Estimating Transportation Demand, Part 1

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Recall last week’s lecture:
Procedural Framework for Transportation Systems Evaluation

**KEY INPUTS**
- Identify Evaluation Subject
- Identify Concerns of Decision-makers and Stakeholders
- Establish Goals, Objectives, Performance Measures
- Define Analysis Dimensions (Spatial and Temporal Scopes, Affected Parties, etc.)
- Recognize Legal and Administrative Requirements

**DEVELOPMENT AND REFINEMENT OF ALTERNATIVES**
Appropriateness, Adequacy, Implementation Feasibility

**ESTIMATION OF AGENCY AND USER COSTS AND BENEFITS (MONETARY)**

**ESTIMATION OF OTHER COSTS AND BENEFITS**
- Technical Impacts (Increased Condition, Longevity, Safety, Mobility, etc.)
- Environmental Impacts (Air, Water, etc.)
- Ecological Impacts (Fauna, Flora, Habitats)
- Aesthetic Impacts
- Social Impacts (Accessibility to Disabled Civil Rights, etc.
- Economic Efficiency, Economic Development Impacts

**EVALUATION**
- Economic Efficiency, Effectiveness and Equity
- Financial Feasibility
- Legal and Administrative Feasibility
- Sensitivity of Findings to Uncertainties in Input Parameters

**DECISION MAKING**
Choose the Best Alternative (Policy, Physical Improvement, etc.)
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Contents of Today’s Lecture

- Introduction
- Units of Transportation Demand
- Transportation Demand in the Context of Classical Economics
- Classification of Demand Models
Introduction
What is Demand?

Demand: The extent to which consumers seek a product.

Transportation Demand: The nr. of trips that individuals/firms are prepared to make under a given set of conditions (trip price, trip time, cost, security, comfort, safety, etc.).

- is generated by the need of humans to carry out socio-economic activities
- described as a *derived* demand because trips are undertaken not for the sake of traveling but rather for an expected activity at the end of a journey (reporting for work, shopping, returning home, picking up or delivering goods, etc.)
Transportation Demand by Mode

Types of Passenger Transportation Modes:

- Air
- Water
- Rail
- Bus
- Auto
- Bicycle
- Walk
- Other
Transportation Demand by **Mode**

Types of **Freight** Transportation Modes:

- Air
- Water
- Rail
- Truck
- Pipeline
What is a “modal share” of transportation demand?

Is the distribution of the overall amount of travel demand among the various modes.

Example, modal share of travelers between two cities.
How do We Measure Transportation Demand?
Units of Transportation Demand

• Number of vehicles
• Number of passengers
• Number of trips
Units of Transportation Demand

- Number of vehicles
- Number of passengers
- Number of trips
Units of Transportation Demand

- Number of vehicles
- Number of passengers
- Number of trips
- Number of vehicle-miles
- Number of passenger-miles
- Number of trip-miles
- Amount of freight (tons)
- Number of freight-miles
Importance of Transportation Demand in Systems Evaluation

(Why do we need to estimate demand?)

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Choose the Best Alternative (Policy, Physical Improvement, etc.)
Importance of Transportation Demand in Systems Evaluation

(Why do we need to estimate demand?)

• Provides a basis for predicting the need for a proposed transportation system, in terms of passenger, freight or vehicle volumes expected to use the facility.

• Helps provide a basis for deciding to go ahead with a proposed project or policy change.

• Influences the proposed size of the project or the scope of proposed operational policies.

• Provides a basis for quantifying the benefits (positive impacts) of the proposed facility on the facility (e.g., total savings in travel time).

• Provides a basis for quantifying the costs (adverse impacts) of the proposed facility on the environment (e.g., noise, air pollution, etc.).

• Knowing the expected demand at each future year helps in developing agency cost streams for preserving facilities whose deterioration or performance are influenced by usage.
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Transportation Demand in the Classical Economics Context
Transportation Demand in Context of Classical Economics

• *Transportation Demand*
  The amount of trips that travelers are willing to undertake.

• *Demand functions or demand models*
  Mathematical expressions that describe transportation demand.
  \[ V = f(X_1, X_2, \ldots, X_n) \]
Demand functions or demand models

\[ V = f(X_1, X_2, \ldots X_n) \]

\( X_1, X_2, \ldots X_n \) are the variables that affect transportation demand.

Of these variables, some are mode-specific (example, trip price, trip comfort, trip time, etc.).

Others are generic (example, trip-maker’s income).

Multi-attribute vs. single-attribute demand functions.

The most common variable (or attribute) is Trip Price.
Demand functions or demand models

The most common variable is trip price.

Therefore, the most common demand function is as follows:

\[ V = f(Price) \]
• When trip price increases, the demand for trips decreases

• When trip prices decreases, the demand for trips increases

• In Economics, this is known as *The Law of Demand*

• Any exceptions? Yes. For abnormal goods and services, the Law of Demand does not apply.
Abnormal demand curves

**Abnormal Goods and Services**

- **Giffen Goods**
  (Inferior, but staple goods and services).

- **Veblen Goods**
  (a good made more fashionable by a higher price).

*Note: In this course, we are only interested in transportation demand as a normal good!*
Shifting in the Transportation Demand Function

- Recall the basic, single-attribute demand function
- \( V = f(Price) \)

- Is it possible to have a change in demand even when the price is fixed?
- In other words, can we have a “shift” in the demand curve?
**Shifts in the Transportation Demand Function**

What Causes Shifts in the Demand Curve?

(a) A Shift in the **Right** Direction

Cause: A competing good or service is made less attractive to the customer

**Example:**
For auto travel,
- increased auto security, safety;
- reduced transit comfort, safety, and security, or
- higher transit prices can cause an increase in auto demand even when auto trip price is constant
(a) A Shift in the Left Direction

Cause: A competing good or service is made more attractive to the customer

**Example:**
For auto travel,
- decreased auto security, safety;
- increased transit comfort, safety, and security, or
- reduced transit prices can cause a decrease in auto demand even when auto trip price is constant
Classification of Demand Models
Classification of Demand Models

- Single attribute vs. Multiple attribute
- Aggregate vs. Disaggregate
- Deterministic vs. Stochastic
- Time series (trend) vs. Cross-sectional

- Further classification of Cross-sectional models:
  - Demand estimation based on end point attributes vs.
  - Demand estimation based on attributes of entire network.

- Classification by Functional Form
Classification of Demand Models

Single attribute vs. multiple attribute demand models

**Single attribute**: only one variable

\[ \text{Demand} = f(X) \]

Examples:  
\[ \text{Demand} = f(\text{Trip Price}) \]

\[ \text{Demand} = f(\text{Trip Time}) \]

**Multiple attribute**: more than one variable

\[ \text{Demand} = f(X_1, X_2, \ldots, X_N) \]

Examples:  
\[ \text{Demand} = f(\text{Trip Price, Time, Safety, Comfort, etc.}) \]
Classification of Demand Models

Disaggregate vs. aggregate demand models

Consider the following situation:

We seek to estimate the travel demand between the Indian cities of Hyderabad and Chennai.
Classification of Demand Models

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Classification of Demand Models

Aggregate vs. disaggregate demand models

Consider the following situation:

We seek to estimate the travel demand between the Indian cities of Hyderabad and Chennai.

**Hyderabad**
- Population = 2.1M
- Area = 410 sq. km
- Number of Industries = 420
- Nr. of Shopping centers = 134

**Chennai**
- Population = 1.2M
- Area = 265 sq. km
- Number of Industries = 140
- Nr. of Shopping centers = 84

Overall Demand

$$= f(pop_H, pop_C, Area_H, Area_C, \text{etc.})$$

Travelers between H and C
- For each traveler:
  - Income
  - Occupation
  - Etc.

Demand of each traveler $$i$$

$$= f(INC_i, OCC_i, \text{etc.}X)$$

Overall demand = sum of travelers demands
Classification of Demand Models

Aggregate vs. disaggregate demand models

**Aggregate demand models**: the variables are combined for all travelers and pertain to the areas (regions, cities, towns, etc.)

\[
\text{Overall Demand} = f(\text{Characteristics of the demand-generating regions})
\]

Characteristics include population, regional area, number or total area (sq. ft.) of industries, shops, schools, etc.,

**Disaggregate demand models**: the variables are for each individual traveler

\[
\text{Demand} = f(\text{Characteristics of individual traveler})
\]

Characteristics include income, occupation, etc.

\(f\) is often an econometric discrete choice models (logit, probit, etc.)

Overall demand = sum of demand of individual travelers
Classification of Demand Models

Deterministic vs. stochastic

**Deterministic demand models**: the exact outcome (travel demand) can be predicted with certainty.
- Makes the demand estimation process very easy
- May not be realistic

**Stochastic demand models**: the exact outcome (travel demand) is not known with certainty
- The estimated demand is falls between a certain minimum and maximum, and is governed by a probability distribution
- Each exact demand has a certain probability of occurring
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**Deterministic demand models**: the exact outcome (travel demand) can be predicted with certainty.
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**Stochastic demand models**: the exact outcome (travel demand) is not known with certainty
- The estimated demand is falls between a certain minimum and maximum, and is governed by a probability distribution
- Each exact demand has a certain probability of occurring
- Makes the demand estimation process relatively complicated
- More realistic in real world where there are so many uncertainties
Classification of Demand Models

Time Series vs. Cross-sectional Models
Classification of Demand Models

Time Series vs. Cross-sectional Models

So, how do we estimate demand in Year 2009?
Classification of Demand Models

Time Series vs. Cross-sectional Models

To estimate demand in Year 2009:

\[ \text{Demand}_{2009} = f(Y_{2001}, Y_{2002}, \ldots, Y_{2006}) \]
Classification of Demand Models

Time Series vs. Cross-sectional Models

So, how do we estimate demand in Year 2009?

\[
\text{Demand}_{2009} = f(Y_{2001}, Y_{2002}, \ldots, Y_{2006})
\]

OR

\[
\text{Demand in Year 2009} = f(\text{POP}_{2009}, \text{AVG}\_\text{INC}_{2009}, \text{AREA}\_\text{BUSINESS}_{2009})
\]
Classification of Demand Models

Time Series vs. Cross-sectional Models

**Time Series demand models**: Here, we estimate demand on the basis of historical demand for that specific system or for similar systems.

**Cross-sectional demand models**: Here, we estimate demand using the present characteristics of the region that affect travel demand.

**Panel (or pooled) demand models**

Uses both time-series and cross sectional approaches. Econometric techniques often used.
Example of demand estimation using time series

The historical demand for a certain rail transit system is as follows:

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<thead>
<tr>
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<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>1.25</td>
<td>1.37</td>
<td>1.45</td>
<td>1.58</td>
<td>1.72</td>
<td>1.95</td>
<td>2.31</td>
<td>2.48</td>
</tr>
</tbody>
</table>

Use the linear and exponential functional forms to predict the expected demand at year 2008.

**Solution**

The expected demand in the year 2008 can be determined using the mathematical functional forms of the linear and exponential curves as follows:

**Linear form:** \( V = 0.089(Year – 1990) – 1.1408 \) \( (R^2 = 0.95) \)

Thus, the projected demand in Year 2008 on the basis of linear trends = \( 0.089(2008 – 1990) – 1.1408 = 2.74 \)

**Exponential form:** \( V = 1.2106e^{0.0499(Year – 1990)} \) \( (R^2 = 0.98) \)

Thus, the projected demand in Year 2008 on the basis of exponential trends = \( 1.2106e^{0.0499(2008 – 1990)} = 2.75 \)
Class Discussion

Why is the “Trend” approach not always appropriate for demand estimation?
Demand estimation using cross-sectional data

Example
The total rail demand (passengers in thousands per day) between City A and Town B, $V_{ij}$, is:

$$V_{ij} = INC_{ij}^{0.316} \times POP_{ij}^{0.221}$$

Where $INC_{ij}$ = average income for the two urban center in ten thousands

$POP_{ij}$ = average population of the two urban centers, in millions

Determine the rail demand ten years from now when the average per capita income is $35,600, average population of the two urban centers is 3 million.

Solution
$$V_{ij} = 3.56^{0.316} \times 3^{0.221} = 1,904 \text{ passengers per day.}$$
Classification of Demand Models

- Further classification of Cross-sectional demand models:
  - Demand estimation based on endpoint attributes only, vs.
  - Demand estimation based on attributes of entire network.
Demand Estimation Based only on Attributes of Corridor/Project or its End Points

Examples

1. Air travel demand

\[ V_{12} = \frac{Z}{1 + \beta_1 e^{\beta_2 Q}} \]

*Z* is a measure of socio-economic activity
*Q* is schedule frequency
Beta’s are model parameters

2. Intercity passenger demand models

Kraft-SARC model, McLynn model, Baumol-Quandt model:

\[ V_{12} = A * (P_1 P_2)^B * C(I_1 I_2)^D * E(t_{M1} t_{M2}) * G(c_{M1} c_{M2}) \]

*P* is population, *I* is income, *t* is the time taken by mode *m*, *c* is the average passenger cost of taking mode *m*. 
Demand Estimation Based only on Attributes of Corridor/Project or its End Points

Examples

3. Transit demand

\[ V_{12} = T^{-0.3} p^{-0.2} A^{0.1} I^{-0.25} \]

\[ V_{12} = \text{transit ridership/hr between 1 and 2} \]
\[ T = \text{transit travel time (hrs)} \]
\[ C = \text{transit fare ($)} \]
\[ A = \text{cost of auto trip ($)} \]
\[ I = \text{average income ($)} \]
Demand Estimation Based only on Attributes of Corridor/Project or its End Points

Is it enough to estimate demand for a link based only on attributes of the end points?
Demand Estimation based on Attributes of Entire Parent Network

Trip Generation:
What generates the trips? – Trip productions.

2. Trip Distribution:
For the trips generated, how are they distributed (shared) among the various destination points?

3. Traffic Assignment
Which routes are taken by the travelers from any origin to any destination?

4. Mode Choice or Mode Split
For a given set of travelers on each chosen route, what fraction takes which mode (auto, bus, walk, rail, air, etc.)

This is known as the Transportation Planning Model (TPM)
Classification of Demand Models

Classification by the Functional Form of the Demand Model

Generally, \( V = f(X) \)

where \( X \) is:

- (for disaggregate demand), is a factor (or vector of factors) that affects the individual travel demand, such as trip price, time, safety, comfort, etc.

- (for aggregate demand), is a factor of vector of factors that affect the overall travel demand, such as population, average income, employment levels, etc.

- for a time series demand model (often aggregate), is simply the time in years

The Big Question: What is the shape of \( f \)?
Common Functional Forms

**Linear**

\[ \text{Demand} = a + bX \]

**Power**

\[ \text{Demand} = aX^b, \ b > 1 \]

\[ \text{Demand} = aX^b, \ b < 1 \]
Exponential Demand Models

Demand = $a \cdot b^x$

- $0 < b < 1$
- $b > 1$
Common Functional Forms

Modified Exponential Demand Models

\[ \text{Demand} = c + a \cdot b^x \]
Logistic Demand Models

\[ \text{Demand} = \frac{1}{(c + ab^x)} \]
Common Functional Forms

Gompertz Demand Models

\[ \text{Demand} = ca^{bx} \]