Transportation Economics and Decision Making
Travel Behavior

- Many practical transportation policy issues are concerned with choice of mode
- Example: the gain or loss of transit revenue caused by the fare increase depends on how travellers mode choice are affected by the increase.
- If few current transit riders switch to other modes, revenue will increase less than proportionally to the fare increase
Travel Behavior (2)

- The effects of changes in transit routes and schedules on ridership, revenues and traffic congestion all depend on how the changes affect individual traveller’s mode choice.
- In most situations planners must choose among a variety of fare schedules and service designs.
- An understanding of separate and combine effects of these decisions on travel mode choice is essential to selection of best plan to meet specific transportation objectives.
Two well known and frequently used prediction methods are
- Method of elasticity
- Method of aggregate mode choice modeling

Both of these methods have serious defects that greatly restrict their practical usefulness.
For example, the method of elasticities can not predict accurately the effects of making several changes in the transit service simultaneously.
- (increasing both fare and schedule; and adding a new route)

Aggregate mode split models can be exceedingly costly and cumbersome to develop.
- Moreover, they are subject to serious biases and prediction errors owing to their reliance on aggregate data rather than records of individual trips
The range of policy questions that can be treated with aggregate models is quite limited.

- For example, it is not quite possible to conduct multi-modal analysis with these models.
- Several different modes such as bus transit, rail transit, carpool, and single-occupant vehicles

In today’s class our concentration will be on the third choice of models—referred as disaggregate models.
Disaggregate models achieve higher degree of policy sensitivity than either elasticity and aggregate mode choice models.

Disaggregate models can represent a wider range of policy variables than can either elasticity or aggregate models and they can treat multimodal problems without difficulty.

Moreover, disaggregate models avoid biases inherent in aggregate models, and they are much more efficient in terms of data and computational requirements.
A number of agencies these days use disaggregate models for modeling and policy analysis.

This makes important for transportation professionals to understand the principles underlying the development and use of disaggregate models, since failure to understand these principles can lead to

- erroneous models and
- serious prediction errors
Role of Choice in Travel Demand

- Travel is a result of choices made by individuals or collective decision making units such as households.
- An individual preparing to travel to work must choose:
  - Whether to drive alone, carpool, or take transit
  - When to leave home
  - Which route to choose etc.
- The objective of travel demand is to model and predict the outcomes of these choices by individuals.
To model outcomes of individuals...

- Identify the decisions that must be made and the options, or alternative outcomes, that are available to the individual.
- Identify variables likely to affect the choices of interest
- Develop mathematical model that describes dependence on the relevant variables
Preferences

- An individual’s choice represents an expression of his/her preference among the available options at the time and under the conditions in which the choice is made.
- It is important to understand that the preferences relevant to choices are the ones that pertain to the chooser’s existing circumstances not to an ideal set of circumstances.
Example: a commuter boarding a bus may think himself that he would really rather take a taxi if he could afford it.

He is taking a bus only because he does not have much money.

Such thoughts do not imply that the commuter prefers taxi to bus under the existing circumstances.

He would prefer taxi to bus under ideal circumstances (having a lot of money), but under the existing circumstances he prefers bus.
Preference among a set of options depend on the 
▪ Attributes of the options 
▪ And of the individual involved

Attributes of the travel mode that are relevant
▪ Travel time 
▪ Travel cost 
▪ Comfort 
▪ Reliability

Attributes of the individual include
▪ Income 
▪ Auto ownership
Utility Theory

- According to utility maximization principle, there is a mathematical function $U$, called utility function, whose numerical value depends on the
  - Attributes of the available options and individual
- The utility function has the property that its value for one option exceeds its value for another if and only if the individual prefers the first option to the second.
- Thus ranking of available options according to individual’s preference or ranking per utility function’s value are the same.
Let $C$ denote the set of options available to an individual.

E.g. drive alone, carpool, and bus.

$C$ is called as the choice set.

Let $X_i$ denote the attribute for the individual in question.

Let $S$ denote attribute of the individual that are relevant to preferences among options in $C$ (income, car ownership etc.).
Utility Function: Mathematical Representation (2)

- U has a property that for any two options in i and j in C
  \[ U(X_i, S) > U(X_j, C) \]
- Implies that the individual prefers alternative i to alternative j and will choose i if given choice between i and j.
Role of Choice in Travel

- Travel is the result of choices made by individuals or collective decision making by households.
- Example: an individual preparing to travel to work must choose whether
  - Drive alone
  - Take bus, transit
  - Carpool
Role of Choice in Travel

- The utility function is defined to have following properties.
  - The function $U$ is the same for all options. Differences among options are accounted for by differences in the numerical values of attribute $X$ not by changing the function $U$.
- The utility of an alternative depends only on attribute of that alternative and of the individual.
A utility model for mode choice

- Suppose that an individual can travel to work by
  - Drive alone
  - Carpooling
  - Bus
- Assume the relevant attributes are
  - Travel time
  - Cost
- Assume the relevant attribute of the individual is income
Example

- Let
  - $T$ denote door to door travel time in hours
  - $C$ denote travel cost in dollars
  - $Y$ denote annual income in thousands of dollars per year
- Let the utility function be $U(T, C, Y) = -T - 5C/Y$
- Suppose the values of travel time and cost for the available modes are

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time (T), Hours</th>
<th>Cost (C), $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Alone</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Carpool</td>
<td>0.75</td>
<td>1</td>
</tr>
<tr>
<td>Bus</td>
<td>1</td>
<td>0.75</td>
</tr>
</tbody>
</table>
### Example (2)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Y=40</th>
<th>Y=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Alone</td>
<td>-0.75*</td>
<td>-1.50</td>
</tr>
<tr>
<td>Carpool</td>
<td>-0.88</td>
<td>-1.25*</td>
</tr>
<tr>
<td>Bus</td>
<td>-1.09</td>
<td>-1.38</td>
</tr>
</tbody>
</table>

* Alternative with highest utility

Individual with income 40,000 chooses Drive alone as the alternative
Individual with income 10,000 chooses Carpool as the alternative
Now, suppose, quality of transit service is improved so that travel time for bus is 0.75 hours

The revised utilities are

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time (T), Hours</th>
<th>Cost ©, $</th>
<th>Y=40</th>
<th>Y=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Alone</td>
<td>0.5</td>
<td>2</td>
<td>-0.75*</td>
<td>-1.50</td>
</tr>
<tr>
<td>Carpool</td>
<td>0.75</td>
<td>1</td>
<td>-0.88</td>
<td>-1.25</td>
</tr>
<tr>
<td>Bus</td>
<td>0.75</td>
<td>0.75</td>
<td>-0.84</td>
<td>-1.13*</td>
</tr>
</tbody>
</table>

The higher income individual chooses drive alone
The lower income individual chooses bus
Although the example is very simple it illustrates some important characteristics of choice models based on the utility maximization principle.

- First, it shows how a utility function can be used to describe the dependence of preferences and choices on attributes of the options and individuals.
- (the same utility function describes the performance of more than one individual)
- It is not necessary to have separate utility function for each individual if differences among individuals can be accounted for by attribute variable such as income.
Second the example illustrates the use of utility theory to predict changes in preferences and choices that occur when an attribute of one of the option changes.

Finally, the example illustrates advantages of utility models over traditional choice models:

- It can treat three or more (any) number of competitive modes (traditional models can only take two modes at a time).
- Since the utility model operates at the individual level, it guarantees that the percentage of individuals choosing a mode are always in the range of 0-100%.
- Many traditional models do not have this property.
Non-uniqueness of utility functions

In the first example problem, we considered the following utility function

\[ U(T, C, Y) = -T - \frac{5C}{Y} \]

Let us consider three other forms

\[ V(T, C, Y) = -TY - 5C \]
\[ W(T, C, Y) = 10 - 20T - 100C/Y \]
\[ X(T, C, Y) = -T^2 - 10CT/Y - 25C^2/Y^2 \]
# Different Formulations Leading to Same Result

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time (T), Hours</th>
<th>Cost ©, $</th>
<th>Y=40</th>
<th>Y=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Alone</td>
<td>0.5</td>
<td>2</td>
<td>-30.00*</td>
<td>-15.00</td>
</tr>
<tr>
<td>Carpool</td>
<td>0.75</td>
<td>1</td>
<td>-35.00</td>
<td>-12.50*</td>
</tr>
<tr>
<td>Bus</td>
<td>1</td>
<td>0.75</td>
<td>-43.75</td>
<td>-13.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time (T), Hours</th>
<th>Cost ©, $</th>
<th>Y=40</th>
<th>Y=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Alone</td>
<td>0.5</td>
<td>2</td>
<td>-5.00*</td>
<td>-20.00</td>
</tr>
<tr>
<td>Carpool</td>
<td>0.75</td>
<td>1</td>
<td>-7.50</td>
<td>-15.00*</td>
</tr>
<tr>
<td>Bus</td>
<td>1</td>
<td>0.75</td>
<td>-11.88</td>
<td>-17.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time (T), Hours</th>
<th>Cost ©, $</th>
<th>Y=40</th>
<th>Y=10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Alone</td>
<td>0.5</td>
<td>2</td>
<td>-0.56*</td>
<td>-2.25</td>
</tr>
<tr>
<td>Carpool</td>
<td>0.75</td>
<td>1</td>
<td>-0.77</td>
<td>-1.56*</td>
</tr>
<tr>
<td>Bus</td>
<td>1</td>
<td>0.75</td>
<td>-1.20</td>
<td>-1.89</td>
</tr>
</tbody>
</table>
Consider the utility function and income distribution of the individuals as follows:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Time (T), Hours</th>
<th>Cost (C), $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Alone</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Carpool</td>
<td>0.75</td>
<td>1</td>
</tr>
<tr>
<td>Bus</td>
<td>1</td>
<td>0.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Income</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>33</td>
<td>25</td>
</tr>
<tr>
<td>37</td>
<td>20</td>
</tr>
<tr>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Income</th>
<th>Drive Alone</th>
<th>Carpool</th>
<th>Bus</th>
<th>Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>-1.09</td>
<td>-1.04</td>
<td>-1.22</td>
<td>Carpool</td>
</tr>
<tr>
<td>19</td>
<td>-1.03</td>
<td>-1.01</td>
<td>-1.20</td>
<td>Carpool</td>
</tr>
<tr>
<td>27</td>
<td>-0.87</td>
<td>-0.94</td>
<td>-1.14</td>
<td>Drive Alone</td>
</tr>
<tr>
<td>33</td>
<td>-0.80</td>
<td>-0.90</td>
<td>-1.11</td>
<td>Drive Alone</td>
</tr>
<tr>
<td>37</td>
<td>-0.77</td>
<td>-0.89</td>
<td>-1.10</td>
<td>Drive Alone</td>
</tr>
<tr>
<td>40</td>
<td>-0.75</td>
<td>-0.88</td>
<td>-1.09</td>
<td>Drive Alone</td>
</tr>
</tbody>
</table>
Aggregate travel behavior

- Based on the income distribution 20% of population use carpool, and 80% choose drive alone, and none use bus
- Notice that aggregate travel behavior cannot be predicted correctly by averaging the utility values over individuals.
- The drive alone utility would be \(-0.86 (0.05(-1.09)+0.15(-1.03)+...+0.10(-0.75))\)
- The average utility of carpooling and bus would be \(-0.93\) and \(-1.13\) respectively.
- Use of average utility would result in erroneous prediction
Inadequacy of Deterministic Utility Models

- If deterministic utility models describe travel behavior correctly, then similar individuals would be expected to make same travel choices when faced with same set of alternatives.
- In practice, however, it is not unusual for apparently similar individuals make different choices when faced with similar or even identical alternatives.
- In fact the same individual makes different choices when faced with same alternatives on different occasions.
Inadequacy of Deterministic Utility Models (2)

- Deterministic utility models cannot treat such “unexplained” variation in travel behavior.
- First, analyst and the individuals making travel choices being modeled are unlikely to have the same information about the available alternatives.
- Second, the analyst is unlikely to know all the characteristics of each individual that are relevant to mode choice.
Inadequacy of Deterministic Utility Models (3)

- Deterministic utility models can be modified to “random utility models” to achieve the “unexplained effect”
- Instead of predicting that an individual will choose a particular mode with certainty, these models provide probabilities that each of the available modes will be chosen.
Limitations of Analyst’s Information

- Omission of relevant variables from the model
- Measurement error
- Proxy variables
- Difference between individuals may be ignored
- Day to day variations in the choice context may be ignored
Example-1 (Missing Variable)

- Let the utility functions of three modes be
  \[ U_{DA} = -T_{DA} - 5C_{DA}/Y + 0.4(A-1) \]
  \[ U_{CP} = -T_{DA} - 5C_{CP}/Y + 0.2(A-1) \]
  \[ U_B = -T_B - 5C_B/Y \]

- Households without cars use bus, with one car use carpool, and two cars use drive alone
Example-1 (Missing Variable)

- Without taking car ownership into account everyone will choose carpool.
  - But with inclusion of car ownership will lead to
    - Zero car individuals will choose bus
    - One car individuals will choose carpool
    - Two cars individuals will choose drive alone

- Thus omission of automobile ownership variable from the utility function causes variation in travel choices that are not explained in the model.
Measurement Error

- Let us assume that different individuals have different travel times for the automobile modes.
- Specifically assume that the drive alone and carpool travel times for individuals are distributed in the following relative frequencies

<table>
<thead>
<tr>
<th>Percentage of individuals</th>
<th>20%</th>
<th>50%</th>
<th>20%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA Time</td>
<td>0.4</td>
<td>0.5</td>
<td>0.60</td>
<td>0.70</td>
</tr>
<tr>
<td>Carpool Time</td>
<td>0.65</td>
<td>0.75</td>
<td>0.85</td>
<td>0.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Percentage Individuals</th>
<th>Zero Cars</th>
<th>No Auto Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20%</td>
<td>50%</td>
</tr>
<tr>
<td>Drive Alone</td>
<td>-1.47</td>
<td>-1.57</td>
</tr>
<tr>
<td>Carpool</td>
<td>-1.18</td>
<td>-1.28</td>
</tr>
<tr>
<td>Bus</td>
<td>-1.25</td>
<td>-1.25</td>
</tr>
<tr>
<td>Chosen Mode</td>
<td>Carpool</td>
<td>Bus</td>
</tr>
</tbody>
</table>
## Measurement Error

<table>
<thead>
<tr>
<th>Percentage Individuals</th>
<th>One Cars</th>
<th>Two Cars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20%</td>
<td>50%</td>
</tr>
<tr>
<td>Drive Alone</td>
<td>-1.07</td>
<td>-1.17</td>
</tr>
<tr>
<td>Carpool</td>
<td>-0.98</td>
<td>-1.08</td>
</tr>
<tr>
<td>Bus</td>
<td>-1.25</td>
<td>-1.25</td>
</tr>
<tr>
<td>Chosen Mode</td>
<td>Carpool</td>
<td>Carpool</td>
</tr>
</tbody>
</table>
Measurement Error (2)

- Ignoring distribution of travel times of zero and one car households result in predictions that do not reflect the true variations in mode choice.
- In other words, actual choices vary in ways not explained by the model used to make predictions.