3-4 TRANSPORTATION SYSTEMS MODELING

Transportation planning by its very definition is concerned with future travel demands and putting in place the facilities and services that will accommodate these demands. The challenge to transportation planners is to make reliable forecasts of traffic demand that reflect the effects of changes in population, social, and economic conditions as well as changes in the transportation network. Figure 3-7, for example, illustrates the relationship between the many different factors that influenced travel demand in the United States over the last decades.

The recognized components of future travel demand include:

1. *Existing traffic*. Traffie currently using an existing highway that is to be improved.
2. *Normal traffic growth*. Traffic that can be explained by anticipated growth in state or regional population or by areawide changes in land use.
3. *Diverted traffic*. Traffic that switches to a new facility from nearby roadways.
4. *Converted traffic*. Traffic changes resulting from change of mode.
5. *Change of destination traffic*. Traffic that has changed to different destinations, where such change is attributable to the attractiveness of the improved transportation and not to changes in land use.
6. *Development traffic*. Traffic due to improvements on adjacent land in addition to the development that would have taken place had the new or improved highway not been constructed.
7. *Induced traffic*. Traffic that represents trips that would not have been made, but now are because of improved transportation.

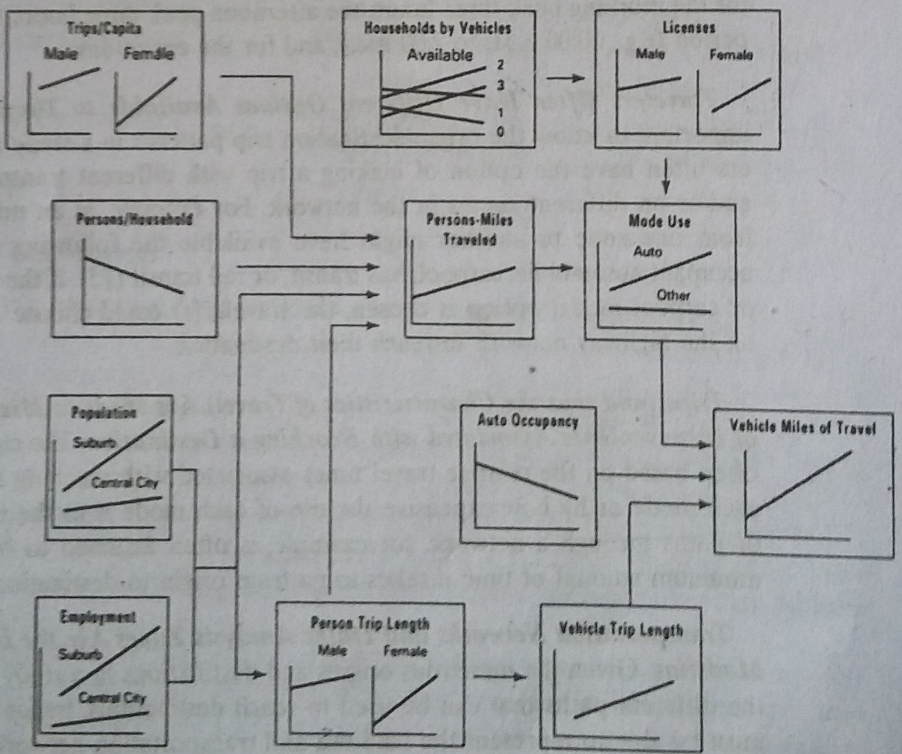


FIGURE 3-7 Factors in growth of personal travel. (Source: As adapted from Federal Highway Administration, *Travel Behavior Issues in the 90's: 1990 Personal Transportation Survey*.)

The models used to predict future travel demand must account for these different components of the likely traffic flow that will occur given future conditions.

Basic Concepts in Transportation Systems Modeling

Most transportation models are based on some fundamental assumptions and approaches that heavily influence how these models are used by transportation planners and engineers (*1, 13, 14*). The most important are as follows:

Tripmaking Is a Function of Land Use The concept of derived demand discussed earlier is a critical point of departure in model development. Most models are developed on the assumption that tripmaking is related to the types of land use at the origin and destination ends of the trip.

Trips Are Made for Different Purposes Trips are made to accomplish different objectives. In the morning, a large percentage of travel in urban areas consists of individuals going to work or going to school. In midday, the types of trips might include shopping, personal business and recreational. Because modeling is based on the types of activities and land uses found at both ends of the trip, the modeling process often treats these trips separately and then aggregates them at the end for an estimate of the total number of trips on the network.

Trips Are Made at Different Times of the Day The basis for most modeling is the determination of origin and destination patterns in the study area. These patterns will clearly differ by time of day in that different types of trips are being made at different times of the day. Thus, modeling is often done with an origin-destination trip table (a matrix that indicates the trip patterns) that represents defined time periods. It is not uncommon, for example, to have traffic estimates for the morning peak three hours, the afternoon peak three hours, the midday time period (e.g., 10:00 A.M. to 2:00 P.M.), and for the entire day.

Travelers Often Have Different Options Available to Them Not only is it important to know the origin-destination trip patterns in a study area, but travelers often have the option of making a trip with different transportation modes and/or on different routes in the network. For example, in an urban area, a trip from one zone to another might have available the following options: single-occupant automobile, carpool, bus transit, or rail transit (*15*). If the single-occupant or carpool modal option is chosen, the traveler(s) could choose different routes on the highway network to reach their destination.

Trips (and thus the Characteristics of Travel) Are Made to Minimize the Level of Inconvenience Associated with Reaching a Destination The choice of mode is often based on the relative travel times associated with reaching a destination by each mode or by how expensive the use of each mode is to the user. The choice of paths through a network, for example, is often assumed to be based on the minimum amount of time it takes to go from origin to destination.

Transportation Networks and Traffic Analysis Zones Are the Basis of Systems Modeling Given the numerous origins and destinations in a study area, and given the different paths that can be used to reach destinations, transportation models must be able to represent the land use and transportation network characteristics that are fundamental to trip estimation. As noted earlier, traffic analysis zones are used to represent the land use and demographic data that influence tripmaking.

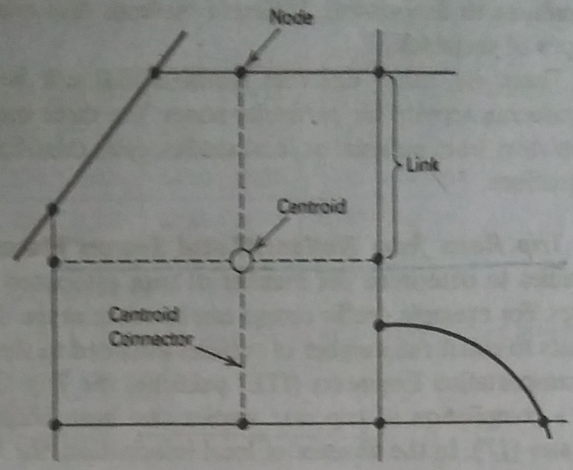


FIGURE 3-8 Representation of a transportation network. (Source: Federal Highway Administration, *Traffic Assignment*.)

The transportation system is often pictured as a network of *nodes* and *links* that conceptually represent intersections and roadways (*16*). Figure 3-8 shows a representation of a transportation network.

Transportation modeling consists primarily of four steps (and is thus often referred to as the "four-step" modeling process). These will be denoted with the following variables:

Trip Generation (T_i):	The number of trips produced in traffic analysis zone i
Trip Distribution (T_{ij}):	The number of trips produced in zone i and attracted to zone j
Mode Split (T_{ijm}):	The number of trips produced in zone i and attracted to zone j traveling by mode m
Trip Assignment (T_{ijmr}):	The number of trips produced in zone i and attracted to zone j traveling by mode m over route r

Trip Generation

The trip generation step in transportation modeling relates the number of trips being produced from a zone or site by time period to the land use and demographic characteristics found at that location. A necessary input step into trip generation is to have some indication of what the land use and demographic characteristics are likely to be. For future conditions, special models are used to estimate population, number of dwelling units, auto ownership, income, employment, retail sales, and other factors that will likely characterize the future conditions for this zone. In many cases, and especially for regional or statewide planning, these future estimates are provided by economic or demographic planners rather than by transportation professionals.

Studies have shown that the rate of tripmaking is closely related to three characteristics of land use: (1) intensity of land use (e.g., dwelling units per acre, employees per acre, etc.), (2) character of land use (e.g., average family income, car ownership, etc.), and (3) location relative to major economic activities (e.g., closeness to downtown). Different methods thus relate tripmaking rates to these types of variables.

There are many different methods that can be used to estimate the trip-producing activity for particular zones. The three most common methods include trip rates from national or local studies, cross classification analysis, and regression equations.

Trip Rates from National/Local Sources Planners often undertake special studies to determine the number of trips associated with different types of land uses. For example, traffic counts can be taken at the driveways of stores or restaurants to count the number of vehicles attracted to these locations. The Institute of Transportation Engineers (ITE) publishes the *Trip Generation Handbook*, which is a compilation of trip rate studies that have occurred throughout the United States (*17*). In the absence of local information, the *Handbook* is often used as a source of information on trip rates.

Cross Classification Analysis If good data are available from a study area to provide information on the relationship between socioeconomic variables and tripmaking, cross classification analysis can be used to develop relevant trip rates. An illustration of cross classification analysis is shown in Figure 3-9. In this case data were available from the Census on the number of persons per household and household income and the corresponding number of trips made per household type. By estimating the number of future households and applying the calculated trip rates, the future number of trips produced in this zone can be calculated.

Regression Analysis Given the high correlations that typically exist between trip rates and socioeconomic variables, many models use least-squares regression equations to estimate trip production per zone. The ITE *Handbook* also provides regression equations for estimating trip productions for certain types of land use. A typical regression equation might look like the following:

$$T_i = 0.34(P_i) + 0.21(DU_i) + 0.12(A_i)$$

$$A_j = 57.2 + 0.87(E_j)$$

where
T_i = total number of trips produced in zone i
A_j = total number of trips attracted to zone j
P_i = total population for zone i
DU_i = total number of dwelling units for zone i
A_i = total number of automobiles in zone i
E_j = total employment in zone j

Trip Distribution

The major product of the trip distribution step in transportation modeling is the *trip table*, an origin-destination matrix that shows the number of trips originating in the study zones and where these trips are destined to. The major method of producing such trip tables is the gravity model.

The gravity model is so named because of its similarity to Newton's law of gravity. Employed first for sociological and marketing research, the gravity model began to be used for transportation studies in the early 1950s. Since that time, the

Auto Ownership

Household Size	0		1		2+	
	HH	Trips	HH	Trips	HH	Trips
1	1,200	2,520	2,560	6,144	54	130
2	874	2,098	3,456	9,676	5,921	20,165
3+	421	1,137	2,589	8,026	8,642	33,704

Number of trips per household size by auto ownership, obtained from regional study

Auto Ownership

Household Size	0	1	2+
1	2.1	2.4	2.4
2	2.4	2.8	3.4
3+	2.7	3.1	3.9

Trips per household obtained from previous matrix

Auto Ownership

Household Size	0	1	2+
1	25	125	3
2	32	175	254
3+	10	89	512

Forecasted number of households in study zone by auto ownership and size

Auto Ownership

Household Size	0	1	2+	
1	52	300	7	
2	77	490	864	Total
3	27	276	2001	4,094

Forecasted number of trips in zone determined by multiplying trip rates by number of households in category

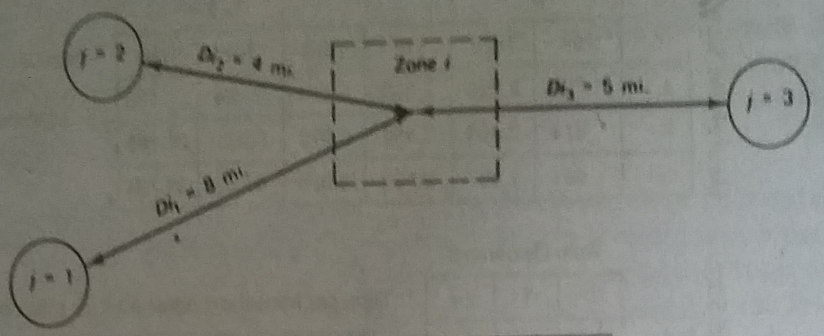
FIGURE 3-9 Cross classification analysis.

model has been slightly modified and has become the predominant technique for trip distribution. The original version of the model was of the form:

$$T_{ij} = \left[\frac{\dfrac{A_j}{(D_{ij})^n}}{\dfrac{A_1}{(D_{i1})^n} + \dfrac{A_2}{(D_{i2})^n} + \cdots + \dfrac{A_m}{(D_{im})^n}} \right] P_i \tag{3-1}$$

where T_{ij} = trips from zone i to zone j for a specified purpose
P_i = total trips produced at zone i for the specified purpose
A_j = a measure of attraction of the jth zone for trips of this purpose
D_{ij} = distance from zone i to zone j for m zones
n = some exponent that varies with trip purpose

Consider the following numerical example. Given a residential zone that produces a total of 110 shopping trips per day, distribute these trips to shopping centers 1, 2, 3 in accordance with the gravity model. Distances between zones are shown on the sketch. The value of n in the gravity model is 2. Use the amount of commercial floor space within the destination zone as the measure of attractiveness:



Shopping Center	Floor Space (thousand ft²)
1	184
2	215
3	86

$$\text{Trips from zone } i \text{ to zone } 1 = \frac{\frac{184}{(8)^2}}{\frac{184}{(8)^2} + \frac{215}{(4)^2} + \frac{86}{(5)^2}} \times 110 = 16$$

$$\text{Trips from zone } i \text{ to zone } 2 = \frac{\frac{215}{(4)^2}}{\frac{184}{(8)^2} + \frac{215}{(4)^2} + \frac{86}{(5)^2}} \times 110 = 75$$

Similarly, the trips from zone i to zone 3 = 19

Total trips = 110

The gravity model has been modified in recent years to reflect research and experience with the model. It has been found that decreases in travel propensity are more closely related to travel time than to distance. In addition, it has been established that the exponent of travel time, n, varies not only with trip purpose but also with trip length. Trip distribution analyses are therefore usually stratified according to travel time t with different calibrated values of the exponent being determined for a given city and trip length. Furthermore, to facilitate efficient computer use of gravity models, it is now the practice to represent the effect of spatial separation on travel between zones in the form of travel time factors

$$F_t = \frac{C}{t^n}$$

where C is a constant. Instead of a surrogate measure of attractiveness such as commercial floor space or number of employees, actual zonal total trip attractions are used in the equation. Current gravity models permit an analyst to make adjustments to allow for special social or economic conditions by choice of socioeconomic adjustment factor.

Currently, the recommended formulation of the gravity model is

$$T_{ij} = \frac{A_j F_{t_{ij}} K_{ij}}{\sum_{\text{all zones}} A_x F_{t_{ij}} K_{ix}} \times P_i \tag{3-2}$$

where F_{ij} = travel time factor for travel time between zones i and $j = \frac{C}{t_{ij}^{n}}$

K_{ij} = socioeconomic adjustment factor between zones i and j

A_j = total attractions at zone j

P_i = total trips produced at zone i for the specified purpose

Mode Split Models

Mode split models predict the number of travelers who will choose one mode over others for making a particular trip. A great deal of research has been undertaken to better specify models that correctly reflect the individual's decision-making process in making this choice. Empirical evidence indicates that the following factors influence mode choice:

1. Type of trip (e.g., trip purpose, time of day)
2. Characteristics of the tripmaker (e.g., income, age, auto ownership)
3. Characteristics of the transportation system (e.g., relative travel times for the modes available to make the trip)

The most recent advances in transportation modeling have focused on what are called *individual choice models*, which relate modal choice to the utility associated with each mode. The utility or attractiveness of each mode can be defined with a variety of variables relating to travel costs, travel time, reliability, and so on. Different model formulations have been used to predict mode choice based on different modal utilities, but the most common formulation is called the *logit model* and is of the following form.

$$P_{it} = \frac{e^{U_{it}}}{\sum_{\text{All } j} e^{U_{jt}}} \tag{3-3}$$

where P_{it} = probability of individual t choosing mode i

U_{it} = utility of mode i to individual t

U_{jt} = utility of mode j to individual t

An example of this type of mode split model follows. Assume that we know there are 1,000 trips being made between zones i and j (which we obtained from trip distribution). There are three modes available to make this trip. The utility of the individual modes is defined as

$$U_{\text{auto}} = 1.0 - 0.1(TT_{\text{auto}}) - 0.05(TC_{\text{auto}})$$
$$U_{\text{bus}} = -0.1(TT_{\text{bus}}) - 0.05(TC_{\text{bus}})$$
$$U_{\text{walk}} = -5.0 - 0.1(TT_{\text{walk}})$$

where TT = travel time by mode in minutes

TC = travel cost by mode in dollars

Assume that we know that the travel time for auto is 5 minutes, for bus 15 minutes, and for walking 20 minutes. The corresponding costs are \$0.60 for auto and \$0.50 for bus. Substituting these numbers into the utility equations results in the following estimates of modal utilities:

$$U_{\text{auto}} = 0.47 \qquad U_{\text{bus}} = -1.525 \qquad U_{\text{walk}} = -2.5$$

Using Eq. 3-3, we find the following probabilities associated with the use of each mode:

$$P_{auto} = \frac{e^{0.47}}{e^{0.47} + e^{-1.525} + e^{-2.5}} = 0.842$$

$$P_{bus} = \frac{e^{-1.525}}{e^{0.47} + e^{-1.525} + e^{-2.5}} = 0.114$$

$$P_{walk} = \frac{e^{-2.5}}{e^{0.47} + e^{-1.525} + e^{-2.5}} = 0.043$$

Given the 1,000 trips between these two zones, one would predict that 842 would use the automobile, 114 would use the bus, and 43 would walk.

In some cases, such as small urban areas, the mode split step is not used in the modeling process because there are few alternative modes. The auto is the only way of making a trip. In larger urban areas, however, mode split is an important step in the modeling process.

Trip Assignment

The final step in transportation modeling is to assign trips to paths in the network. The most important concept in trip assignment is that travelers will choose a path that minimizes travel time from origin to destination. Trip assignment models, therefore, are based on minimum time algorithms that identify the minimum time paths through networks. Common to all assignment approaches is the existence of link performance functions that relate travel time to factors such as volume and roadway capacity. Figure 3-10 graphically illustrates the concept of a link performance function. In this figure the time associated with travel on a link in the network is related in a nonlinear way with the amount of traffic on that link. As shown, the closer this volume approaches the capacity of the roadway, the greater travel time is associated with traversing this link. In practical terms this relationship means that as a roadway becomes congested, it will take a longer time to travel the link distance, and thus the model will assign fewer vehicles to that link.

Several approaches toward network assignment are commonly used by planners. All of them use the minimum time path concept in producing estimated volumes for each link in the network.

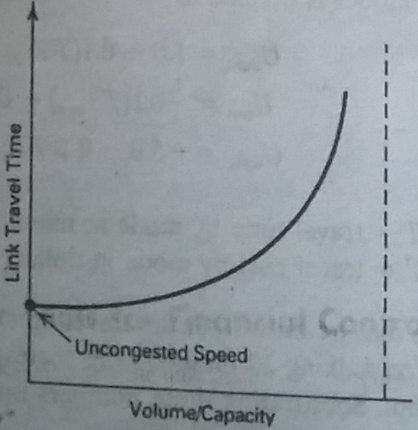


FIGURE 3-10 Graphical representation of link performance.

All-Or-Nothing Assignment This assignment procedure estimates the shortest time path between each zonal pair in the system based on uncongested speeds and assigns all of the volume making these trips to the shortest path. Therefore if there are 1,000 trips going from zone i to zone j and the shortest path consists of a route defined by a set of links, all 1,000 trips would be assigned to each link. Clearly, such an assignment ignores the effect congestion has on an individual's choice of route. In general, all-or-nothing assignments are only used in those situations where uncongested conditions are expected to occur.

Capacity Restraint Assignment Capacity restraint assignment recognizes that the travel time on a link will clearly be related to the amount of traffic using that link as illustrated in Figure 3-10. Therefore, capacity restraint assignment begins with some increment of the total trips making a trip between an origin and destination and assigns this increment to the shortest time path. The travel times for each link are then recalculated using an equation that represents the nonlinear function in Figure 3-10, and another increment of trips is assigned to the shortest time path using the revised time estimates. In this way the shortest time path between an origin and destination could change over several iterations as congestion builds up on specific links, thus making another route the shortest time path. For example, 800 of the 1,000 trips discussed earlier could be assigned to one path because it represented the shortest time path, but 200 of the trips might be assigned to another path because at some point in the assignment process the path followed by the 800 trips was no longer the shortest time path.

Stochastic Equilibrium Assignment Stochastic assignment assumes that several routes between an origin and destination might be perceived by travelers as having equal times or otherwise be equally attractive to the traveler. As a result these routes might be equally used by the travelers. In this case, route choice probabilities are calculated often using a similar concept of the logit model formulation presented above and then used to estimate from a probabilistic perspective the number of trips that will take different routes.

The result of the assignment step is an estimate of the volumes or riders that will be found on each link in the network. These estimated volumes can then be used to determine where deficiencies exist in the system (e.g., by comparing the volumes to existing capacity). The resulting volumes can also be compared to other assignments that are undertaken with different input assumptions to determine the effects of different policies. For example, a transportation model could be used to determine the effect of reducing the number of trips originating at certain locations through the use of parking restraints or carpool incentives. The impact on the transportation system of such policies would be estimated by running the model with reduced trip generation numbers and comparing the resulting link assignments with nonadjusted trip generation numbers.

Although the examples in this section are primarily oriented toward highway planning, the same approach toward modeling is used for transit planning. In this case the network is the transit network and the assignment process is oriented toward which transit route will most likely be used by those who will use transit.

The four-step modeling process described in the previous sections has been the mainstay of transportation planning for the past 50 years. New, computer-based models are being developed that simulate the individual vehicle or traveler in very fine detail. These so-called microsimulation models are based on underlying assumptions or algorithms of how vehicles and individuals behave. So, instead of predicting the aggregate movement of traffic flows, microsimulation models predict the paths and behavior of hundreds of thousands of individual trips. These models are in the early stages of development, but it is likely that over the next decade, microsimulation models will become important tools in analyzing transportation demand.

3-5 PLAN AND PROJECT EVALUATION

The previous section presented the typical approach to modeling transportation networks. The model outputs, in essence, are numbers that show what each alternative is likely to mean in terms of estimated volumes or riders. These estimated volumes can be related to a wide variety of other issues that might be important in identifying more desirable alternatives. For example, a reduction in auto volumes could be related to decreases in air pollutants. Thus, volume estimates are critical elements in the evaluation of transportation plans and projects. However, as was indicated earlier in this chapter, the evaluation process is often much broader than simply estimates of volumes. In most cases, the evaluation of alternatives includes a large number of measures of effectiveness, many of which are not related to traffic volume. The evaluation process therefore necessarily incorporates information from a wide variety of sources.

Table 3-2 shows typical criteria used to assess different impacts of the alternatives being considered. As shown, there are impacts associated with estimated travel volumes, but there are also a large number of impact categories that go beyond transportation impacts. In particular, impact categories associated with land use, the environment, distribution (or equity) of benefits, and financial issues are often important considerations in the public debate surrounding which alternative is more desirable than others.

In recent years, the issue of who benefits from transportation improvements versus who suffers disproportionate burdens has become an important evaluation question. *Environmental justice* is the term used when such a benefits and burdens assessment is applied to low-income and minority households. An environmental justice assessment investigates how transportation plans, programs, and projects provide benefits to all segments of society, and the extent to which the expected impacts and costs are shared proportionately.

In most cases, the method of portraying the evaluation results is in the form of a matrix with the different measures of effectiveness along one axis and the alternatives under consideration along another. As can be seen in Table 3-2, some of the measures of effectiveness can have numerical values associated with the impact (e.g., number of trips, transit boardings, air quality emissions, costs, etc.). However, it is quite common for some measures of effectiveness to be "measured" with subjective assignments of the degree to which the alternative achieves the stated measure. For example, compatibility with land use plans can be measured by subjectively assigning high, medium, or low to this particular impact category. This approach to measuring impacts is very common for those types of issues that are important to the decision makers, but for which there is no quantitative measurement.

Another set of measures that is becoming increasingly important in evaluation is the financial feasibility of the proposed actions. For many years, transportation plans were developed with little consideration for the level and source of funding to implement the recommended actions. Today, transportation plans and programs are to be financially realistic, which means that actions recommended should be accompanied by a strategy for funding their implementation. Such funding might include traditional sources such as government transportation funds, but increasingly is including innovative sources of funding such as tolls, impact fees, and private sector contributions.

A final characteristic of successful plan evaluation is the strategy for public involvement. Opportunities for public input and comment should be provided throughout the plan development process. However, such opportunities are especially important during the evaluation phase. This is the first time in the planning process that sufficiently detailed information is available for the public to understand what is being proposed. Public involvement strategies include a wide variety of techniques. The most common technique is the public hearing, which is required by law for many types of project planning. Other techniques include newspaper supplements, public meetings, special television shows, web pages, voter surveys, brochures and pamphlets, focus groups, and design workshops. The results of this public review and input are incorporated into the overall evaluation process and often presented to decision makers when the preferred alternative is being selected. For controversial plans or projects, the level of public involvement activities can be quite high.

PROBLEMS

3-1 Assume that the following goals have been established for a transportation planning study.

Goal 1: The transportation system should provide mobility for all segments of the population.

Goal 2: The transportation system should minimize impact on the natural environment.

Define at least three objectives for each goal that could be used to achieve the stated purpose. For each objective, define a measure of effectiveness that could be used to measure the degree to which the objective is achieved.

3-2 The regional planning agency has adopted persons per vehicle as a performance measure that can be used to measure the level of success of regional policies. These policies are designed to increase vehicle occupancy so that traffic congestion will be reduced. Given the types of data collection techniques discussed in this chapter, outline a data collection strategy that would provide input into this performance measure.

3-3 Figure 3-7 shows the relationship among the many different factors that result in travel demand. As illustrated, travel demand is a resultant of sociodemographic, land use, and traveler characteristics. For one of the "input" trends shown on this figure, conduct a more detailed analysis of the past and future trends associated with this input. How will this input likely change in the future? And how will this affect the total vehicle miles traveled?

3-4 Given the following data from your local planning agency, use cross classification analysis to determine the number of trips that will occur in the future if the estimated number of future households is as shown.

Household Income	1		2		3+	
	HH	Trips	HH	Trips	HH	Trips
Low	350	1,190	5,640	23,124	4,230	19,458
Medium	675	2,498	6,950	31,275	9,641	47,241
High	540	2,106	2,420	11,616	3,202	17,291

Current Tripmaking

Household Income	Household Size		
	1	2	3+
Low	105	275	430
Medium	220	1,222	2,412
High	90	120	250

Future Zonal Households

3-5 Referring to the sketch in Section 3-4, calculate the interzonal trips due to 450 work trips produced at zone i. There are 750 attractions at zone 1, 400 attractions at zone 2, and 300 attractions at zone 3. The exponent of travel time is 0.6 and the travel times are 9 minutes to zone 1, 5 minutes to zone 2, and 7 minutes to zone 3. Assume all socioeconomic adjustment factors and the value of C are equal to 1.0.

3-6 A calibration study resulted in the following utility equation for different modes in a particular city:

$$U_k = a_k - (0.25)(X_1) - (0.032)(X_2) - (0.015)(X_3) - (0.002)(X_4)$$

where a_k = mode specific constant
X_1 = access plus egress time in minutes
X_2 = waiting time in minutes
X_3 = line-haul time in minutes
X_4 = out-of-pocket cost in cents

For a particular origin-destination pair, the forecasted number of trips is 5,000. For this particular trip, there are two modes available, bus and auto.

a) If the characteristics of these two modes are as follows, how many trips will be taken by bus? by car?

	X_1	X_2	X_3	X_4
Automobile	5	0	20	100
Bus	10	15	40	50

Assume that the mode specific constant is equal to −0.12 for the automobile and −0.22 for bus.

b) Assume that a new mode, rapid transit, is to be introduced into the market between these two zones. The characteristics of this new service are as follows:

$$X_1 = 10 \quad X_2 = 5 \quad X_3 = 30 \quad X_4 = 75$$

Assume from experience in other cities that the mode specific constant for rapid transit is −0.41. What will be the modal shares of the 5,000 trips between these two zones for all three modes?

c) Assume that the city council wants to increase ridership on transit in this new three-mode system. They are considering one of two actions: lower the fare on bus and rapid transit to a flat $0.25 for all trips, or place a surcharge of $2.00 on all cars parking in these zones. Which policy would you recommend to achieve the council's objective?

3-7 Obtain a transportation improvement program (TIP) for a metropolitan area with which you are familiar. What types of projects will be implemented in that region over the next several years? What are the different types of funding sources?

REFERENCES

1. Meyer, M., and E. Miller, *Urban Transportation Planning: A Decision-Oriented Approach*, 2nd ed., McGraw-Hill, New York (2001).

2. Federal Highway Administration, *Highway Performance Monitoring System Field Manual*, U.S. Department of Transportation (1987).

3. Pisarski, A., *Commuting in America II*, ENO Transportation Foundation, Washington, D.C. (1996).

4. Cambridge Systematics, Inc., "A Guidebook for Performance-Based Transportation Planning," *National Cooperative Highway Research Program Report 446*, National Academy Press, Washington, D.C. (2000).