Modal Split

Introduction

The third stage in travel demand modeling is modal split. The trip matrix or O-D matrix obtained from the trip distribution is sliced into number of matrices representing each mode. First the significance and factors affecting mode choice problem will be discussed. Then a brief discussion on the classification of mode choice will be made. Two types of mode choice models will be discussed in detail. The binary mode choice and multinomial mode choice. The chapter ends with some discussion on future topics in mode choice problem.

This model has both advantages and dis advantages for crime analysis. At a theoretical level, it is the most developed of the four stages since there has been extensive research on travel mode choice. For crime analysis, on the other hand, it represents the 'weakest link' in the analysis since there is very little available information on travel mode by offenders. Since researchers cannot interview the general public in order to document crimes committed by respondents or, in most cases, even interview offenders after they have been caught, there is very little information on travel mode by offenders that has been collected.
Consequently, we have to depend on the existing theory of travel mode choice and adapt it intuitively to crime data. The approach is solely theoretical and depends on the validity of the existing theory and on the intuitiveness of guesses. Hopefully, in the future, there will be more information collected t ha t would allow the model to be calibrated against some real data. But, for the time being, we are limited in what can be done.

Mode choice

The choice of transport mode is probably one of the most important classic models in transport planning. This is because of the key role played by public transport in policy making. Public transport modes make use of road space more efficiently than private transport. Also they have more social benefits like if more people begin to use public transport, there will be less congestion on the roads and the accidents will be less. Again in public transport, we can travel with low cost. In addition, the fuel is used more efficiently. Main characteristics of public transport is that they will have some particular schedule, frequency etc.

On the other hand, private transport is highly flexible. It provides more comfortable and convenient travel. It has better accessibility also. The issue of mode choice, therefore, is probably the single most important element in transport planning and policy making. It affects the general efficiency with which we can travel in urban areas. It is important then to develop and use models which are sensitive to those travel attributes that influence individual choices of mode.

Theoretical Background

The theoretical background behind the mode split module is presented first. Next, the specific procedures are discussed with the model being illustrated with data from Baltimore County.

Utility of Travel and Mode Choice

The key aim of mode choice analysis is to distinguish the travel mode that travelers (or, in the case of crime, offenders) use in traveling between an origin location and a destination location. In the travel demand model, the choice is for travel between a particular origin zone and a particular destination zone. Thus, the trips that ar e distributed from each origin zone to each destination zone in the trip distribution module ar e further split into distinct travel modes. With few exception s, the assumption behind the mode split decision is for a two-way trip. That is, if an offender decides on driving to a particular crime location, we normally assume that this person will also drive back to the origin location. Similarly, if the offender takes a bus to a crime location, then that person will also take the bus back to the origin location. There are, of course, exceptions. A ca r thief ma y take a bus t o a crime location, then steal a car and drive back. But, in general, without information to the contrary, it is assumed that the travel mode is for a round trip journey.

Underlying the choice of a travel mode is assumed to be a utility function. This is a function that describes the benefits and costs of travel by that mode (Ortuzar and Willumsen, 2001). This can be writ t en with a conceptual equation:

$$\text{Utility} = F(\text{benefits, costs})$$

where ‘f’ is some function of the benefits and the costs. The benefits have to do with the advantages in traveling to a particular destination from a particular origin while the costs have to do with the real and perceived costs of using a particular mode. Since the benefits of traveling a particular destination from a particular origin are probably equal, the differences in utility between travel modes essentially represent differences in costs. Thu s, equation below breaks down to:

$$\text{Utility cost} = F(\text{costs})$$

If different travel modes (e.g., driving, biking, and walking) ar e each represented by a separate utility cost function, then they can be compared:

$$\text{Utility cost}_1 = F_1(\text{cost}_1 + \text{cost}_2 + \text{cost}_3 + \ldots\ldots + \text{cost}_k)$$

$$\text{Utility cost}_2 = F_2(\text{cost}_1 + \text{cost}_2 + \text{cost}_3 + \ldots\ldots + \text{cost}_k)$$

$$\text{Utility cost}_3 = F_3(\text{cost}_1 + \text{cost}_2 + \text{cost}_3 + \ldots\ldots + \text{cost}_k)$$

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$$\text{Utility cost}_L = F_L(\text{cost}_1 + \text{cost}_2 + \text{cost}_3 + \ldots\ldots + \text{cost}_k)$$

where Utility cost $_1$ through Utility cost$_L$ represents L distinct travel modes, cost 1 through cost k represent k cost components an d ar e variables, an d F1 through FL represent L different utility function s (one for each mode).

There are several observations that can be made about this representation. First, each of the cost components can be applied to all modes. However, the cost components are variables in that the values may or may not be the same. For example, if cost $_1$ is the operating cost of traveling from an origin t o a destination, the cost for a driver is, of course, a lot higher than for a bus passenger since the latter person shares that cost with other passengers. Similarly, if cost $_2$ is the travel time from a particular origin zone to a particular destination zone, then travel by private automobile may be a lot quicker than by public bus. As mentioned, time differences can be converted in to costs by applying some type of hourly wage/price to the time. To take one more example, for driving mode, there could be a cost in parking (e.g., in a central business district); for transit use, on the other hand, this cost component is zero. In other words, each of the travel modes has a different cost structure. The same costs can be enumerated, but some of them will not apply (i.e., they have a value of 0).

Second, the costs can be perceived costs a s well a s rea l costs. For example, a number of studies have demonstrated that private automobile is seen as far more convenient to most people than a bus or train (e.g., see Schnell, Smith, Dimsdale, and Thrasher, 1973; Roemer and Sinha , 1974; WASH COG, 1974; Carnegie-Mellon University, 1975; Johnson, 1978; Levine and Wachs, 1986b). 'Convenience' is defined in terms of ease of access and effort involved in travel (e.g., how long it takes to walk to a bus stop from an origin location, the number of transfers that have to made to reach a final destination, and the time it takes to walk from the last bus stop to the final destination). While it is sometimes difficult to separate the effects of convenience from travel itself, it is clear that most people perceive this as dimension in travel choice. In t urn, convenience can be converted in to a monetary value in order to allow it to be calculated in a cost equation, for example how much people are willing to pay in time savings to yield an equivalent amount of convenience (e.g., asking how many more minutes in travel time by bus a n individual would be willing to absorb in order to give up having to drive).

Third, these costs can be considered at an aggregate as well as individual level. At an aggregate level, they represent average or median costs (e.g., the average time it takes to travel between zone A and zone B by private automobile, bus, train, walk in g, or biking; the average dollar value assigned by a sample of survey respondents to the convenience they associate in traveling by car as opposed to bus).

On the other hand, at an individual level, the costs are specific to the individual. For example, travel time differences between car and bus can be converted into an hourly wage using the individual's income; someone making $100,000 a year is going to price that time savings differently than someone making only $25,000 a year. Fourth, a more controversial point, the specific mathematical function that ties the costs together into a particular utility function may also differ. Typically, most travel demand models have assumed t ha t a similar mathematical function is used for all travel modes; this is the negative exponential function described below (Domencich and McFadden , 1975; Ortuzar an d Willumsen, 2001). However, there is no rea son why different function s cannot be used. Thus, the equation s above identify different function s for the modes, F1 through F L. One can thin k of this in terms of weights. Each of the different mathematical function weigh t the cost components differently.

It is an empirical question whether individuals apply different functions to evaluating the different modes. For example, most people would not drive just to travel one block (unless it was pouring r a in or unless a heavy object had to be delivered or picked up). Even though it is convenient to get into a vehicle and drive the one block, most people see the effort involved (and, most likely, the fuel and oil costs) as not being worth it. In other words, it appears that a different utility function is being applied to walking as opposed to driving (i.e., walk for distances u p t o a certain distance; drive thereafter). A strict utility theorist might dis agree with this interpretation saying that the per minute cost of walking the one block and back was less than monetized per minute cost of operating the vehicle (which may include opening a garage door, getting into the vehicle, starting the vehicle, driving out of the parking spot, closing the garage door, and then driving the one block). In other words, it could be argued that the difference in behaviors has to do with the values of the different cost components, rather than the way they ar e weighted together (the mathematical function). In retrospect, one can explain any difference, however, that crime trips appear to show different likelihoods by travel mode and that treating each of these functions as distinct allows more flexibility in the framework.

Factors influencing the choice of mode

The factors may be listed under three groups:

- Characteristics of the trip maker : The following features are found to be important:
    1. car availability and/or ownership;
    2. possession of a driving license;
    3. household structure (young couple, couple with children, retired people etc.);
    4. income;
    5. decisions made elsewhere, for example the need to use a car at work, take children to school, etc.;
    6. residential density.
- Characteristics of the journey: Mode choice is strongly influenced by:
    1. The trip purpose; for example, the journey to work is normally easier to undertake by public transport than other journeys because of its regularity and the adjustment possible in the long run;

2. Time of the day when the journey is undertaken.
3. Late trips are more difficult to accommodate by public transport.

- Characteristics of the transport facility: There are two types of factors.One is quantitative and the other is qualitative. Quantitative factors are:
  1. relative travel time: in-vehicle, waiting and walking times by each mode;
  2. relative monetary costs (fares, fuel and direct costs);
  3. availability and cost of parking

  Qualitative factors which are less easy to measure are:

  4. comfort and convenience
  5. reliability and regularity
  6. protection, security

A good mode choice should include the most important of these factors.

Types of modal split models

Trip-end modal split models

Traditionally, the objective of transportation planning was to forecast the growth in demand for car trips so that investment could be planned to meet the demand. When personal characteristics were thought to be the most important determinants of mode choice, attempts were made to apply modal-split models immediately after trip generation. Such a model is called trip-end modal split model. In this way different characteristics of the person could be preserved and used to estimate modal split. The modal split models of this time related the choice of mode only to features like income, residential density and car ownership.

The advantage is that these models could be very accurate in the short run, if public transport is available and there is little congestion. Limitation is that they are insensitive to policy decisions example: Improving public transport, restricting parking etc. would have no effect on modal split according to these trip-end models.

Trip-interchange modal split models

This is the post-distribution model; that is modal split is applied after the distribution stage. This has the advantage that it is possible to include the characteristics of the journey and that of the alternative modes available to undertake them. It is also possible to include policy decisions. This is beneficial for long term modeling.

Aggregate and disaggregate models

Mode choice could be aggregate if they are based on zonal and inter-zonal information. They can be called disaggregate if they are based on household or individual data.

Binary logit model

Binary logit model is the simplest form of mode choice, where the travel choice between two modes is made. The traveler will associate some value for the utility of each mode. If the utility of one mode is higher than the other, then that mode is chosen. But in transportation, we have disutility also. The disutility here is the travel cost. This can be represented as:

$$c_{ij} = a_1 t_{ij}^v + a_2 t_{ij}^w + a_3 t_{ij}^t + a_4 t_{nij} + a_5 F_{ij} + a_6 \phi_j + \delta \qquad (1)$$

where t_{ij}^v is the in-vehicle travel time between i and j, t_{ij}^w is the walking time to and from stops, t_{ij}^t is the waiting time at stops, F_{ij} is the fare charged to travel between i and j, ϕ_j is the parking cost, and δ is a parameter representing comfort and convenience. If the travel cost is low, then that mode has more probability of being chosen. Let there be two modes (m=1,2) then the proportion of trips by mode 1 from zone i to zone j is(P_{ij}^1) Let c_{ij}^1 be the cost of traveling from zone i to zone j using the mode 1, and $c_{ij}2$ be the cost of traveling from zone i to zone j by mode 2,there are three cases:

1. if $c_{ij}^2 - c_{ij}^1$ is positive, then mode 1 is chosen.
2. if $c_{ij}^2 - c_{ij}^1$ is negative, then mode 2 is chosen.
3. if $c_{ij}^2 - c_{ij}^1 = 0$, then both modes have equal probability.

This relationship is normally expressed by a logit curve as shown in figure 1 Therefore the proportion of trips by mode 1 is given by:

$$P_{ij}^1 = T_{ij}^1 / T_{ij} = \frac{e^{-\beta c_{ij}^1}}{e^{-\beta c_{ij}^1} + e^{-\beta c_{ij}^2}} \quad (2)$$

This functional form is called logit, where c_{ij} is called the generalized cost and β is the parameter for calibration. The graph in figure 1 shows the proportion of trips by mode 1 (T_{ij}^1/T_{ij}) against cost difference.

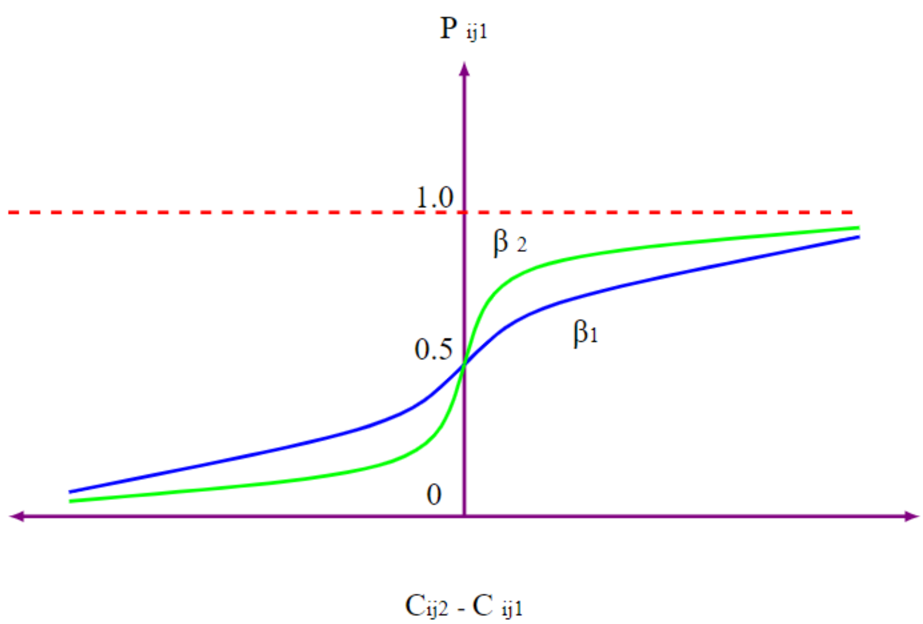

Figure 1: Logit Function

Discrete Choice Analysis

No matter how the utility function s are defined, they have to be combined in such a way as to allow a discrete choice. That is, a n offender in traveling from zone A to zone B makes a discrete choice on travel mode. There may be a probability for travel by each mode, for example 60% by ca r and 40% by bus. But, for an individual, the choice is car or bus, not a probability. The probabilities are obtained by a sample of individuals, for example of 10 individuals 6 went by car and 4 went by bus. But, still, at the individual level, there is a distinct choice that was made.

Multinomial Logit Function

A common mathematical framework that used is for mode choice modeling at an aggregate level is the multinomial logit function (Domincich and McFadden, 1975; Stopher and Meyburg, 1975; Oppenheim, 1980; Ortuzar and Willumsen, 2001):

$$P_{ijL} = \frac{e^{(-\beta C_{ijL})}}{\sum_{L=1}^{P} [e^{(-\beta C_{ijL})}]}$$

where P_{ijL} is the probability of using a mode for any particular trip pair (particular origin and particular destination) L is the travel mode, C_{ij} is the cost of traveling from origin zone i to destination zone j, e is the base of the natural logarithm, an d $ is a coefficient. Several observations can be made about this function. First, each travel mode, L, has its own costs and benefits, and can be evaluated by itself. That is, there is a distinct utility function for each mode. This is the numerator of the equation, e (-$C ijL). However, the choice of any one mode is dependent on its utility value relative to other modes (the denominator of the equation). The more choices t ha t ar e available, obviously, the less likely an individual will use that mode. But the value associated with the mode (the utility) does not change. As mentioned above, we generally assume that the benefit of traveling between any two zones is identical for all modes and, hence, any differences a r e du e t o costs.

Second, the mathematical form is the negative exponential. The exponential function is a growth function in which growth occurs at a constant rate (either positive - growth, or negative - decline). The use of the negative exponential assumes that the costs are related to the likelihood as a function that declines at a constant rate. It is actually a ‘disincentive’ or ‘dis \count’ function rather than a utility function, per se. That is, as the costs increase, the probability of using that mode decreases, all other things being equation. Still, for historical reasons, it is still called a utility function.

$$\text{Utility cost}_i = e^{(-\beta C_{ijL})}$$

$$\text{Ln}(\text{Utility cost}_L) = C_{ijL} = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_k X_k$$

Where: C_{ijL} is a cumulative cost made up of components X1, X2 through Xk , " is a constant, an d $1 through $k ar e coefficients for the individual cost components. Thu s, we see that the utility function is a loglinear model. Thus, the utility function is Poisson distributed, declining at a constant rate with increasing cumulative costs. Domincich and McFadden (1975) suggest that the error terms a r e not Poisson distribut ed, but skewed in a Weibul function, there ar e a variety of different models that incorporate skewed error terms (negative binomial, a simple linear correction of dispersion) so that the Weibul is but one of a number of possible descriptors. Nevertheless, the mean utility is a Poisson-type function.

We can, therefore, write a *generalized relative utility function* as:

$$P_{ijL} = \frac{F_L(-\beta C_{ijL})}{\sum_{L=1}^{P}[F_L(-\beta C_{ijL})]} = \frac{I_{ijL}}{\sum_{L=1}^{P}[I_{ijL}]}$$

Where: the terms are the same as in previous except the function, F_L, is some function that is specific to the travel mode, L. The numerator is defined as the impedance of mode L in traveling between two zones i and j, while the denominator is the sum of all impedances.

Notice that the ratio of the cost function for one mode relative to the total costs is also the ratio of the impedance for mode L relative the tot a l impedance. The tot a l impedance was defined previously as the disincentive to travel a s a function of separation (distance, travel time, cost). We see that the share of a particular mode, therefor e, is the proportion of the total impedance of that mode. This share will vary, of course, with the degree of separation. For any given separation, there will usually be a different share for each mode. For example, at low separation between zones (e.g., zones that are next to each other), walking and biking ar e much more attractive than taking a bus or a train and, perhaps even driving. At greater separation (e.g., zones t ha t ar e 5 miles apart), walking and biking are a l most irrelevant choices and the likelihood of driving or u sing public transit is much greater. In other words, the share that any one mode occupies is not constant, but varies with the impedance function.

Why then can't we estimate the mode split directly at the trip distribution stage? If the trip distribution function is:

$$T_{ij} = \alpha P_i^{\lambda} \beta A_j^{\tau} I_{ij}$$

and if these trips, in t urn, are split into distinct modes u,

$$T_{ijL} = \alpha P_i^{\lambda} \beta A_j^{\tau} I_{ijl}$$

where T_{ijL} is the number of trips between two zones, i and j, by mode L, P i is the production capacity of zone i, Aj is the attraction of zone j, " an d $ are constants that are applied to the productions and attractions respectively, 8 an d J ar e 'finetuning' exponents of the productions and attractions respectively, an d $_{IijL}$, is the impedance of using mode L to travel between the two zones? The answer is, yes, it could be calculated directly. If I_{ijL} was a perfectly defined mode impedance function (with no error), then the mode share could be calculated directly at the distribution stage instead of separating the calculations into two distinct stages. The problem, however, is that the impedance functions are never perfect (far from it, in fact) and t ha t re-scaling is required both to get the origin s and destinations balanced in the trip distribution stage and to ensure that the probabilities in equation above add to 1.0.

Measuring Travel Costs

The next question is what types of travel costs are there that define impedance? As mentioned above, there ar e real a s well as perceived costs that affect a travel mode decision. Some of these can be measured easily, while others are very difficult requiring detailed surveys of individuals. Among these costs are:

- Distance or travel time. As mentioned throughout this discussion, distance is only a rough indicator of cost since it is in variant with respect to time. Actual travel time is a much better indicator because it varies throughout the day and can be easily converted in to a travel time value, for example by multiplying by a unit wage.

- Other rea l costs, such as the operating costs of a private vehicle (fuel, oil, maintenance), parking, and insurance. Some of these can be subsumed under travel time value by working out an hourly price for travel.
- Perceived costs, such as convenience, fear of being caught by an offender, ease of escape from a crime scene, difficulties in moving stolen goods, and fear of retaliation by other offenders or gangs).

Some of these costs can be measured and some cannot. For example, the value of travel time can be inferred from the median household income of a zone for aggregate analysis or from the actual household income for individual-level analysis. Parking can be averaged by zone. Insurance costs can be estimated from zone averages if the da t a can be obtained. Many perceived costs also can be measured. Convenience, for example, could be measured from a general survey. The fear of being ca ugh t can be inferred from the amount of surveillance in a zone (e.g., the number of police personnel, security guards, security cameras). Even though it may be a difficult enumeration process, it is still possible to mea sure these costs and come up with some a verage estimate. Other perceived costs, on the other hand, may not be easily measured. For example, the fear an offender belonging to one gang has about retaliation from another gang is not easily measured. Similarly, the costs in moving stolen goods by a thief is not easily measured; one would need to know the location of the distributors of these goods. In practice, travel modelers make simple assumption s about costs because of the difficult y in measuring many of them. For example, travel time is taken as a proxy for all the operating costs. Parking costs can be incorporated through simple assumption s about the distribution a cross zones (e.g., zones within the central business distract - CBD, ar e given an average high parking costs; zones that are central, but not in the CBD, are assigned moderate parking costs; zones t ha t ar e suburban ar e assigned low parking costs). It would be just too time consuming to document each and every cost affecting travel behavior, particularly if we are developing a model of offender travel.

Aggregate and Individual Utility Functions

One of the big debates in travel modeling is whether to use aggregate or individual utility function s to calculate mode share. The aggregate approach measures common costs for each zone, assuming an average value. The disaggregate approach (sometimes called 'second generation' models) measures unique costs for individuals, then sums upward to yield values for each zone pair. Even though the end result is an allocation of costs to each zone pair, the articulation of unique costs at the individual level ca n, in theory, allow a more realistic assessment of the utility function that is applied to a region.

The aggregate approach will measure costs by averages. Thus, a typical equation for driving mode might be:

$$\text{Total cost}_{ij} = \alpha + \beta_1 T_{ij} + \beta_2 P_j$$

Where: T_{ij} is the average travel time between two zones, i and j, an d P_{ij} is the average parking cost for parking in zone j. Notice that there a r e a limited number of variables in an aggregate model (in this case, only two) and t ha t the assigned average is for an entire zone. Notice also that the parking cost is applied only to the destination zone. It is assumed that any traveler will pay t ha t fee in that zone irrespective of which origin zone he/she came from.

A disaggregate approach can allow more cost components, if they are measured. Thus, a typical equation for driving mode might be:

$$\text{Total cost}_{ijk} = \alpha + \beta_1 T_{ijk} + \beta_2 P_j + \beta_3 C_{ijk} + \beta_4 CM_{ijk} + \beta_5 S_{ijk}$$

where T_{ijk} is the travel time for individual k between two zones, i and j, P_{ij} is the average parking cost for parking in zone j, C_{ijk} is the convenience of traveling to zone j from zone i for individual k , C_{Mijk} is the comfort and privacy experienced by individual k in traveling from zone i to zone j, and S_{ijk} is the perceived safety experienced by individual k in traveling from zone i to zone j. Notice that there ar e more cost variables in the equation and t ha t the model is targeted specifically to the individual, k . Two individuals who live next door to each other and who travel to the same destination may evaluate these components differently. If these individuals have substantially different incomes, then the value of the travel time will differ. If one values privacy enormously while the other doesn't, then the cost of driving for the first is less than for the second. Similarly, convenience is affected by both travel time and the ease of getting in and out of vehicle. Finally, the perception of safety ma y differ for these two hypothetical individuals. There ar e many studies t ha t have documented the significant role played by safety in affecting, particularly, transit trips (Levine and Wachs, 1986b).

In other words, the aggregate approach applies a very elementary type of utility function whereas the disaggregate approach allows much more complexity and individual variability. Of course, one has to be able to measure the individual cost components, a difficult task under most circumstances. There is also a question about which approach is more accurate for correctly forecasting actual mode splits. Historically, most Metropolitan Planning Organizations have used the aggrega t e method because it's easier. However, more recent research (Domin cich and McFadden, 1975; Ben-Akiva and Lerman, 1985; McFadden, 2002) has suggested that the disaggregate modeling may be more accurate. At the very minimum, the disaggregate is more amen able to policy interpretations because it is more behavioral. If one could interview travelers with a survey, then it is possible to explore the variety of cost factors that affect a decision on both destination and mode split, and a more realistic (if not unique) utility function derived. Bu t, as mentioned above, with crime trips, this is very difficult, if not impossible, to do. Consequently, for the time being, we're stuck with an aggregate approach towards modeling the utility of travel by offenders.

Relative Accessibility

For this version of Crime Stat, an approximation to a utility function was created. The approach is to estimate a relative accessibility function and then apply that function to the predicted trip distribution. The relative accessibility function is a mathematical approximation t o a utility function, rather than a measured utility function by itself. Because the cost components cannot be measured, at least for offenders, we use an inductive approach. Reasonable assumptions are made and a mathematical function is found that fits these assumptions. It is a plausible model, not an analytical one. The plausibility comes by making reasonable assumptions about actual travel behavior. One can assume that walking trips will occur for short trips, say under two miles. Bicycle trips, on the other hand, could occur over longer distances, but will still be relatively short (also, there is always the risk of traffic on the safety of bicycle trips). Transit trips (bus and train) will be used for moderately long distances but require an actual transit network. Finally, driving trips are the most flexible because they can occur over any size distance and road network. They are less likely to be used for very short trips, on the other hand, due to rea sons discussed above.

Hierarchical Approach to Estimating Mode Accessibility

Using this approach, specific steps can be defined to produce a plausible accessibility model. To help in establishing a model, an Excel spread sheet has been developed for making these calculations (Estimate m ode split impedance values.xls). It can also be downloaded from the CrimeStat download page. The spreadsheet has been defined with respect to distance, but it can be adapted for any type of impedance (travel time or cost). A spreadsheet has been used because it is more flexible than incorporating it as a routine in CrimeStat to estimate the parameters. There is not a single solution to the parameters estimates, and the different choices can be seen more easily in a spreadsheet.

Define target proportions

First, define the modes. In the CrimeStat mode split routine, up to five different modes ar e allowed. These have default names of “Walk”, “Bike”, “Drive”, “Bu s”, and “Train”. The user is not required to use these names nor all five modes. Clearly, if there is not a train system in the study area, then the “Train” mode does not apply. Travel modelers use variations on these, such as “drive alone,” carpool”, “automobile”, “motor cycle”, and so forth.

Second, define the target proportions. These are the expected proportions of travel for each mode. Where would such proportions come from? There have been many studies of driving and transit behavior, but relatively few studies of bicycle and pedestrian use (Turner, Shunk, and Hottenstein, 1998; Schwartz et a l, 1999; Porter, Suhrbier and Schwart z, 1999). There ar e not simple tables that one can look up default values. To solve this problem, examples were sough t from different size metropolitan area s. Estimates of travel mode share for all trip purposes (work and non-work) were obtained from1) Ottawa (Ottawa , 1997); 2) Portland (Portland, 1999); and Houston4 . Table below shows the estimated shares. The Houston da t a does not include walking and biking shares, and transit trips ar e not distinguished by mode in the Port land an d Ottawa data.

Estimated Mode Share for Three Metropolitan Areas
All Trip Purposes

		Ottawa	Portland	Houston
Population:		725 thousand (1995)	2.0 million (2001)	4.6 million (2000)
Percent of trips by:		(1995)	(1994)	(2025 forecast)
	Driving	73.5%	88.6%	98.3%
	Transit	15.2%	3.0	1.7% (bus 1.1%; rail 0.6%)
	Walking	9.6%	4.6%	-
	Bicycle	1.7%	1.0%	-
	Other	-	2.8%	-

Example:

The total number of trips from zone i to zone j is 4200. Currently all trips are made by car. Government has two alternatives- to introduce a train or a bus. The travel characteristics and respective coefficients are given in table below. Decide the best alternative in terms of trips carried.

	t_{ij}^{v}	t_{ij}^{walk}	t_{ij}^{t}	F_{ij}	φ_{ij}
coefficient	0.05	0.04	0.07	0.2	0.2
car	25	–	–	22	6
bus	35	8	6	8	–
train	17	14	5	6	–

Solution

- First, use binary logit model to find the trips when there is only car and bus. Then, again use binary logit model to find the trips when there is only car and train. Finally compare both and see which alternative carry maximum trips.

- Cost of travel by car=c_{car} = 0.05 × 25 + 0.2 × 22 + 0.2 × 6 = 6.85
- Cost of travel by bus=c_{bus} = 0.05 × 35 + 0.04 × 8 + 0.07 × 6 + 0.2 × 8 = 4.09
- Cost of travel by train=c_{train} = 0.05 × 17 + 0.04 × 14 + 0.07 × 5 + 0.2 × 6 = 2.96
- Case 1: Considering introduction of bus, Probability of choosing car, $p_{ij}^{car} = \frac{e^{-6.85}}{e^{-6.85}+e^{-4.09}} = 0.059$
- Probability of choosing bus, $p_{ij}^{bus} = \frac{e^{-4.09}}{e^{-6.85}+e^{-4.09}} = 0.9403$
- Case 2: Considering introduction of train, Probability of choosing car $p_{ij}^{car} = \frac{e^{-6.85}}{e^{-6.85}+e^{-2.96}} = 0.02003$
- Probability of choosing train $p_{ij}^{train} = \frac{e^{-2.96}}{e^{-6.85}+e^{-2.96}} = 0.979$
- Trips carried by each mode

  Case 1: T_{ij}^{car} = 4200×0.0596 = 250.32 T_{ij}^{bus} = 4200×0.9403 = 3949.546

  Case 2: T_{ij}^{car} = 4200×0.02 = 84.00 T_{ij}^{train} = 4200×0.979 = 4115.8

  Hence train will attract more trips, if it is introduced.

Example:

Let the number of trips from zone i to zone j is 5000, and two modes are available which has the characteristics given in Table below. Compute the trips made by mode bus, and the fare that is collected from the mode bus. If the fare of the bus is reduced to 6, then find the fare collected.

	$\underline{t_{ij}^{u}}$	$\underline{t_{ij}^{w}}$	t_{ij}^{t}	f_{ij}	ϕ_j
car	20	-	18	4	
bus	30	5	3	9	
a_i	0.03	0.04	0.06	0.1	0.1

	$\underline{t_{ij}^u}$	$\underline{t_{ij}^w}$	t_{ij}^t	f_{ij}	ϕ_j	c_{ij}	p_{ij}	T_{ij}
ar	20	-	18	4		2.08	.52	2600
bus	30	5	3	9		2.18	.475	2400
a_i	.03	.04	.06	.1	.1			

The base case is given below.

Cost of travel by car (Equation) =

$$c_{car} = 0.03 \times 20 + 18 \times 0.06 + 4 \times 0.1$$

= 2.08

Cost of travel by bus (Equation) =

$$c_{bus} = 0.03 \times 30 + 0.04 \times 5 + 0.06 \times 3 + 0.1 \times 9$$

= 2.18

Probability of choosing mode car (Equation) =

$$p_{ij}^{car} = \frac{e^{-2.08}}{e^{-2.08} + e^{-2.18}}$$

= 0.52

Probability of choosing mode bus (Equation) =

$$p_{ij}^{bus} = \frac{e^{-2.18}}{e^{-2.08} + e^{-2.18}}$$

= 0.475

Proportion of trips by car =

T_{ij}^{car} = 5000 * 0.52 = 2600

Proportion of trips by bus =

T_{ij}^{bus} = 5000 * 0.475 = 2400

Fare collected from bus =

$$T_{ij}^{bus} \times F_{ij}$$

= 2400*9 = 21600

When the fare of bus gets reduced to 6,

Cost function for bus=

$$c_{bus} = 0.03 \times 30 + 0.04 \times 5 + 0.06 \times 3 + 0.1 \times 6$$

= 1.88

Probability of choosing mode bus (Equation) =

$$p_{ij}^{bus} = \frac{e^{-1.88}}{e^{-2.08} + e^{-1.88}}$$

= 0.55

Proportion of trips by bus =

$$T_{ij}^{bus}$$

= 5000*0.55 = 2750

Fare collected from the bus

$$T_{ij}^{bus} \times F_{ij}$$

= 2750*6 = 16500

The results are tabulated in table.