Transportation Planning

1. Four-Step Travel Modeling Process

The conventional sequential process for estimating transportation demand that is often called the “four-step” process:

- Step 1—Trip Generation.
- Step 2—Trip Distribution.
- Step 3—Mode Choice.
- Step 4—Assignment.

Figure (1) below explain Four-step modeling process.

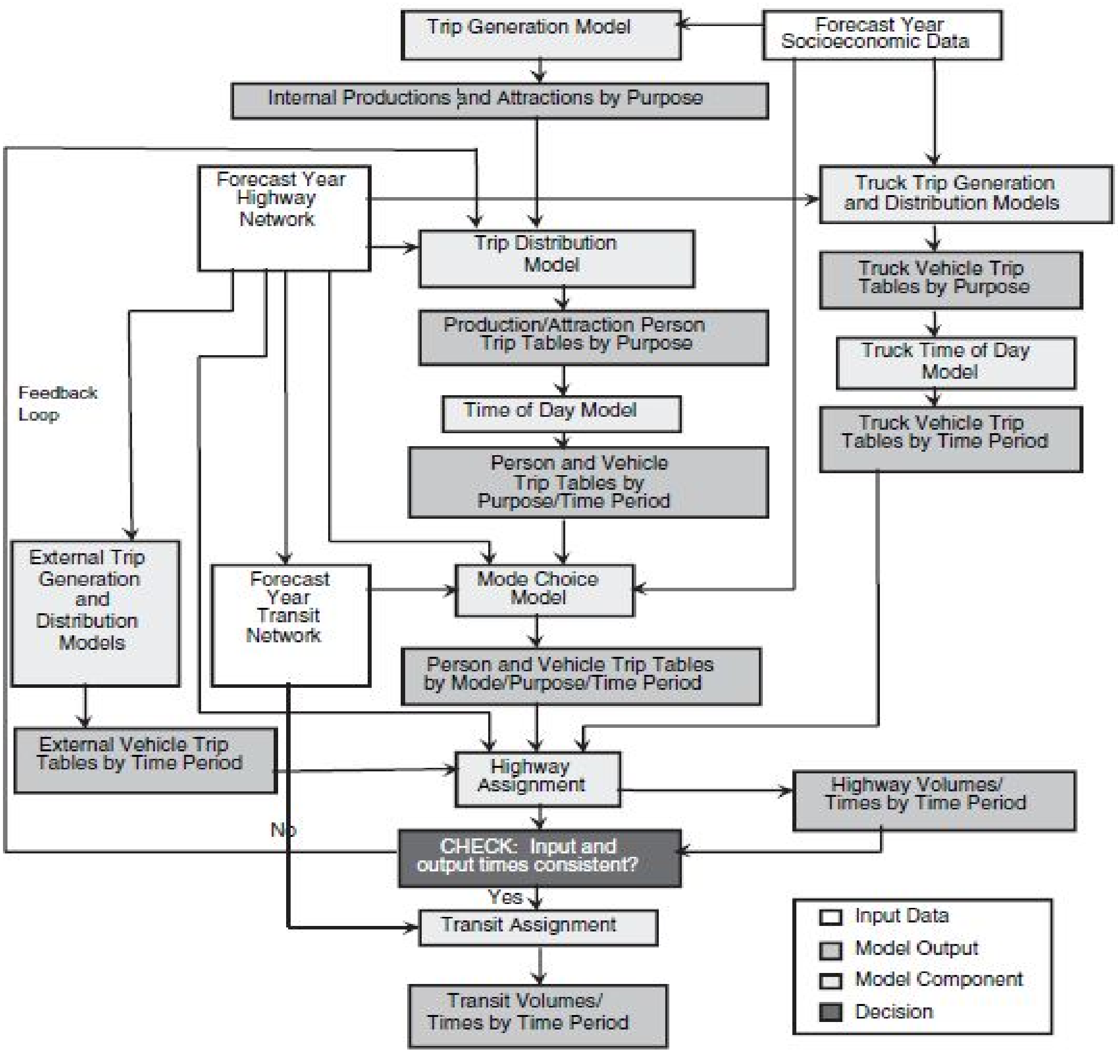

Figure 1 Four-step modeling process.

2. Trip Generation

Trip generation is commonly considered as the first step in the four-step modeling process. It is intended to address
the question of how many trips of each type begin or end in each location. It is standard practice to aggregate trips to a
specific unit of geography (e.g., a traffic analysis zone).5 The estimated numbers of trips will be in the unit of travel that
is used by the model, which is usually one of the following:

- Vehicle trips;
- Person trips by motorized modes (auto and transit); or
- Person trips by all modes, including both motorized and nonmotorized (walking, bicycling) modes.

Trip generation models require explanatory variables that are related to trip-making behavior and functions that estimate the number of trips based on these explanatory variables. While these functions can be nonlinear, they are usually assumed to be linear equations, and the coefficients associated with these variables are commonly called trip rates. Whether the unction is linear or nonlinear, it should always estimate zero trips when the values of the explanatory variables are all zero. Mathematically, this is equivalent to saying that the trip generation equations should include no constant terms.

2.1 Model Function

The purpose of trip generation is to estimate the number of average weekday trip ends by purpose for each zone.
In four-step models, the trip ends of home-based trips are defined as productions, representing the home ends of trips, and attractions, representing the nonhome end, regardless of whether home is the origin or destination. In other words, for home-based trips, the production end may be the destination and the attraction end, the origin if the trip-maker is returning home. For nonhome-based trips, for convenience the production end is defined as the trip origin and the attraction end as the trip destination.
For home-based trips, the number of trip productions in a zone is, naturally, based on the number of households in the zone. Household characteristics can affect trip making; therefore, in trip production models, households are usually classified by some of these characteristics, which often include the number of persons, workers, children, or vehicles, or the household income level. The trip rates for each purpose vary depending on the household classifications, which may not be the same for all trip purposes.
Trip attractions are based on other variables besides households, because several types of activities (commercial, employment, residential, etc.) are often located at the nonhome trip end. The type of activity that affects the number of trip attractions depends on the trip purpose. For example, home-based work trip attractions are usually estimated best by using employment as the explanatory variable. Other purposes typically use different sets of variables (school enrollment or employment for home-based school trips, retail employment for home-based shopping trips, etc.).

Home-based nonwork, home-based other, and nonhome-based trip attraction models usually use a linear combination of several different variables (employment by type, households, etc.).

The number of nonhome-based trips made in a region does depend on the number of households, but unlike home-based trips, they need not have one end in the zone where the household of the trip-maker is located. One way in which models deal with this issue is to use household-based nonhome-based trip production rates to estimate regional productions and to allocate this regional total to zones based on other variables. A common convention is to assume that the regional nonhome-based trips are allocated to each zone based on the number of nonhome-based trip attractions in the zone.

2.2 Special Generators

While estimates of passenger trip activity based on rates applied to household or employment in a zone can address the majority of conditions, there are special conditions when these rates are insufficient to accurately estimate trip activity. These conditions might be because the trip activity is due to considerations not directly related to the number of employees or households in a zone—for example, trips to airports, hospitals, colleges, or large recreational facilities. Additional estimates of trip activity may also be necessary because the trip generation rates are for average conditions that are not applicable to specialized conditions—for example, shopping productions or attractions to "big box" retail stores that have shopping trip rates per employee that are higher than typical retail employment. These activity locations are often referred to as "special generators."

The term "special generators" is somewhat misleading in that the different travel behavior associated with them is not limited to trip generation. While it is true that the number of trips generated by these sites is not readily modeled using conventional trip attraction models, the sensitivity of trip distribution to variables such as time and cost is also different than that of other trips. Ideally, such travel should be treated as a separate trip purpose so that separate models for trip generation, trip distribution, and mode choice could be applied, but unless there are detailed surveys of the special generator with a sufficient sample size for model estimation, it is unlikely that this could be done.

Trip rates are not developed for special generators. Rather, the numbers of trips attracted to these locations are exogenously estimated using separate data sources, such as surveys or counts conducted at the special generators. Hence there are no parameters for trip generation at special generators, and default parameters cannot be provided. It is important to consider how special generator travel is considered relative to the trip purposes used in the model. Generally, trips attracted to special generators are estimated separately from the attractions for the trip purposes used in the model, but the special generator attractions must be considered in examining the balance between productions and attractions. Since separate trip distribution, time-of-day, and mode choice models are not available for special generator travel, the analyst must decide how these features will be modeled for special generators (for example, using the models for home-based nonwork or nonhome-based travel).

2.3 Balancing Productions and Attractions

The regional totals of productions and attractions for each trip purpose are equal because each trip has one production end and one attraction end. However, the model results may not be equal because productions and attractions are estimated separately. While trip distribution models can often be applied with different production and attraction totals, certain types of model formulations (such as the gravity model) produce better results if productions and attractions are equal, or close to equal.

Because trip productions are estimated for the household, which is the same as the basis of the sampling frame of the surveys from which trip generation models are estimated, trip production models are generally estimated using records representing individual households, for which the total number of trips should be reported in the household survey.

Trip attractions, on the other hand, occur at locations for which a complete set of survey records comprising all trips to the attractor will not be available. It is therefore common convention to adjust trip attractions to match productions by purpose at the regional level. This “balancing” of productions and attractions must take into account trips with one end outside the region and trips attracted to special generators.

It is good practice to review the ratio between unbalanced attractions and productions as a large difference might indicate problems with employment estimates, trip rates, etc. Most literature on best practices recommends that the difference between unbalanced regional attractions and productions be kept to +/-10 percent for each purpose, although a review of model validation reports shows that this standard is often exceeded. Upwards of +/-50 percent difference at the regional level might be considered acceptable under certain conditions and trip purposes.

2.5 Trip Productions

While other model forms are sometimes used, the most common form of trip production model is the cross-classification model. The households in each zone are classified by two or more variables, and the number of households in each category is multiplied by the appropriate “trip rate,” representing the average number of trips per household for the category. Mathematically, the number of trips generated in a zone is given by:

$$P_i^p = \sum_k P\ rate_{pk} * h_{ik}$$

where:

P_i^p = Number of trip ends produced for purpose p in zone i;

$Prate_{pk}$ = The production trip rate for purpose p per household for category k; and

h_{ik} = The number of households in category k in zone i.

The state of the practice for trip production models is to create tables of trip rates by two or more dimensions, for example by household income and by household size (number of persons). Most commonly, trip production models are two- dimensional, although three-dimensional models are sometimes used, especially in larger areas where more data are available. The households in each zone are segmented along the two dimensions, and the trip rate is estimated for each combination of the two variables. For example, a cross-classification of households by three income levels (say, low, edium, and high) and number of persons (1, 2, 3, and 4+) would have the number of households divided into 12 segments, one for each income level–number of persons combination, and would use 12 corresponding trip production rates.

2.6 Trip Attractions

Accurately estimating trip attractions can be significantly more difficult and problematic than estimating trip productions.
Whether trip attraction model parameters are estimated from local data or are transferred, they are usually derived from household survey data, which collects travel information at the production end of trips. Such surveys do not provide control totals at trip attraction locations. It is common practice to estimate the parameters, such as coefficients in linear regression equations, at an aggregate level such as districts (groups of zones), implying that the results may not be as accurate at more disaggregate spatial levels (such as zones). Some regions have attempted to address this issue through the use of establishment surveys, where the data are collected at the attraction end of trips, but the wide variety of establishment types and the expense of obtaining sufficient sample sizes at each type means that accuracy issues are not completely resolved. It is therefore recommended that analysts use the information provided here (indeed, locally derived trip attraction information as well) with extreme caution and to be prepared to adjust parameters to produce more reasonable results as needed.

Trip attraction models are most often linear equations with variables representing the amount of activity in a zone— typically employment by type, student enrollment at school sites, and households or population—and coefficients reflecting the effects of these variables on trip making to the zone for the appropriate purpose. The equations follow the form:

$$A_i^p = \sum_k A\ rate_{pk} * v_{ik}$$

where:

A_i^p = Attraction of trip ends for purpose p in zone i;
$Arate_{pk}$ = Rate of attraction trip ends for purpose p per unit of variable k; and
v_{ik} = Value of variable k in zone i.

To summarize, the model parameters for trip generation are the trip production and attraction rates, represented by Pratepk and Aratepk in Equation above.

2.6 Basis for Data Development

When sufficient local data are available, best practice for the development of trip generation models is to estimate the model parameters from household activity/travel survey data using statistical techniques such as linear regression. Typically, sample sizes for these surveys are sufficient for model estimation, although the required amount of data depends on factors such as:

- The number of parameters to be estimated, such as the number of cells in cross-classification models;
- The number of households occurring in each crossclassification cell in the population, and in the survey sample; and
- The resolution of the geographic units (e.g., zones) at which the models will be applied.

2.7 Trip Productions

For trip productions, cross-classification trip rates were estimated from the 2009 NHTS for the classic three trip purposes, for urban areas stratified by population. Additionally, trip rates for home-based school trips are presented, along with a home-based other trip purpose that represents all home-based nonwork and nonschool trips. These rates represent average weekday person trips, including both motorized and nonmotorized trips, and were estimated using the weighted NHTS data. Initially, separate rates were estimated for the six urban area population ranges, but, in many cases, the rates did not vary by population category, and combined rates for multiple population ranges are presented.

Note that the 2009 NHTS does not include travel for children younger than five years old. If an analyst wishes to model the travel of younger children and to use the information provided in this chapter, he/she should be prepared to slightly adjust the trip rates for all purposes except homebased work upward, with a more substantial increase in home-based school trips (if that purpose is modeled and includes pre-school/day care travel).

2.8 Trip Attractions

Documented trip attraction models from a number of MPOs were available in the MPO Documentation Database. Different model calibration methods also added to the variation among models. Some of the models were estimated using regression techniques that could produce somewhat surprising results. For example, regression model calibration techniques can result in negative coefficients for some of the variables. A home-based shop trip attraction model could have, say, a positive coefficient for retail employment and a negative coefficient for basic employment. Such occurrences might be explained as “second-level” relationships—each retail employee attracts a certain number of home-based shop trips during the day, but as the amount of basic employment increases around the retail location, the number of home-based shop trips decreases due to unattractiveness of, say, an industrial area.

However, some illogical regression results were also observed in the review. An example is a home-based work model using multiple employment categories as independent variables with some of the coefficients being positive and some negative.

Since each employee should attract a reasonable average number of home-based work trips each day, a negative model coefficient for an employment category is not logical.

Tables C.5 through C.9 in Appendix C show the trip rates by purpose cross-classified by the preferred pairs of variables for home-based work, homebased nonwork, nonhome-based, home-based school, and home-based other trips, respectively.

Table C.5. Home-based work trip rates.

Number of Workers by Number of Autos

	Workers				
Autos	**0**	**1**	**2**	**3+**	**Average**
0	0.0	1.0	2.4	5.1	**0.5**
1	0.0	1.0	2.6	5.1	**0.8**
2	0.0	1.3	2.6	5.1	**1.6**
3+	0.0	1.3	2.6	5.1	**2.3**
Average	**0.0**	**1.2**	**2.6**	**5.1**	**1.4**

Number of Persons by Number of Autos

	Persons					
Autos	**1**	**2**	**3**	**4**	**5+**	**Average**
0	0.2	0.7	1.0	1.0	1.0	**0.5**
1	0.6	0.8	1.2	1.7	1.5	**0.8**
2	0.7	1.3	2.0	2.0	2.3	**1.6**
3+	0.9	1.4	2.6	2.9	3.3	**2.3**
Average	**0.5**	**1.2**	**2.0**	**2.3**	**2.4**	**1.4**

Number of Persons by Income Level

	Persons					
Household Income	**1**	**2**	**3**	**4**	**5+**	**Average**
i	0.2	0.6	0.8	1.3	1.8	**0.6**
ii	0.3	0.8	1.5	1.6	2.0	**0.8**
iii	0.7	1.0	1.8	2.3	2.6	**1.3**
iv	0.8	1.5	2.4	2.4	2.6	**1.9**
v	0.9	1.6	2.4	2.4	2.6	**2.0**
Average	**0.5**	**1.2**	**2.0**	**2.3**	**2.4**	**1.4**

Table C.6. Home-based nonwork trip rates.

Number of Persons by Number of Workers, Urban Area Greater Than 500,000 Population

	Household Size					
Workers	**1**	**2**	**3**	**4**	**5+**	**Average**
0	1.8	4.0	5.6	9.2	10.5	**3.5**
1	1.8	4.0	6.6	9.9	12.4	**4.9**
2		4.0	7.0	11.4	14.5	**7.9**
3+			7.0	11.4	14.5	**10.8**
Average	**1.8**	**4.0**	**6.7**	**10.6**	**13.4**	**5.6**

Number of Persons by Number of Workers, Urban Area Less Than 500,000 Population (Including Non-Urban Areas)

	Household Size					
Workers	**1**	**2**	**3**	**4**	**5+**	**Average**
0	1.8	3.6	5.6	8.1	8.8	**3.4**
1	1.8	3.6	6.7	8.7	11.8	**4.6**
2		3.6	6.7	10.1	14.4	**6.8**
3+			6.7	11.2	15.3	**10.8**
Average	**1.8**	**3.6**	**6.7**	**9.5**	**12.9**	**5.1**

Number of Persons by Number of Vehicles, Urban Area Greater Than 500,000 Population

	Household Size					
Vehicles	**1**	**2**	**3**	**4**	**5+**	**Average**
0	1.4	3.8	5.6	7.5	10.0	**3.2**
1	1.9	3.9	6.5	9.0	11.8	**3.7**
2	2.4	4.0	6.5	11.0	14.0	**6.8**
3+	2.5	4.0	7.3	11.0	14.5	**8.6**
Average	**1.8**	**4.0**	**6.7**	**10.6**	**13.4**	**5.6**

Table C.6. (Continued).

Number of Persons by Number of Vehicles, Urban Area Less Than 500,000 Population (Including Non-Urban Areas)

	Household Size					
Vehicles	**1**	**2**	**3**	**4**	**5+**	**Average**
0	1.2	3.3	5.1	8.1	10.3	**2.6**
1	1.9	3.6	6.7	9.5	10.3	**3.5**
2	2.0	3.6	6.7	9.5	12.1	**5.6**
3+	2.0	3.6	6.7	9.5	14.7	**6.9**
Average	**1.8**	**3.6**	**6.7**	**9.5**	**12.9**	**5.1**

Number of Persons by Income Level, Urban Area Greater Than 500,000 Population

	Household Size					
Household Income	**1**	**2**	**3**	**4**	**5+**	**Average**
i	1.7	3.7	5.0	9.1	11.5	**4.1**
ii	1.7	4.1	6.0	9.9	11.5	**4.7**
iii	1.9	4.1	6.9	9.9	13.1	**5.0**
iv	2.0	4.1	6.9	10.4	14.7	**6.2**
v	2.3	4.1	7.1	11.8	15.4	**7.6**
Average	**1.8**	**4.0**	**6.7**	**10.6**	**13.4**	**5.6**

Number of Persons by Income Level, Urban Area Less Than 500,000 Population (Including Non-Urban Areas)

	Household Size					
Household Income	**1**	**2**	**3**	**4**	**5+**	**Average**
i	1.4	3.2	5.1	7.9	7.5	**3.3**
ii	1.9	3.4	6.8	8.9	11.9	**4.1**
iii	1.9	3.7	6.8	8.9	12.4	**4.9**
iv	1.9	3.7	6.8	10.0	14.1	**6.2**
v	2.2	3.7	7.3	10.1	14.8	**7.0**
Average	**1.8**	**3.6**	**6.7**	**9.5**	**12.9**	**5.1**

Table C.7. Nonhome-based trip rates.

Number of Persons by Number of Workers

Workers	Household Size					
	1	2	3	4	5+	Average
0	0.9	1.8	2.7	3.1	3.1	**1.5**
1	1.6	2.4	3.3	4.7	5.0	**2.7**
2		3.2	4.5	5.9	6.1	**4.5**
3+			4.8	7.0	8.1	**6.7**
Average	**1.3**	**2.5**	**3.8**	**5.3**	**5.7**	**3.0**

Number of Persons by Number of Vehicles

Vehicles	Household Size					
	1	2	3	4	5+	Average
0	0.7	1.7	2.0	3.7	3.9	**1.3**
1	1.4	2.3	3.5	3.9	3.9	**2.0**
2	1.6	2.6	3.9	5.5	5.6	**3.5**
3+	1.6	2.7	4.5	5.8	7.1	**4.4**
Average	**1.3**	**2.5**	**3.8**	**5.3**	**5.7**	**3.0**

Number of Persons by Income Level

Household Income	Household Size					
	1	2	3	4	5+	Average
i	0.7	1.4	2.7	3.4	3.4	**1.6**
ii	1.0	1.8	2.8	3.9	3.9	**1.9**
iii	1.5	2.4	3.5	4.7	5.0	**2.7**
iv	1.8	3.0	4.4	5.5	6.8	**3.8**
v	2.0	3.2	4.6	6.5	8.3	**4.7**
Average	**1.3**	**2.5**	**3.8**	**5.3**	**5.7**	**3.0**

Table C.8. Home-based school trip rates.

Number of Persons by Number of Children

Children	Household Size 1	2	3	4	5+	Average
0	0.0	0.0	0.5	1.0	1.1	**0.1**
1	0.0	1.0	1.0	1.7	1.8	**1.1**
2			1.6	1.8	2.6	**1.9**
3+				2.7	2.7	**2.7**
Average	**0.0**	**0.1**	**0.8**	**1.7**	**2.5**	**0.6**

Number of Persons by Number of Vehicles

Vehicles	Household Size 1	2	3	4	5+	Average
0	0.0	0.1	0.8	1.5	1.6	**0.3**
1	0.0	0.1	0.8	1.6	2.4	**0.3**
2	0.0	0.1	0.8	1.7	2.6	**0.7**
3+	0.0	0.1	0.8	1.8	2.7	**1.0**
Average	**0.0**	**0.1**	**0.8**	**1.7**	**2.5**	**0.6**

Number of Persons by Income Level

Household Income	Household Size 1	2	3	4	5+	Average
i	0.0	0.1	0.7	1.2	1.5	**0.4**
ii	0.0	0.1	0.8	1.6	2.6	**0.5**
iii	0.0	0.1	0.8	1.6	2.6	**0.5**
iv	0.0	0.1	0.8	1.6	2.6	**0.7**
v	0.0	0.1	0.8	1.9	2.8	**1.0**
Average	**0.0**	**0.1**	**0.8**	**1.7**	**2.5**	**0.6**

Table C.9. Home-based other trip rates (excluding work and school).

Number of Persons by Number of Workers, Urban Area Greater Than 500,000 Population

	Household Size					
Workers	**1**	**2**	**3**	**4**	**5+**	**Average**
0	1.8	3.9	5.1	7.6	8.8	**3.3**
1	1.8	3.9	5.8	8.2	9.7	**4.4**
2		3.9	6.1	9.3	12.1	**6.8**
3+			6.2	9.5	12.1	**9.2**
Average	**1.8**	**3.9**	**5.8**	**8.7**	**10.9**	**4.9**

Number of Persons by Number of Workers, Urban Area Less Than 500,000 Population (Including Non-Urban Areas)

	Household Size					
Workers	**1**	**2**	**3**	**4**	**5+**	**Average**
0	1.8	3.5	5.2	6.7	6.7	**3.2**
1	1.8	3.5	5.9	7.3	9.5	**4.1**
2		3.5	6.1	8.2	11.5	**5.9**
3+			6.1	9.6	12.5	**9.2**
Average	**1.8**	**3.5**	**6.0**	**7.9**	**10.3**	**4.6**

Number of Persons by Number of Vehicles, Urban Area Greater Than 500,000 Population

	Household Size					
Vehicles	**1**	**2**	**3**	**4**	**5+**	**Average**
0	1.4	3.5	5.0	5.9	8.6	**2.9**
1	1.9	3.8	5.6	7.1	9.2	**3.4**
2	2.4	4.0	5.7	9.2	11.1	**6.0**
3+	2.5	4.0	6.4	9.2	12.2	**7.5**
Average	**1.8**	**3.9**	**5.8**	**8.7**	**10.9**	**4.9**

Table C.9. (Continued).

Number of Persons by Number of Vehicles, Urban Area Less Than 500,000 Population (Including Non-Urban Areas)

	Household Size					
Vehicles	**1**	**2**	**3**	**4**	**5+**	**Average**
0	1.2	3.0	4.5	6.8	8.1	**2.4**
1	1.9	3.5	6.2	8.0	8.1	**3.2**
2	2.0	3.6	6.2	8.0	9.9	**5.0**
3+	2.0	3.6	6.2	8.0	11.6	**6.0**
Average	**1.8**	**3.5**	**6.0**	**7.9**	**10.3**	**4.6**

Number of Persons by Income Level, Urban Area Greater Than 500,000 Population

	Household Size					
Household Income	**1**	**2**	**3**	**4**	**5+**	**Average**
i	1.6	3.5	4.0	7.4	9.6	**3.7**
ii	1.7	3.9	5.3	8.0	9.6	**4.1**
iii	1.9	3.9	5.9	8.0	10.4	**4.5**
iv	2.0	4.1	6.2	8.6	12.2	**5.5**
v	2.3	4.1	6.3	9.8	12.4	**6.6**
Average	**1.8**	**3.9**	**5.8**	**8.7**	**10.9**	**4.9**

Number of Persons by Income Level, Urban Area Less Than 500,000 Population (Including Non-Urban Areas)

	Household Size					
Household Income	**1**	**2**	**3**	**4**	**5+**	**Average**
i	1.4	3.0	4.6	6.9	5.7	**3.0**
ii	1.9	3.3	6.0	7.5	9.2	**3.7**
iii	1.9	3.7	6.0	7.5	10.0	**4.4**
iv	1.9	3.7	6.0	8.3	11.3	**5.4**
v	2.2	3.7	6.5	8.3	12.2	**6.1**
Average	**1.8**	**3.5**	**6.0**	**7.9**	**10.3**	**4.6**

Example Calculations

Consider a zone with 1,000 households located in an urban area of under 500,000 in population where a trip production model with the classic three trip purposes is being developed. The MPO has estimated the number of households in the zone cross-classified by number of persons and number of vehicles, as depicted in Table 1.

For home-based work trips, the number of households in each cell is multiplied by the trip rate from the second section of Table C.5, yielding the number of home-based work trips in each cell of the cross-classification in Table 2.

So this zone produces 1,839 home-based work trips. Similarly, home-based nonwork and nonhome-based trip productions can be computed using the fourth section of Table C.6 and the second section of Table C.7, performing the same type of calculations.

Reasonableness checks of the trips per household by purpose estimated from trip production model results can beperformed. Information on the national sample represented by the HTS, as represented by Tables C.5 through C.7, indicate that the average household in urban areas

of greater than 500,000 in population makes 10.0 person trips: 1.4 homebased work trips, 5.6 home-based nonwork trips, and 3.0 nonhome-based trips. The average household in urban areas of less than 500,000 in population makes 9.5 person trips:
1.4 home-based work trips, 5.1 home-based nonwork trips, and 3.0 nonhome-based trips.
The range of person trips per household in the MPO Documentation Database is about 1.3 to 2.0 home-based work trips, 2.6 to 5.9 home-based nonwork trips, and 1.6 to 4.5 nonhome-based trips. Total person trips per household range from 7.0 to 11.5.

Table 1. Example number of households by numbers of persons and autos.

	Persons					
Autos	1	2	3	4	5+	Total
0	10	10	10	0	0	**30**
1	50	100	70	20	10	**250**
2	0	150	200	100	50	**500**
3+	0	0	40	80	100	**220**
Total	**60**	**260**	**320**	**200**	**160**	**1,000**

Table 2. Example number of home-based work trips.

	Persons					
Autos	1	2	3	4	5+	Total
0	2	7	11	0	0	20
1	30	80	84	34	15	243
2	0	195	400	200	115	910
3+	0	0	104	232	330	666
Total	**32**	**282**	**599**	**466**	**460**	**1,839**

Example 1.

Suppose the trip attraction rates from homebased work model 1, home-based nonwork model 3, and nonhome-based model 1 are applied for a region. In a review of traffic assignment results, it is discovered that too many trips are crossing the cordon boundary around the CBD. In such a case, it might be reasonable to reduce the home-based nonwork and nonhome-based trip attraction rates for retail and service employment in the CBD and to balance those reductions in the CBD trip rates with increases of the values for the rates for non-CBD zones. However, before making such adjustments, other checks should be performed, including the accuracy of CBD socioeconomic data, mode shares to the CBD, and comparison of CBD through traffic to observed origin-destination data.

Example 2.

Suppose a region has forecasts for only households, retail employment, and nonretail employment available. None of the three home-based nonwork model forms match the independent variables available for the region. In this case, it might be reasonable to test both home-based nonwork models 2 and 3, ignoring the coefficients for the missing variables. Careful attention should be paid to traffic assignment results around industrial areas and educational facilities. The “best performing” model in terms of reproducing traffic volumes would be selected. If neither model performed well, it might be appropriate to mix the rates to address the issues.

Example 3

A travel survey produced the data shown in Table 1. Twenty households were interviewed. The table shows the number of trips produced per day for each of the households (numbered 1 through 20), as well as the corresponding annual household income and the number of automobiles owned. Based on the data provided, develop a set of curves showing the number of trips per household versus income and auto ownership.

Table 1 Survey Data Showing Trips per Household, Income, and Auto Ownership

Household Number	Trips Produced per Household	Household Income ($1000s)	Autos per Household
1	2	16	0
2	4	24	0
3	10	68	2
4	5	44	0
5	5	18	1
6	15	68	3
7	7	38	1
8	4	36	0
9	6	28	1
10	13	76	3
11	8	72	1
12	6	32	1
13	9	28	2
14	11	44	2
15	10	44	2
16	11	52	2
17	12	60	2
18	8	44	1
19	8	52	1
20	6	28	1

Solution:

Step 1. From the information in Table 12.1, produce a matrix that shows the number and percentage of households as a function of auto ownership and income grouping (see Table 2). The numerical values in each cell represent the number of households observed in each combination of income‑auto ownership category. The value in parentheses is the percentage observed at each income level. In actual practice, the sample size would be at least 25 data points per cell to ensure statistical accuracy. Figure 3 illustrates how the data shown in Table 2 are used to develop relationships between the percent of households in each auto ownership category by household income.

<u>Table 2.</u> Number and Percent of Household in Each Income Category versus Car Ownership.

	Autos Owned			
Income ($1000s)	*0*	*1*	*2+*	*Total*
24	2(67)	1(33)	0(0)	3(100)
24–36	1(25)	3(50)	1(25)	5(100)
36–48	1(20)	2(40)	2(40)	5(100)
48–60	—	1(33)	2(67)	3(100)
>60	—	1(25)	3(75)	4(100)
Total	4	8	8	20

Note: Values in parentheses are percent of automobiles owned at each income range.

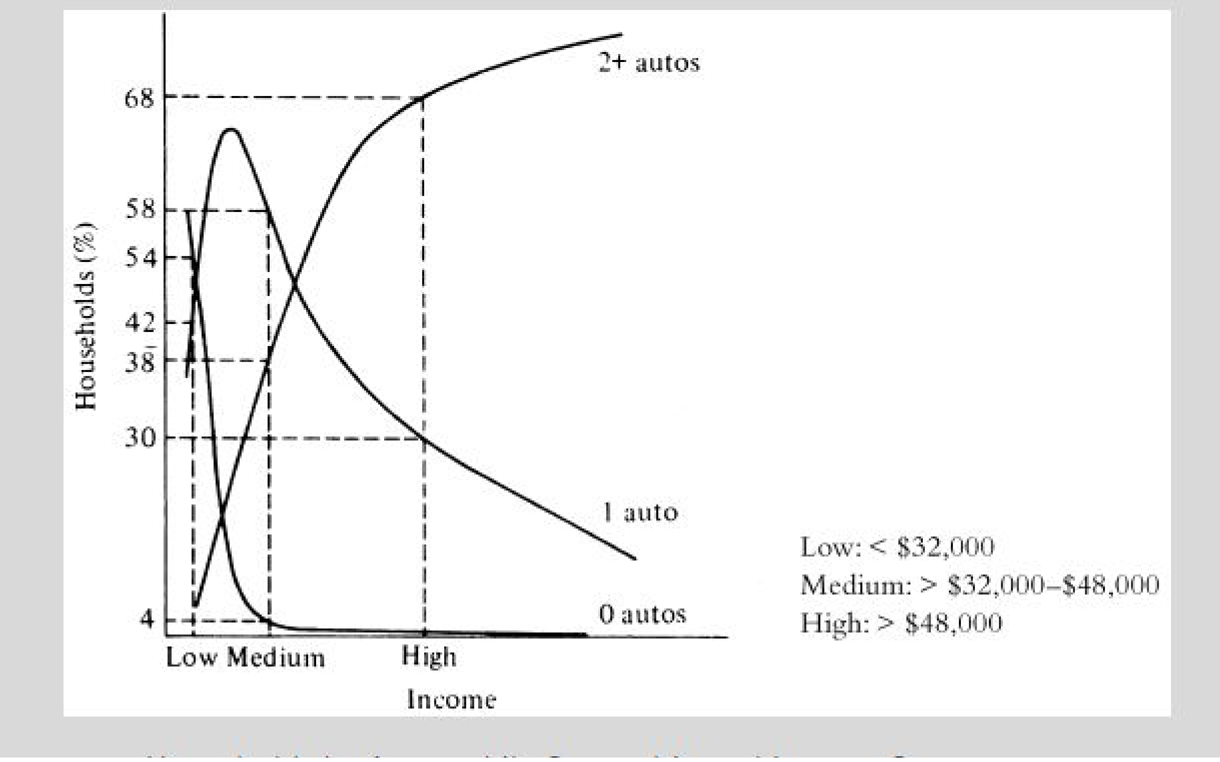

Figure 3. Households by Automobile Ownership and Income Category.

<u>Step 2.</u> A second table produced from the data in Table 1 shows the average number of trips per household versus income and cars owned. The results shown in Table 3 are illustrated in Figure 4 on page 597, which depicts the relationship between trips per household per day by income and auto ownership. The table indicates that for a given income, trip generation increases with the number of cars owned. Similarly, for a given car ownership, trip generation increases with the rise in income.

Step 3. As a further refinement, additional O-D data (not shown in Table 1) can be used to determine the percentage of trips by each trip purpose for each income category. These results are shown in Figure 5, wherein three trip purposes are used: home-based work (HBW), home-based other (HBO), and non-home-based (NHB). The terminology refers to the origination of a trip as either at the home or not at the home.

Table 3 Average Trips per Household versus Income and Car Ownership.

	Autos Owned		
Income ($1000s)	*0*	*1*	*2+*
≤24	3	5	—
24–36	4	6	9
36–48	5	7.5	10.5
48–60	—	8.5	11.5
>60	—	8.5	12.7

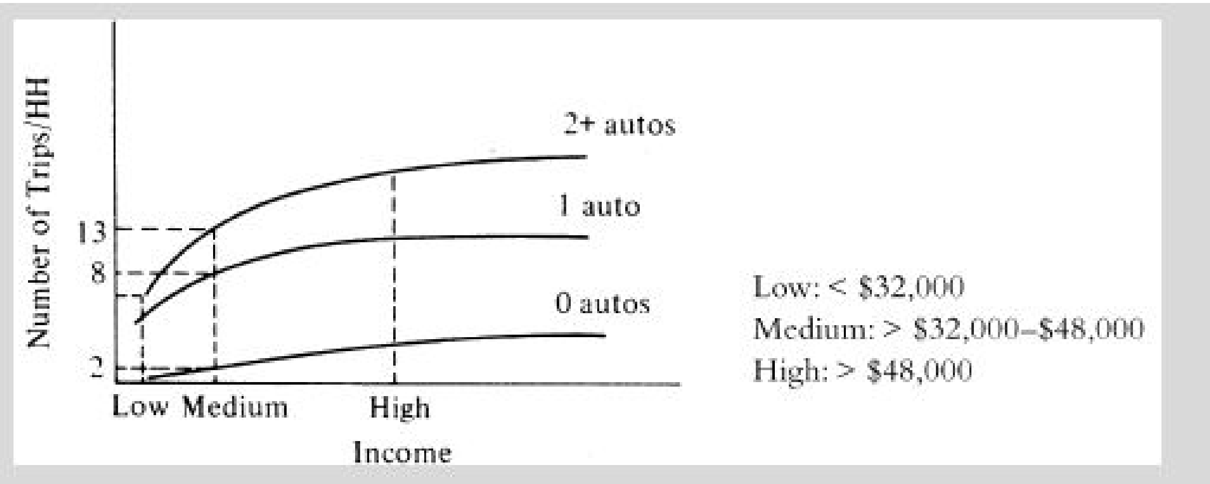

Figure 4 Trips per Household per Day by Auto Ownership and Income Category.

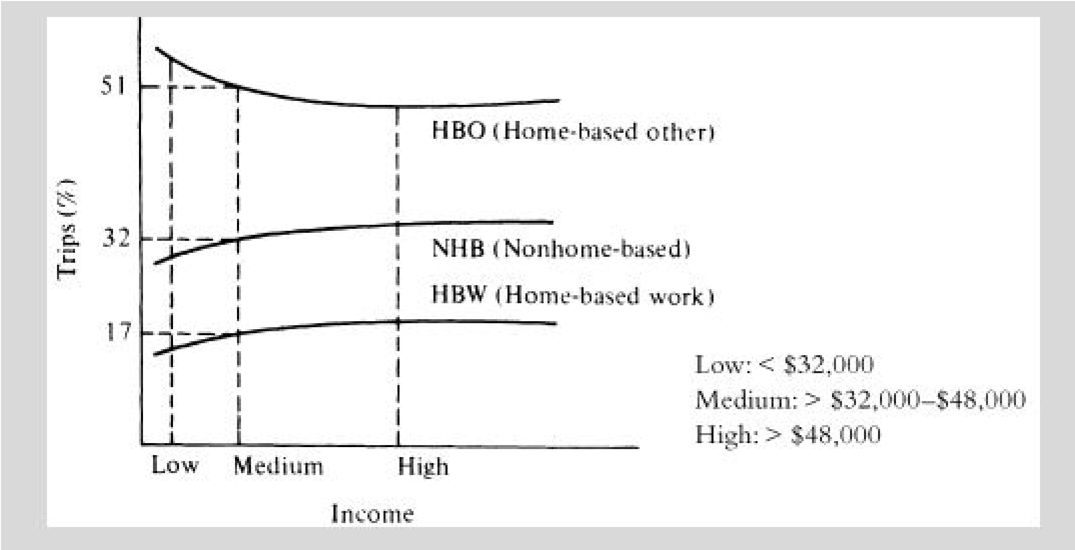

Figure 5 Trips by Purpose and Income Category.

The trip generation model that has been developed based on survey data can now be used to estimate the number of home- and non-home-based trips for each trip purpose.

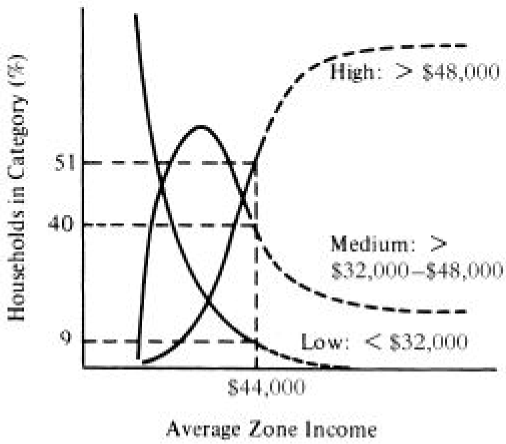

Figure 2. Average Zonal Income versus Households in Income Category.

Example 4

Consider a zone that is located in a suburban area of a city. The population and income data for the zone are as follows.

Number of dwelling units: 60

Average income per dwelling unit: $44,000

Determine the number of trips per day generated in this zone for each trip purpose, assuming that the characteristics depicted in Figures 12.2 through 12.5 apply in this situation. The problem is solved in four basic steps.

Solution:

Step 1. Determine the percentage of households in each economic category. These results can be obtained by analysis of census data for the area. A typical plot of average zonal income versus income distribution is shown in Figure 2. For an average zonal income of $44,000, the following distribution is observed.

Income ($)	Households (%)
Low (under 32,000)	9
Medium (32,000–48,000)	40
High (over 48,000)	51

Step 2. Determine the distribution of auto ownership per household for each income category. A typical curve showing percent of households, at each income level, that own 0, 1, or 2_ autos is shown in Figure 3, and the results are listed in Table 4.
Table 4 shows that 58% of medium-income families own one auto per household. Also, from the previous step, we know that a zone, with an average income of $44,000, contains 40% of households in the medium-income category. Thus, we can calculate that of the 60 households in that zone, there will be (60) * (0.40) * (0.58) = 14 medium-income households that own one auto.

Table 4 Percentage of Households in Each Income Category versus Auto Ownership.

	Autos/Household		
Income	0	1	2+
Low	54	42	4
Medium	4	58	38
High	2	30	68

Step 3. Determine the number of trips per household per day for each income‑auto ownership category. A typical curve showing the relationship between trips per household, household income, and auto ownership is shown in Figure 4. The results are listed in Table 5.

Table 5 Number of Trips per Household per Day.

	Autos/Household		
Income	0	1	2+
Low	1	6	7
Medium	2	8	13
High	3	11	15

The table shows that a medium-income household owning one auto will generate eight trips per day.

Step 4. Calculate the total number of trips per day generated in the zone. This is done by computing the number of households in each income-auto ownership category, multiplying this result by the number of trips per household, as determined in Step 3, and summing the result. Thus,

$$P_{gh} = HH \times I_g \times A_{gh} \times (P_H)_{gh}$$

$$P_T = \sum_{g}^{3} \sum_{h}^{3} P_{gh}$$

where

HH = number of households in the zone
I_g = percentage of households (decimal) in zone with income level g (low, medium, or high)
A_{gh} = percentage of households (decimal) in income level g with h autos per household ($h = 0, 1,$ or $2+$)
P_{gh} = number of trips per day generated in the zone by householders with income level g and auto ownership h
$(P_H)_{gh}$ = number of trips per day produced in a household at income level g and auto ownership h
P_T = total number of trips generated in the zone

The calculations are shown in Table 12.6. For a zone with 60 households and an average income of $44,000, the number of trips generated is 666 auto trips/day.

Step 5. Determine the percentage of trips by trip purpose. As a final step, we can calculate the number of trips that are HBW, HBO, and NHB. If these percentages are 17, 51, and 32, respectively (see Figure 5), for the medium-income category, then the number of trips from the zone for the three trip purposes are (232) * (0.17) = 40 HBW, (232) * (0.51) = 118 HBO, and (232)* (0.32) = 74 NHB. (Similar calculations would be made for other income groups.) The final result, which is left for the reader to verify, is obtained by using the following percentages: low income at 15, 55, and 30, and high income at 18, 48, and 34. These yield 118 HBW, 327 HBO, and 221 NHB trips.

Table 6 Number of Trips per Day Generated by Sixty Households.

	Income, Auto Ownership	*Total Trips by Income Group*
60 × 0.09 × 0.54 × 1 = 3 trips	L, 0+	
60 × 0.09 × 0.42 × 6 = 14 trips	L, 1+	
60 × 0.09 × 0.04 × 7 = 2 trips	L, 2+	19
60 × 0.40 × 0.04 × 2 = 2 trips	M, 0+	
60 × 0.40 × 0.58 × 8 = 111 trips	M, 1+	
60 × 0.40 × 0.38 × 13 = 119 trips	M, 2+	232
60 × 0.51 × 0.02 × 3 = 2 trips	H, 0+	
60 × 0.51 × 0.30 × 11 = 101 trips	H, 1+	
60 × 0.51 × 0.68 × 15 = 312 trips	H, 2+	415
Total = 666 trips		666

Example 5

A commercial center in the downtown contains several retail establishments and light industries. Employed at the center are 220 retail and 650 non-retail workers. Determine the number of trips per day attracted to this zone.

	Attractions per Household	*Attractions per Nonretail Employee*	*Attractions per Downtown Retail Employee*	*Attractions per Other Retail Employee*
HBW	—	1.7	1.7	1.7
HBO	1.0	2.0	5.0	10.0
NHB	1.0	1.0	3.0	5.0

HBW: (220 × 1.7) + (650 × 1.7) = 1479
HBO: (220 × 5.0) + (650 × 2.0) = 2400
NHB: (220 × 3.0) + (650 × 1.0) = 1310
Total = 5189 trips/day

Balancing Trip Productions and Attractions

A likely result of the trip generation process is that the number of trip productions may not be equal to the number of trip attractions. Trip productions, which are based on census data, are considered to be more accurate than trip attractions. Accordingly, trip attractions are usually modified so that they are equal to trip productions.

Table 8a illustrates how adjustments are made. The trip generation process has produced 600 home-based work productions for zones 1 through 3. However, the same process has produced 800 home-based work attractions. To rectify this imbalance, each attraction value for zones 1 through 3 is reduced by a factor equal to 600/800, or 0.75. The result is shown in Table 8a in the column "Balanced HBW Trips" Now both productions and attractions are equal. A similar procedure is used for HBO trips.

An extra step is required for balancing NHB trips. This extra step is that after total productions and total attractions are equal, the productions for each zone are set equal to the attractions for each zone. For example, in Table 8b, since there are 180 NHB attractions for zone 1 after balancing productions and attractions, then the number of NHB productions for zone 1 is also changed from 100 to 180. The rationale behind this extra step is that the true origin of non-home based trips is not provided by survey or census data, and thus the best estimate of the number of NHB trips produced in each zone is the number of NHB trips attracted to each zone.

Table 8a. Balancing Home-Based Work Trips.

	Unbalanced HBW Trips		*Balanced HBW Trips*	
Zone	*Productions*	*Attractions*	*Productions*	*Attractions*
1	100	240	100	180
2	200	400	200	300
3	300	160	300	120
Total	600	800	600	600

Table 8b. Balancing Non-Home-Based Trips.

	Unbalanced NHB Trips		*Balanced NHB Trips*	
Zone	*NHB Productions*	*NHB Attractions*	*NHB Productions*	*NHB Attractions*
1	100	240	180	180
2	200	400	300	300
3	300	160	120	120
Total	600	800	600	600