	0.3%	13.4%	3.0%	4.7%	8.6%	7.3%
4:00 PM	1.1%	6.2%	2.6%	5.9%	0.4%	16.5%	2.9%	5.9%	9.2%	8.6%
5:00 PM	1.0%	9.0%	3.2%	4.6%	0.6%	3.8%	3.5%	4.6%	8.2%	8.2%
6:00 PM	0.5%	10.5%	3.7%	4.9%	0.8%	2.5%	4.0%	4.9%	7.3%	8.5%
7:00 PM	0.3%	4.5%	4.1%	4.0%	0.4%	1.0%	4.6%	4.0%	5.0%	6.7%
8:00 PM	0.1%	1.9%	2.5%	3.8%	0.0%	0.8%	2.8%	3.8%	3.8%	4.9%
9:00 PM	0.1%	1.2%	1.1%	3.7%	0.0%	0.7%	1.2%	3.7%	2.1%	3.5%
10:00 PM	0.2%	1.2%	0.6%	2.5%	0.1%	0.9%	0.6%	2.5%	1.4%	2.3%
11:00 PM	0.3%	1.3%	0.3%	1.3%	0.0%	0.3%	0.3%	1.3%	0.8%	1.3%
Midnight	0.1%	1.4%	0.2%	0.7%	0.0%	0.0%	0.2%	0.7%	0.3%	0.8%
Total	**54.3%**	**45.7%**	**49.5%**	**50.6%**	**54.0%**	**46.0%**	**49.5%**	**50.6%**	**100.0%**	**100.0%**
7-9 AM	22.0%	0.2%	11.8%	2.3%	40.7%	0.3%	8.1%	2.6%	10.0%	14.0%
3-6 PM	2.6%	25.7%	9.5%	15.3%	1.7%	22.8%	10.5%	14.4%	24.7%	25.3%

The last two rows of each section of Table C.11 show the combined factors for a typical morning peak period (7:00 to 9:00 a.m.) and a typical afternoon peak period (3:00 to 6:00 p.m.). If factors for a period defined differently are desired, then the appropriate rows from Table C.11 can be summed. For example, if factors for all modes for an afternoon peak period defined from 4:00 p.m. to 6:00 p.m. for the classic three trip purposes are desired, the factors for the rows labeled with hours ending at 5:00 and 6:00 p.m. in the all modes section of the table are added together. This would result in the following factors:\

- Home-based work: From home–1.5 percent, To home–19.5 percent.
- Home-based nonwork: From home–6.9 percent, To home–9.5 percent.

• Nonhome based: 15.5 percent.

The factors are applied to daily trips by purpose, as illustrated by the following example. Say that afternoon peak period auto vehicle trips are desired for a period defined as 3:00 to 6:00 p.m. The factors from the auto modes section of Table C.11 are:

• Home-based work: From home−2.6 percent, To home−25.7 percent.
• Home-based nonwork: From home−9.5 percent, To home−15.3 percent.
• Nonhome based: 25.0 percent.

These factors are applied to the daily auto vehicle trip table.
Say that the daily home-based work production-attraction trip table has 100 trips from zone 1 to zone 2 and 50 trips from zone 2 to zone 1.
Applying these factors results in the following origin-destination trips (recall that the home end is the production end for home-based trips):

• 2.6 home to work trips from zone 1 to zone 2.
• 25.7 work to home trips from zone 2 to zone 1.
• 1.3 home to work trips from zone 2 to zone 1.
• 12.9 work to home trips from zone 1 to zone 2.

This means that there are 15.5 home-based work trips traveling from zone 1 to zone 2 and 27.0 home-based work trips traveling from zone 2 to zone 1 in the afternoon peak period. As expected for the afternoon peak, most of these trips are returning home from work. This process would be repeated for the other two trip purposes. Since nonhome-based trips are already on an origin-destination basis, only a single factor is applied to this trip table.

As noted previously, the information provided in Table C.11 represents average national factors from the NHTS, but peaking can vary greatly from one area to another, regardless of urban area size.

To illustrate this point, Table 11 shows the percentage of daily travel by purpose occurring during two periods−7:00 to 9:00 a.m. and 3:00 to 6:00 p.m.−for nine urban areas with populations of approximately 1 million according to the 2000 U.S. Census. While the averages presented in this table, based on data from the 2001 NHTS, have associated statistical error ranges not presented here, it is clear that the percentages for some areas differ significantly from those for other areas. For example, the reported percentage of daily home-based work travel between 3:00 and 6:00 p.m. was nearly twice as high in Providence as in Memphis. This variation indicates that when default parameters such as those in Table C.11 are used in lieu of local data, calibration may be required to obtain model results that are consistent with local conditions.

Table 11. Time-of-day percentages for urban areas of approximately 1 million in population.

	Home-Based Work		Home-Based Nonwork		Nonhome Based		All Trips	
Urban Area	7–9 a.m.	3–6 p.m.	7–9 a.m.	3–6 p.m.	7–9 a.m.	3–6 p.m.	7–9 a.m.	3–6 p.m.
Austin	32.3%	20.8%	12.5%	23.8%	6.9%	24.6%	13.6%	23.7%
Buffalo	23.7%	26.7%	9.3%	23.6%	5.9%	23.6%	9.7%	23.8%
Greensboro	30.3%	24.0%	12.2%	25.6%	8.1%	26.7%	12.7%	25.8%
Jacksonville	29.6%	24.7%	10.4%	24.4%	9.1%	27.1%	11.6%	25.3%
Hartford	26.0%	29.5%	9.2%	25.3%	7.2%	20.5%	10.4%	24.3%
Memphis	35.0%	18.2%	13.6%	25.6%	6.9%	27.2%	13.5%	25.4%
Nashville	32.7%	23.8%	10.1%	24.9%	7.5%	24.7%	10.4%	24.7%
Providence	28.9%	33.7%	11.8%	24.9%	7.9%	16.3%	11.8%	22.4%
Raleigh	32.4%	26.3%	12.0%	26.5%	8.0%	19.1%	12.2%	24.0%
Average	**30.1%**	**25.3%**	**11.2%**	**25.0%**	**7.5%**	**23.3%**	**11.8%**	**24.4%**

Source: 2001 NHTS.

11. Types of Mode Choice Models

Since public transportation is a vital transportation component in urban areas, mode choice calculations typically involve distinguishing trip interchanges as either auto or transit. Depending on the level of detail required, three types of transit estimating procedures are used:
(1) direct generation of transit trips,
(2) use of trip end models, and
(3) trip interchange modal split models.

1. Direct Generation Models

Transit trips can be generated directly, by estimating either total person trips or auto driver trips. Figure 1 is a graph that illustrates the relationship between transit trips per day per 1000 population and persons per acre versus auto ownership. As density of population increases, it can be expected that transit riding will also increase for a given level of auto ownership.

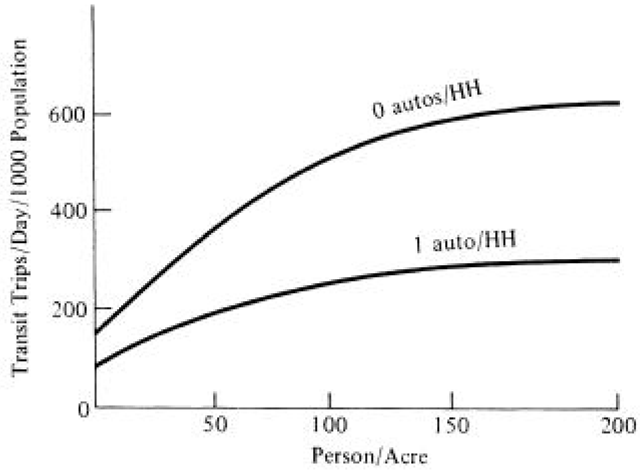

Figure 1 Number of Transit Trips by Population Density and Automobile Ownership per Household.

Example: Estimating Mode Choice by Direct Trip Generation Determine the number of transit trips per day in a zone which has 5000 people living on 50 acres. The auto ownership is 40% of zero autos per household and 60% of one auto per household.

Solution: Calculate the number of persons per acre: 5000 / 50 _ 100. Then determine the number of transit trips per day per 1000 persons (from Figure 1) to calculate the total of all transit trips per day for the zone.

Zero autos /HH: 510 trips /day/1000 population
One auto /HH: 250 trips /day/1000 population
Total Transit Trips: (0.40)(510)(5) + (0.60)(250)(5) = 1020 + 750 = 1770 transit trips per day

2. Trip End Models

To determine the percentage of total person or auto trips that will use transit, estimates are made prior to the trip distribution phase based on land-use or socioeconomic characteristics of the zone. This method does not incorporate the quality of service.
The procedure follows:
1. Generate total person trip productions and attractions by trip purpose.
2. Compute the urban travel factor.
3. Determine the percentage of these trips by transit using a mode choice curve.
4. Apply auto occupancy factors.
5. Distribute transit and auto trips separately.

The mode choice model shown in Figure 2 is based on two factors: households per auto and persons per square mile. The product of these variables is called the urban travel factor (UTF). Percentage of travel by transit will increase in an S curve fashion as the UTF increases.

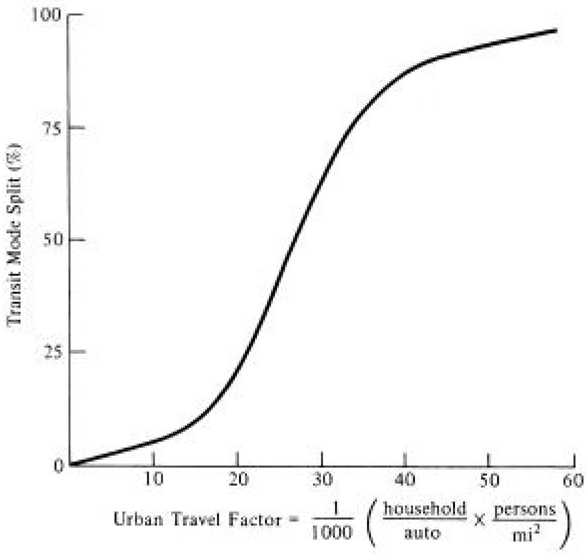

Figure 2 Transit Mode Split versus Urban Travel Factor.

Example Estimating Trip Productions by Transit The total number of productions in a zone is 10,000 trips/day. The number of households per auto is 1.80, and residential density is 15,000 persons/square mile. Determine the percent of residents who can be expected to use transit.

Solution: Compute the urban travel factor.

$$UTF = \frac{1}{1000}\left(\frac{\text{household}}{\text{auto}}\right)\left(\frac{\text{persons}}{\text{mi}^2}\right)$$
$$= \frac{1}{1000} \times 1.80 \times 15{,}000 = 27.0$$

Enter Figure 2. Transit mode split = 45%.

3.Trip Interchange Models

In this method, system level-of-service variables are considered, including relative travel time, relative travel cost, economic status of the trip maker, and relative travel service. An example of this procedure is illustrated using the QRS method which takes account of service parameters in estimating mode choice. The QRS method is based on the following relationship:

$$MS_a = \frac{I_{ijt}^{-b}}{I_{ija}^{-b} + I_{ija}^{-b}} \times 100 \text{ or } \frac{I_{ija}^{b}}{I_{ijt}^{b} + I_{ija}^{b}} \times 100$$

$$MS_t = (1 - MS_a) \times 100$$

where

MS_t = proportion of trips between zone *i* and *j* using transit
MS_a = proportion of trips between zone *i* and *j* using auto
I_{ijm} = a value referred to as the *impedance* of travel of mode *m*, between *i* and *j*, which is a measure of the total cost of the trip. [*Impedance* = (in-vehicle time min) + (2.5 × excess time min) + (3 × trip cost, $/income earned/min).]
b = an exponent, which depends on trip purpose
m = *t* for transit mode; *a* for auto mode

In-vehicle time is time spent traveling in the vehicle, and excess time is time spent traveling but not in the vehicle, including waiting for the train or bus and walking to the station. The impedance value is determined for each zone pair and represents a measure of the expenditure required to make the trip by either auto or transit. The data required for estimating mode choice include (1) distance between zones by auto and transit, (2) transit fare, (3) out-of-pocket auto cost, (4) parking cost, (5) highway and transit speed, (6) exponent values, b, (7) median income, and (8) excess time, which includes the time required to walk to a transit vehicle and time waiting or transferring.
Assume that the time worked per year is 120,000 min.

Example To illustrate the application of the QRS method, assume that the data shown in Table 12 have been developed for travel between a suburban zone S and a downtown zone D. Determine the percent of work trips by auto and transit. An exponent value of 2.0 is used for work travel. Median income is $24,000 per year.

Table 12 Travel Data Between Two Zones, S and D.

	Auto	*Transit*
Distance	10 mi	8 mi
Cost per mile	$0.15	$0.10
Excess time	5 min	8 min
Parking cost	$1.50 (or 0.75/trip)	—
Speed	30 mi/h	20 mi/h

Solution:

$$MS_a = \frac{I_{ija}^b}{I_{ijt}^b + I_{ija}^b}$$

$$I_{SDa} = \left(\frac{10}{30} \times 60\right) + (2.5 \times 5) + \left\{\frac{3 \times [(1.50/2) + 0.15 \times 10]}{24{,}000/120{,}000}\right\}$$

$$= 20 + 12.5 + 33.75$$

$$= 66.25 \text{ equivalent min}$$

$$I_{SDt} = \left(\frac{8}{20} \times 60\right) + (2.5 \times 8) + \left[\frac{3 \times (8 \times 0.10)}{24{,}000/120{,}000}\right] = 24 + 20 + 12$$

$$= 56 \text{ equivalent min}$$

$$MS_a = \frac{(56)^2}{(56)^2 + (66.25)^2} \times 100 = 41.6\%$$

$$MS_t = (1 - 0.416) \times 100 = 58.4\%$$

Thus, the mode choice of travel by transit between zones S and D is 68.4%, and by highway the value is 41.6%. These percentages are applied to the estimated trip distribution values to determine the number of trips by each mode. If for example, the number of work trips between zones S and D was computed to be 500, then the number by auto would be:

500 * 0.416 = 208, and by transit,
the number of trips would be 500 * 0.584 = 292.

<u>4. Logit Models</u>

An alternative approach used in transportation demand analysis is to consider the relative utility of each mode as a summation of each modal attribute. Then the choice of a mode is expressed as a probability distribution. For example, assume that the utility of each mode is

$$U_x = \sum_{i=1}^{n} a_i X_i$$

If two modes, auto (A) and transit (T), are being considered, the probability of selecting the auto mode A can be written as:

$$P(A) = \frac{e^{U_A}}{e^{U_A} + e^{U_T}}$$

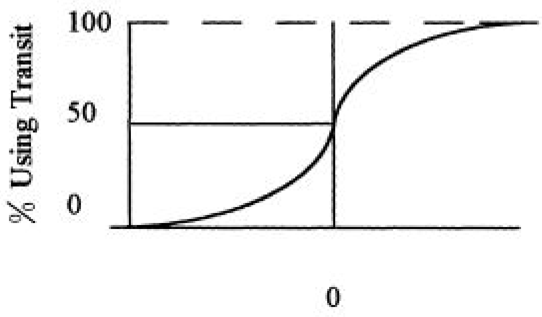

Figure 3. Modal Choice for Transit versus Automobile.

This form is called the logit model, as illustrated in Figure 3 and provides a convenient way to compute mode choice. Choice models are utilized within the urban transportation planning process, in transit marketing studies, and to directly estimate travel demand.

Example The utility functions for auto and transit are as follows.

$$\text{Auto: } U_A = -0.46 - 0.35T_1 - 0.08T_2 - 0.005C$$
$$\text{Transit: } U_T = -0.07 - 0.05T_1 - 0.15T_2 - 0.005C$$

where

T_1 = total travel time (minutes)
T_2 = waiting time (minutes)
C = cost (cents)

The travel characteristics between two zones are as follows:

	Auto	*Transit*
T_1	20	30
T_2	8	6
C	320	100

Solution: Use the logit model to determine the percent of travel in the zone by auto and transit.

$$U_x = \sum_{i=1}^{n} a_i x_i$$

$$U_A = -0.46 - (0.35 \times 20) - (0.08 \times 8) - (0.005 \times 320) = -9.70$$

$$U_B = -0.07 - (0.35 \times 30) - (0.08 \times 6) - (0.005 \times 100) = -11.55$$

$$P_A = \frac{e^{U_A}}{e^{U_A} + e^{U_T}} = \frac{e^{-9.70}}{e^{-9.7} + e^{-11.55}} = 0.86$$

$$P_T = \frac{e^{U_T}}{e^{U_A} + e^{U_T}} = \frac{e^{-11.55}}{e^{-9.7} + e^{-11.55}} = 0.14$$

Borrowing Utility Functions from Other Sources

If a utility function such as that shown in Eq. above is not available, then the coefficients for the function either may be borrowed from another source or derived from survey data. To the extent that the selection of a mode is governed by its in-vehicle travel time, out-of-vehicle travel time, and cost, a utility function may be written as:

$$\text{Utility}_i = b\,(\text{IVTT}) + c\,(\text{OVTT}) + d\,(\text{COST})$$

where

Utility_i = utility function for mode i
IVTT = in-vehicle travel time (min)
OVTT = out-of-vehicle travel time (min)
COST = out-of-pocket cost (cents)

The following approach for calibrating the coefficients b, c, and d in Eq. above are based on methods published in NCHRP Report:

- In-vehicle travel time (IVTT) has a coefficient of b=.025
- Out-of-vehicle travel time has a coefficient of c=0.050 which reflects the observation that time waiting for a vehicle is perceived to be twice as great as time spent inside a moving vehicle
- Cost coefficient d is computed as follows:

$$d = \frac{(b)(1248)}{(TVP)(\text{AI})}$$

where

TVP = the ratio of (value of one hour travel time)/(hourly employment rate). In the absence of other data $TVP = 0.30$

AI = the average annual regional household income, ($)

1248 is the factor that converts $/yr to cents/min.

Example:

A transit authority wishes to determine the number of total travelers in a corridor that will shift from auto to a proposed new bus line. Since local data are unavailable, use of borrowed utility values is the only option. It is believed that the key factors in the decision to use transit will be time and cost. Average annual household income (AI) is $60,000, TVP = 0.30, and waiting time is perceived to be twice as long as riding time. System times and cost values are as follows.

Variable	*Bus*	*Auto*
IVIT (min)	30	20
OVIT(min)	6	8
Cost (cents)	100	320

Determine the proportion of persons who will use the new bus line.

Solution: Determine coefficients b, c, and d based on these data.

$b = -0.025$

$c = -0.050$

$$d = \frac{(b)(1248)}{(TVP)(\text{AI})} = \frac{(-0.025)(1248)}{(0.30)(\$60{,}000)} = -0.00173$$

$a_i = 0$ since the problem stated IVTT, OVTT, and COST sufficiently explain mode choice

The utility functions are:

$$U_{auto} = b\,(IVTT) + c\,(OVTT) + d\,(COST)$$
$$= -0.025(20) + -0.050(8) + -0.00173(320) = -1.454$$
$$U_{bus} = b\,(IVTT) + c\,(OVTT) + d\,(COST)$$
$$= -0.025(30) + -0.050(6) + -0.00173(100) = -1.223$$

The proportion of travelers using the bus is computed:

$$P_{bus} = \frac{e^{U_{bus}}}{e^{U_{bus}} + e^{U_{auto}}} = \frac{e^{-1.223}}{e^{-1.223} + e^{-1.454}} = 0.557$$

Thus, this model predicts that 56% of travelers will use the new bus line.

Example:

Referring to previous Example, upon inaugurating bus service, the percentage of travelers that use the new bus service is actually 65%. Follow-up surveys confirm that the coefficients b, c, and d which were used to estimate potential bus service appear to have been correct. However, the surveys suggest that a further incentive (beyond time and cost) for using the bus is influenced by the availability of laptop outlets at each seat and a complimentary beverage service.

Given this added information, explain how to modify the utility function to reflect the influence of added amenities.

Solution:

Because the coefficients b, c, and d do not include the additional features that favor bus usage, a mode specific coefficient (ai) should be included in one of the utility functions. This term may either be a positive coefficient that is added to the bus utility function or a negative coefficient that is subtracted from the auto utility function. Using the former approach, simply add a constant value (which in this example is 0.3885) to the bus utility functioning order to yield the required 65% of travelers using the bus. The result is shown in the following calculation.

$$P_{bus} = \frac{e^{(U_{bus}+0.3885)}}{e^{(U_{bus}+0.3885)} + e^{U_{auto}}} = \frac{e^{(-1.223+0.3885)}}{e^{(-1.223+0.3885)} + e^{-1.454}} = 0.650$$

Thus, the bus utility function is rewritten and the auto utility function is unchanged, as follows.

$$U_{bus} = a_{bus} + b\,(IVTT) + c\,(OVTT) + d\,(COST)$$
$$U_{bus} = 0.3855 + -0.025(IVTT) + -0.050(OVTT) + -0.00173(COST)$$

Modifying a Logit Model For Changes in Service Parameters

If the value of the IVTT, OVTT, or COST parameters has changed, then the new mode share (Pi) can be calculated from the original mode share Pi and the change in the utility function value as shown in below. This property is useful because determination of ($\acute{P}_i$) does not require knowledge of the mode specific constant ai. Since the a values cancel when calculating Δu_i, the difference between utility functions values, U_{i-new} and U_{i-old} in Eq. below is the incremental logit model and can be applied if the mode is already in service. The incremental logit model cannot be used for new modes where prior data to compute (Pi) are unavailable.

$$P_i' = \frac{P_i e^{\Delta u_i}}{\sum_i P_i e^{\Delta u_i}}$$

where

P_i' = proportion using mode i after system changes
P_i = proportion using mode i before system changes
Δu_i = difference in utility functions values, $U_{i-\text{new}} - U_{i-\text{old}}$

Example:

The regional transportation agency in previous example is considering an investment in signal preemption for transit vehicles which would reduce the in-vehicle travel time for bus service from 30 to 25 min. All other service amenities will remain.
Determine the percentage of travelers will use bus service if this investment is made.

Solution:

$$P_{\text{bus}} = 65\%$$
$$P_{\text{auto}} = 35\%$$
$$\Delta U_{\text{bus}} = U_{\text{busnew}} - U_{\text{busold}}$$
$$\Delta U_{\text{bus}} = [0.3855 + -0.025(\text{IVTT}_{\text{new}}) + -0.050(\text{OVTT}_{\text{new}}) + -0.00173(\text{COST}_{\text{new}})] - [0.3855 + -0.025(\text{IVTT}_{\text{old}}) + -0.050(\text{OVTT}_{\text{old}}) + -0.00173(\text{COST}_{\text{old}})]$$

Since bus travel time is the only variable that has been changed, from 30 to 25 min:

$$\Delta U_{\text{bus}} = -0.025\,(25 - 30)$$
$$\Delta U_{\text{bus}} = 0.125$$
$$\Delta U_{\text{auto}} = 0 \text{ (assuming no change in auto travel time or cost)}$$

$$P'_{\text{bus}} = \frac{P_{\text{bus}} e^{\Delta u_{\text{bus}}}}{P_{\text{auto}} e^{\Delta u_{\text{auto}}} + P_{\text{bus}} e^{\Delta u_{\text{bus}}}}$$

$$P'_{\text{bus}} = \frac{0.65e^{0.125}}{0.35e^{0} + 0.65e^{0.125}} = 0.68$$

Calibrating Utility Functions with Survey Data

A second approach to determine utility function coefficients is to calibrate the coefficients based on survey data using the method of maximum likelihood estimation. Software packages such as SAS and ALOGIT are available that support maximum likelihood estimation and replace manual procedures presented here. To illustrate this process, a simple calibration of a utility function using survey data is shown in Example below.

Example:

A regional transportation agency wishes to calibrate a utility function that can be used with the logit model to predict modal choice between bus, auto, and rail. Survey data were obtained by interviewing seven people identified as persons A through G who reported the travel time for three modes they considered (car, bus, and rail) and the mode that they used. The results of the survey are shown in the following table. The agency has proposed to select a utility function of the form

U = b (time).

Use the method of maximum likelihood estimation to calibrate this utility function for the parameter, b.

Sample Interview Survey Data:

Respondent	*Auto Time (min)*	*Bus Time (min)*	*Rail Time (min)*	*Mode Used*
A	10	13	15	Auto
B	12	9	8	Auto
C	35	32	20	Rail
D	45	15	44	Bus
E	60	58	64	Bus
F	70	65	60	Auto
G	25	20	15	Rail

Solution: The utility function is:

$$U = b\,(\text{IVTT})$$

where

b = a constant to be determined from the calibration process.
IVTT = in-vehicle travel time (in minutes).

A maximum likelihood function may be used to derive model coefficients that replicate the observed data. For these data, a "perfect" function would predict that respondents A, B, and F would select auto; C and G would select rail; and D and E would select bus. For respondent A, the utility function is as shown, since A selected auto and not the bus or rail. Thus,

$$L_A = (P_{A-\text{auto}})$$

the probability that respondent A will select auto, bus, and rail is

$$P_{A,\text{auto}} = \frac{e^{U_{1\text{auto}}}}{e^{U_{1\text{auto}}} + e^{U_{1\text{bus}}} + e^{U_{1\text{rail}}}} = \frac{e^{b10}}{e^{b10} + e^{b13} + e^{b15}}$$

$$P_{A,\text{bus}} = \frac{e^{U_{1\text{bus}}}}{e^{U_{1\text{auto}}} + e^{U_{1\text{bus}}} + e^{U_{1\text{rail}}}} = \frac{e^{b13}}{e^{b10} + e^{b13} + e^{b15}}$$

$$P_{A,\text{rail}} = \frac{e^{U_{1\text{rail}}}}{e^{U_{1\text{auto}}} + e^{U_{1\text{bus}}} + e^{U_{1\text{rail}}}} = \frac{e^{b15}}{e^{b10} + e^{b13} + e^{b15}}$$

Substitution of the appropriate equation into the expression for L_A yields the maximum likelihood function for respondent A.

$$L_A = \left(\frac{e^{b10}}{e^{b10} + e^{b13} + e^{b15}}\right)$$

For the entire data set, therefore, the maximum likelihood function may be computed as

$$L = (L_A)(L_B)(L_C)(L_D)(L_E)(L_F)(L_G)$$

Since b cannot be determined such that L is exactly equal to 1.0, the best possible result is to select a value of b such that L is as close to 1.0 as possible. Theoretically, L could be differentiated with respect to b and equated to zero. However, the nonlinear equations that result usually necessitate the use of specialized software to solve. Plot L versus b is as shown in Figure 4. The value of b = (_0.1504) maximizes L. Thus, the utility expression based on the data collected about user behavior is

$$U = (-0.1504)\ (\text{IVTT})$$

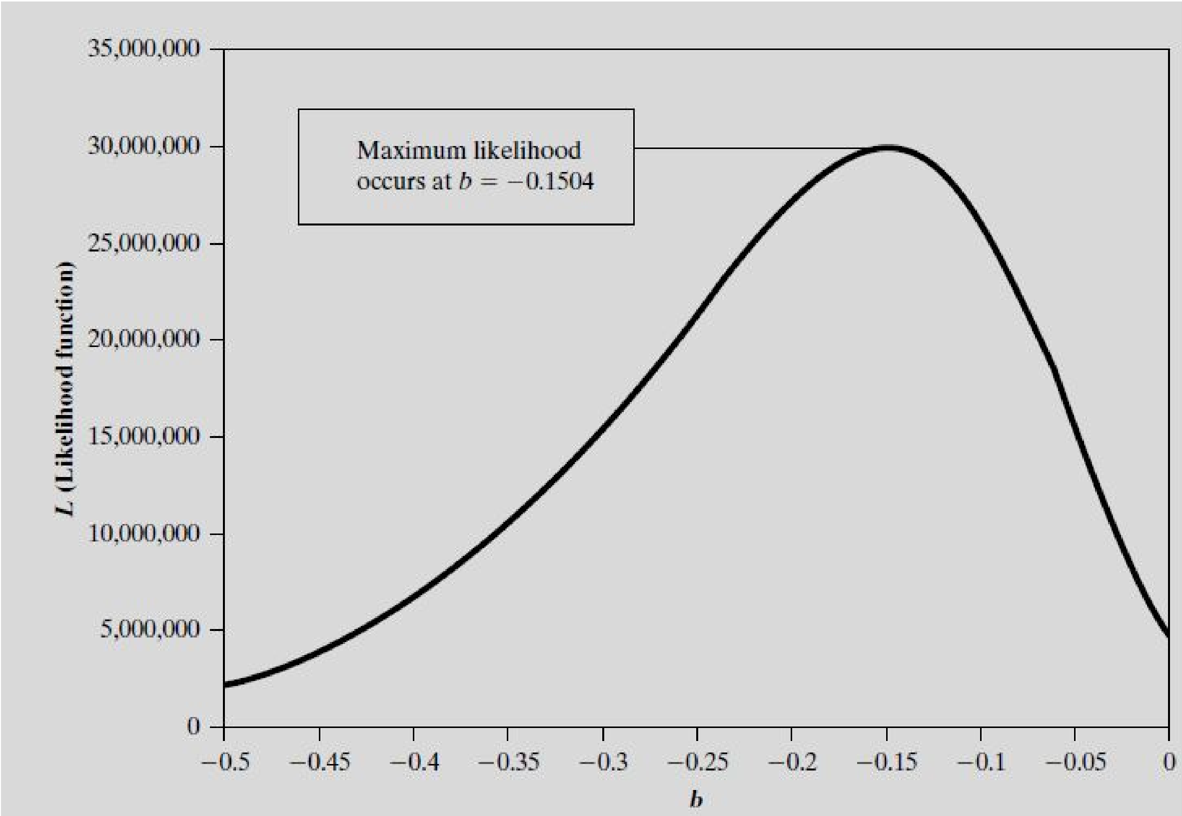

Figure 4 Plot of Maximum Likelihood Function versus b.