PASSENGER TRANSPORT

OUTLINE

- **Hierarchy of choices**
- **Level of service attributes**
- **Estimating the Transfer Penalty***
- **Modeling issues**

  -- data availability

  -- logit revisited

*** Guo, Z and N.H.M. Wilson, "Assessment of the Transfer Penalty for Transit Trips: A GIS-based Disaggregate Modeling Approach." Transportation Research Record 1872, pp 10-18 (2004).**

HIERARCHY OF CHOICES

A. **Long-Term Decisions: made infrequently by any household**

- **where to live**
- **where to work**

Transport is one component of these choices

B. **Medium-Term Decisions**

- **household vehicle ownership**
- **mode for journey to work**

Transport is central to these choices

C. **Short-Term Decisions**

- **daily activity and travel choices:**

What, where, when, for how long, and in what order, by which mode and route

Transport is important for these choices

LEVEL OF SERVICE ATTRIBUTES

A. Important but hard to quantify:

- flexibility
- privacy
- status
- enjoyment/happiness/well-being
- comfort
- safety and security
- reliability

LEVEL OF SERVICE ATTRIBUTES

B. Important but easier to quantify:

- travel time
  - wait time
  - in-vehicle time
  - walk time
- transfers
- cost
  - out of pocket

LEVEL OF SERVICE ATTRIBUTES

Difficulties:

- differences in values among individuals
- objective measures may differ from perceptions
- tendency to focus on what can be measured
- hard to appraise reactions to a very different alternative

ASSESSING THE TRANSFER PENALTY: A GIS-BASED DISAGGREGATE MODELING APPROACH

Outline

- Objectives
- Prior Research
- Modeling Approach
- Data Issues
- Model Specifications
- Analysis and Interpretation
- Conclusions

Source: Guo, Z and N.H.M. Wilson, "Assessment of the Transfer Penalty for Transit Trips: A GIS-based Disaggregate Modeling Approach." Transportation Research Record 1872, pp 10-18 (2004).

OBJECTIVES

- Improve our understanding of how transfers affect behavior
- Estimate the impact of each variable characterizing a transfer
- Identify transfer attributes which can be improved cost-effectively

PREVIOUS TRANSFER PENALTY RESULTS

Previous Studies	Variables in the Utility Function	Transfer Types (Model Structure)	Transfer Penalty Equivalence
Alger et *al,* 1971 Stockholm	Walking time to stop Initial waiting time Transit in-vehicle time Transit cost	Subway-to-Subway Rail-to-Rail Bus-to-Rail Bus-to-Bus	4.4 minutes in-vehicle time 14.8 minutes in-vehicle time 23.0 minutes in-vehicle time 49.5 minutes in-vehicle time
Han, 1987 Taipei, Taiwan	Initial waiting time Walking time to stop In-vehicle time Bus fare Transfer constant	Bus-to-Bus (Path Choice)	30 minutes in-vehicle time 10 minutes initial wait time 5 minutes walk time
Hunt , 1990 Edmonton, Canada	Transfer Constant Walking distance Total in-vehicle time Waiting time Number of transfers	Bus-to-Light Rail (Path Choice)	17.9 minutes in-vehicle time

PREVIOUS TRANSFER PENALTY RESULTS (cont'd)

Previous Studies	Variables in the Utility Function	Transfer Types (Model Structure)	Transfer Penalty Equivalence
Liu, 1997 New Jersey, NJ	Transfer Constant In-vehicle time Out-of-vehicle time One way cost Number of transfers	Auto-to-Rail Rail-to-Rail (Modal Choice)	15 minutes in-vehicle time 1.4 minutes in-vehicle time
CTPS, 1997 Boston, MA	Transfer Constant In-vehicle time Walking time Initial waiting time Transfer waiting time Out-of-vehicle time Transit fare	All modes combined (Path and Mode Choice)	12 to 15 minutes in-vehicle time
Wardman, Hine and Stradling, 2001 Edinburgh, Glasgow, UK	Utility function not specified	Bus-to-Bus Auto-to-Bus Rail-to-Rail	4.5 minutes in-vehicle time 8.3 minutes in-vehicle time 8 minutes in-vehicle time

PRIOR RESEARCH – A CRITIQUE

- Wide range of transfer penalty
- Incomplete information on path attributes
- Limited and variable information on transfer facility attributes
- Some potentially important attributes omitted

MODELING APPROACH

- **Use standard on-board survey data including:**
  - -- actual transit path including boarding and alighting locations
  - -- street addresses of origin and destination
  - -- demographic and trip characteristics

- **Focus on respondents who:**
  - -- travel to downtown Boston destinations by subway
  - -- have a credible transfer path to final destination

MODELING APPROACH

- **Define transfer and non-transfer paths to destination from subway line accessing downtown area**
- **For each path define attributes:**

-- walk time	**-- transfer walk time**
-- in-vehicle time	**-- transfer wait time**

- **Specify and estimate binary logit models for probability of selecting transfer path**

TWO OPTIONS TO REACH THE DESTINATION

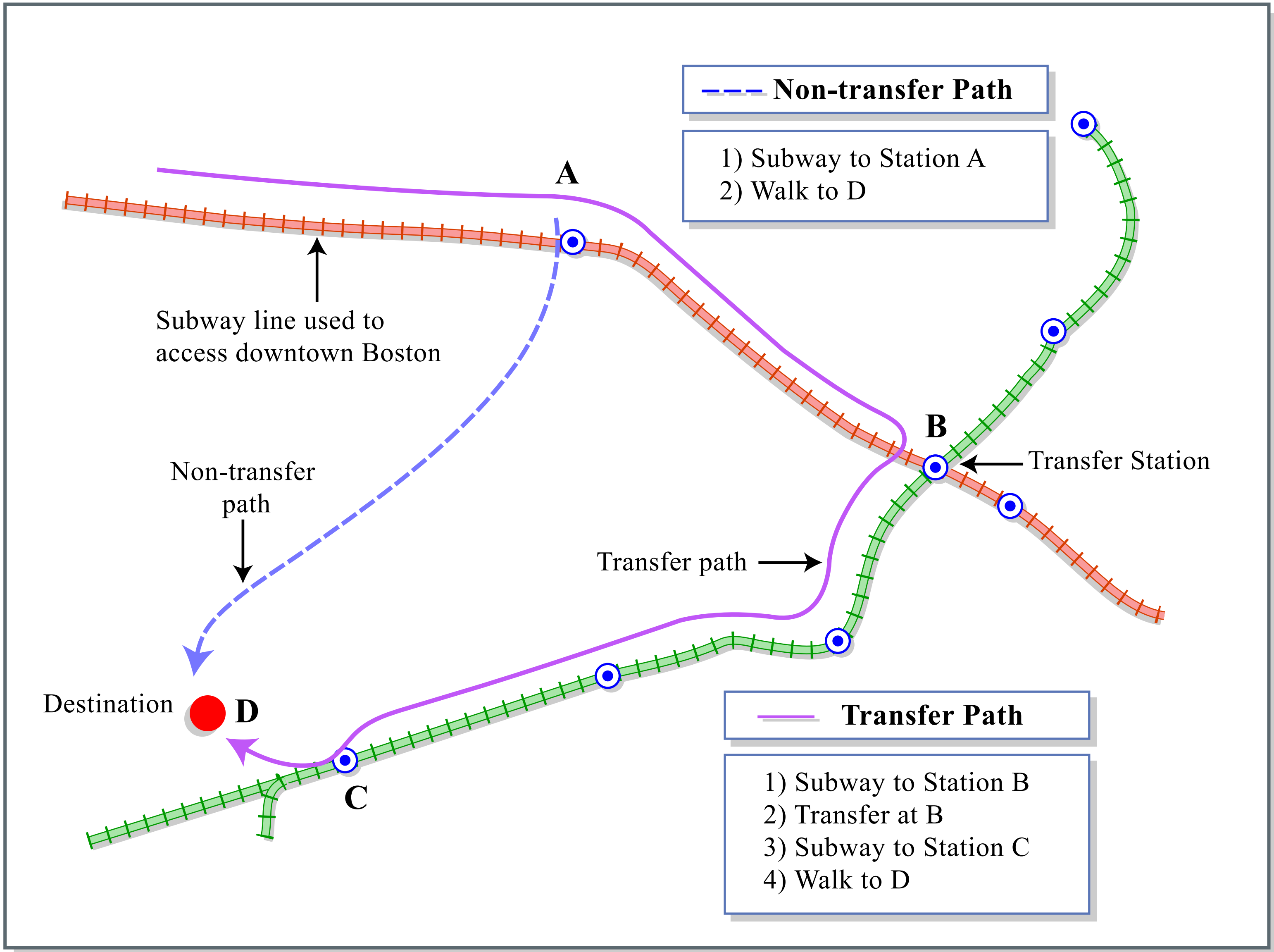


Figure by MIT OCW.

MBTA SUBWAY CHARACTERISTICS

- Three heavy rail transit lines (Red, Orange, and Blue)
- One light rail transit line (Green)
- Four major downtown subway transfer stations (Park, Downtown Crossing, Government Center, and State)
- 21 stations in downtown study area
- Daily subway ridership: 650,000
- Daily subway-subway transfers: 126,000

THE MBTA SUBWAY IN DOWNTOWN BOSTON

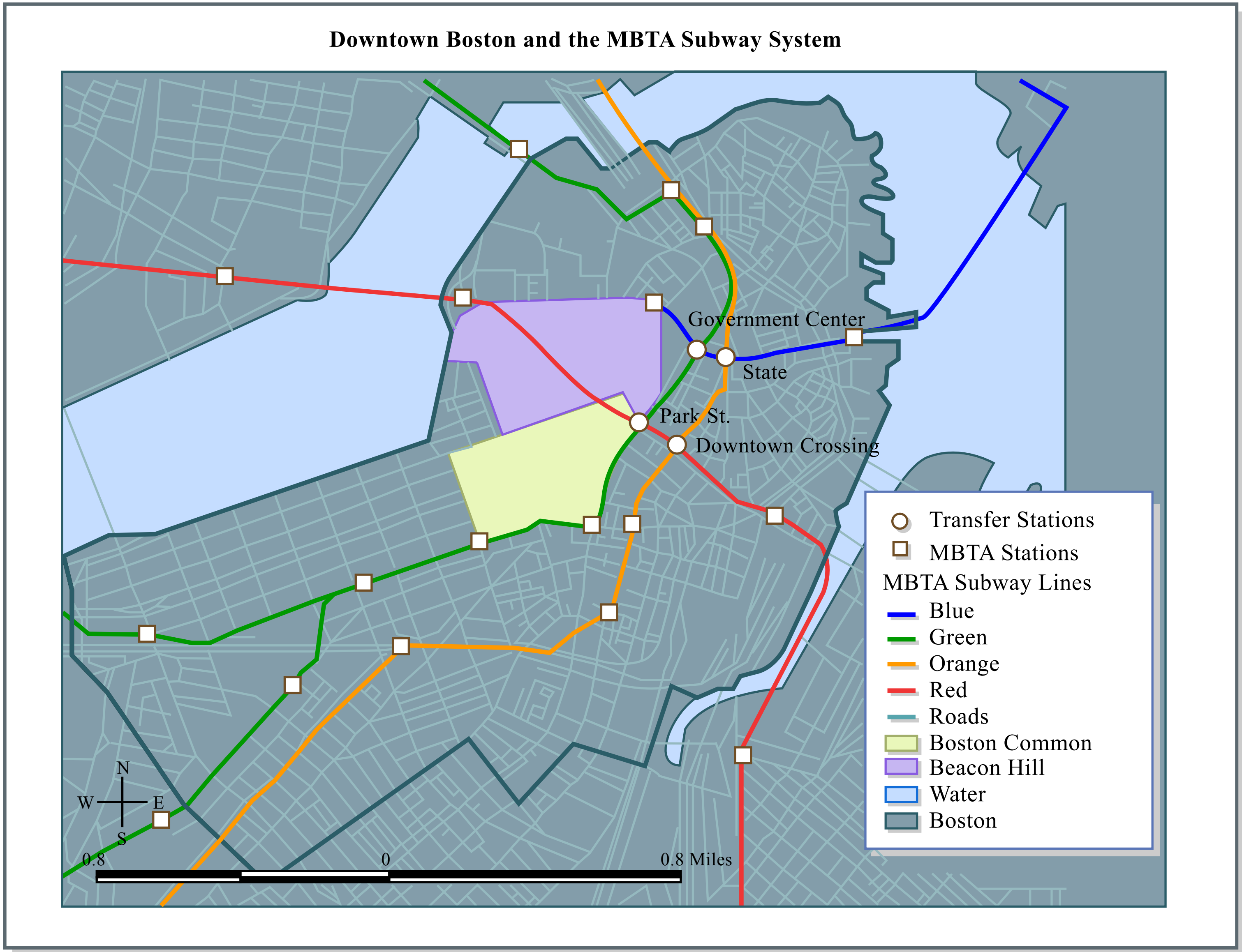


Figure by MIT OCW.

DATA ISSUES

- **Data from 1994 MBTA on-board subway survey**
- **38,888 trips in the dataset**
- **15,000 geocodable destination points**
- **6,500 in downtown area**
- **3,741 trips with credible transfer option based on:**
  - **closest station is not on the subway line used to enter the downtown area**
- **67% of trips with credible transfer option actually selected non-transfer path**
- **3,140 trips used for model estimation**

VARIABLES

A Transit Path Variables

- Walk time savings: based on shortest path and assume 4.5 km per hour walk speed
- Extra in-vehicle time: based on scheduled trip time

B Transfer Attributes

- Transfer walk time
- Transfer wait time: half the scheduled headway
- Assisted change in level: a binary variable with value 1 if there is an escalator

VARIABLES (continued)

C. Pedestrian Environment Variables

- **Land use: difference in Pedestrian Friendly Parcel (PFP) densities**
- **Pedestrian Infrastructure Amenity: difference in average sidewalk width**
- **Open Space: a trinary variable reflecting walking across Boston Common**
- **Topology: a trinary variable reflecting walking through Beacon Hill**

D. Trip and Demographic Variables

THE SEQUENCE OF MODEL DEVELOPMENT

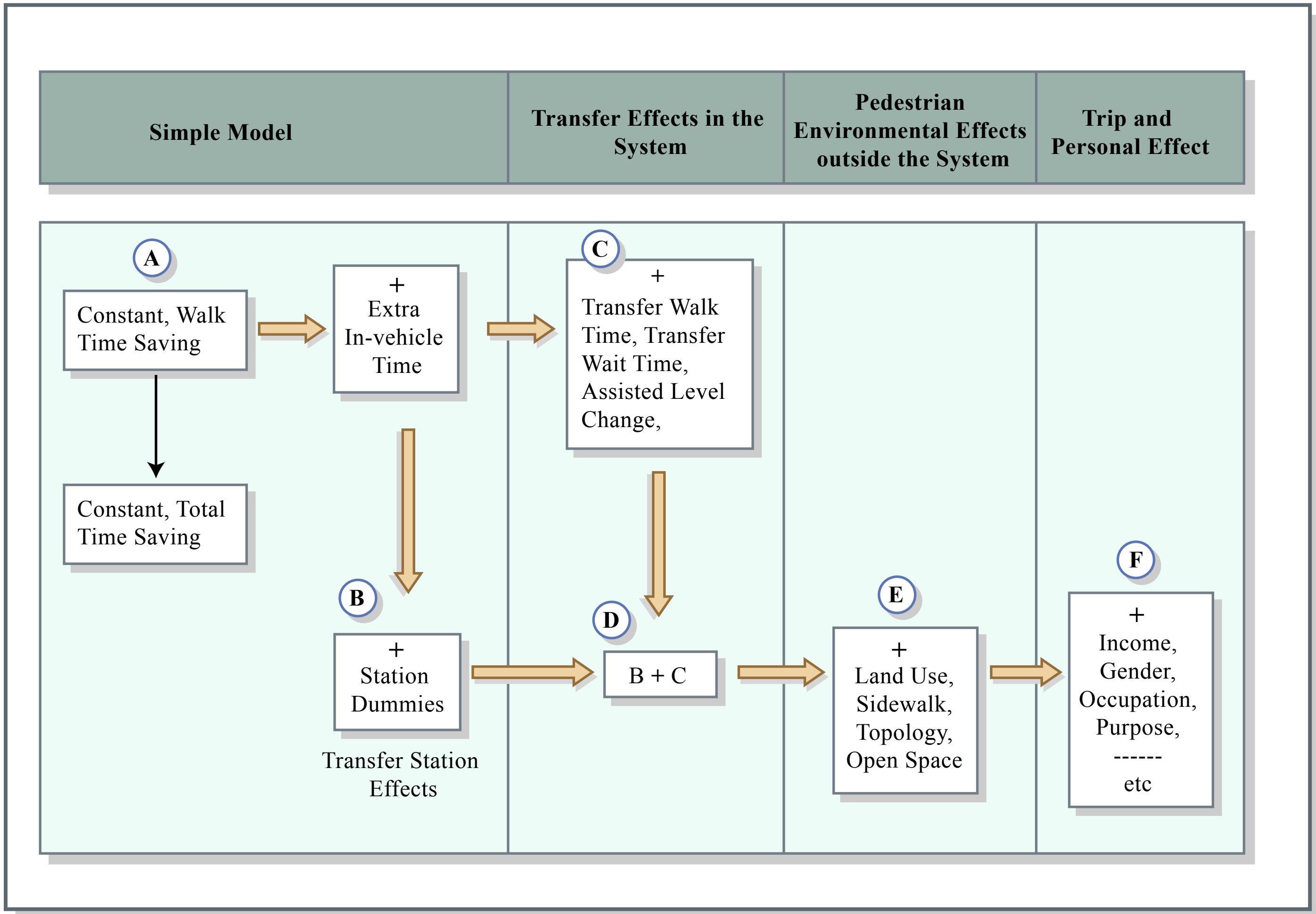


Figure by MIT OCW.

MODEL A: SIMPLEST MODEL

Specification

- Assume every transfer is perceived to be the same
- Only two variables

  -- transfer constant

  -- walk time savings

Findings

- A transfer is perceived as equivalent to 9.5 minutes of walking time

MODEL A RESULTS

Variables	Coefficients	t statistics
Transfer Constant Walk Time Savings (minutes)	-2.39 0.25	-28.57 20.78
# of Observations	3140	
Final log-likelihood	-1501.9	
Adjusted ρ^2	0.309	

MODEL B: TRANSFER STATION SPECIFIC MODEL

Specification

- Assume each transfer station is perceived differently
- Variables are:

  -- walk time savings

  -- extra in-vehicle time

  -- station-specific transfer dummies

Findings

- Improved explanatory power (over Model A)
- Transfer stations are perceived differently
- Park is the best (4.8 minutes of walk time equivalence)
- State is the worst (9.7 minutes of walk time equivalence)

MODEL B RESULTS

Variables	Model A		Model B	
	Coefficients	t statistics	Coefficients	t statistics
Transfer Constant	-2.39	-28.57	-1.39	-12.62
Walk Time Savings	0.25	20.78	0.29	19.54
Extra In-vehicle Time			-0.21	-10.68
Government Center			-1.21	-10.23
State Street			-1.41	-7.44
Downtown Crossing			-1.09	-7.28
# of Observations	3140		3140	
Final log-likelihood	-1501.9		-1368.1	
Adjusted ρ^2	0.309		0.369	

MODEL C: TRANSFER ATTRIBUTES MODEL

Specification

- **Transfer attributes affect transfer perceptions:**

  -- transfer walk time

  -- transfer wait time

  -- assisted change in level

Findings

- **Improved explanatory power (over Model B)**
- **Residual transfer penalty is equivalent to 3.5 minutes of walking time savings**
- **Transfer waiting time is least significant**

MODEL C RESULTS

Variables	Model A		Model B		Model C	
	Coefficients	t statistics	Coefficients	t statistics	Coefficients	t statistics
Transfer Constant	-2.39	-28.57	-1.39	-12.62	-0.99	-6.99
Walk Time Savings	0.25	20.78	0.29	19.54	0.29	18.11
Extra In-vehicle Time			-0.21	-10.68	-0.20	-8.35
Government Center			-1.21	-10.23		
State Street			-1.41	-7.44		
Downtown Crossing			-1.09	-7.28		
Transfer walking time					-1.13	-13.37
Transfer waiting time					-0.16	-1.98
Assisted level change					0.27	2.24
# of Observations	3140		3140		3140	
Final log-likelihood	-1501.9		-1368.1		-1334.32	
Adjusted ρ^2	0.309		0.369		0.385	

MODEL D: COMBINED ATTRIBUTE & STATION MODEL

Specification

- Combines the variables in Model B and C
- Estimates separate models for peak and off-peak periods

Findings

- Improved explanatory power (over Model C)
- Government Center is perceived as worse than other transfer stations
- Residual transfer penalty in off-peak period at other transfer stations vanishes
- In the peak period model the transfer waiting time is not significant

MODEL D RESULTS

Variables	Model A	Model B	Model C	Model D	
	Coefficients	Coefficients	Coefficients	Peak	Off-peak
Transfer Constant	-2.39***	-1.39***	-0.99***	-1.08***	
Walk Time Savings	0.25***	0.29***	0.29***	0.32***	0.22***
Extra In-vehicle Time		-0.21***	-0.20***	-0.24***	-0.17***
Government Center		-1.21***		-1.28***	-1.26*
State Street		-1.41***			
Downtown Crossing		-1.09***			
Transfer walking time			-1.13***	-1.39***	-1.22***
Transfer waiting time			-0.16**		-0.29***
Assisted level change			0.27**	0.39**	0.48***
# of Observations	3140	3140	3140	2173	967
Final log-likelihood	-1501.9	-1368.1	-1334.32	-868.44	-418.99
Adjusted ρ^2	0.309	0.369	0.385	0.414	0.357

Note, ***: $P < 0.001$; **: $P < 0.05$; *: $P < 0.1$

MODEL E: PEDESTRIAN ENVIRONMENT MODEL

Specification

- Better pedestrian environment should lead to greater willingness to walk
- Add pedestrian environment variables to Model D

Findings

- Improved explanatory power (over Model D)
- Greater sensitivity to pedestrian environment in off-peak model
- Both Boston Common (positively) and Beacon Hill (negatively) affect transfer choices as expected
- Pedestrian environment variables can affect the transfer penalty by up to 6.2 minutes of walking time equivalence

MODEL E RESULTS

Variables	Model A	Model B	Model C	Model D		Model E	
				Peak Hour	Non-Peak Hour	Peak Hour	Non-Peak Hour
Transfer Constant	-2.39***	-1.39***	-0.99***	-1.08***		-1.39***	
Walking Time Savings	0.25***	0.29***	0.29***	0.32***	0.22***	0.29***	0.19***
Extra In-vehicle Time		-0.21***	-0.20***	-0.24***	-0.17***	-0.24***	-0.16***
Transfer walking time			-1.13***	-1.39***	-1.22***	-1.28***	-0.99***
Transfer waiting time			-0.16**		-0.29***		-0.27***
Assisted level change			0.27**	0.39**	0.48***	0.39***	0.45*
Government Center		-1.21***		-1.28***	-1.26*	-1.20***	-1.28**
State Street		-1.41***					
Downtown Crossing		-1.09***					
Extra PFP density							-0.20**
Extra sidewalk width						-0.03***	-0.03***
Boston Common						0.73***	0.79***
Beacon Hill						-0.73**	-1.07***
# of Observations	3140	3140	3140	2173	967	2173	967
Final log-likelihood	-1501.9	-1368.1	-1334.32	-868.44	-418.99	-852.472	-402.975
Adjusted ρ^2	0.309	0.369	0.385	0.414	0.357	0.425	0.376
Note, ***: P < 0.001; **: P < 0.05; *: P < 0.1							

ANALYSIS AND INTERPRETATION

- **The transfer penalty has a range rather than a single value**
- **The attributes of the transfer explain most of the variation in the transfer penalty**
- **For the MBTA subway system the transfer penalty varies between the equivalent of 2.3 minutes and 21.4 minutes of walking time**
- **Model results are consistent with prior research findings**

RANGE OF THE TRANSFER PENALTY

Model Number	Underlying Variables	Adjusted ρ^2	The Range of the Penalty (Equivalent Value of)
A	Transfer constant	0.309	9.5 minutes of walking time
B	Government Center Downtown Crossing State	0.369	4.8 ~ 9.7 minutes of walking time
C	Transfer constant • Transfer walk time • Transfer wait time • Assisted Level Change	0.385	4.3 ~ 15.2 minutes of walking time
D	Transfer constant • Transfer walk time • Transfer wait time • Assisted Level Change • Government Center	0.414 (Peak) 0.357 (Off-peak)	4.4 ~ 19.4 minutes of walking time (Peak) 2.3 ~ 21.4 minutes of walking time (Off-peak)

COMPARISON OF THE TRANSFER PENALTY WITH PRIOR FINDINGS

Studies	Alger *et al* 1971		Liu 1997	Wardman *et al* 2001	CTPS 1997	This Research
City	Stockholm		New Jersey	Edinburgh	Boston	Boston
Transfer Type	Subway	Rail	Subway	Rail	All modes	Subway
Value of the Transfer Penalty*	4.4	14.8	1.4	8	12 to 18	1.6 ~ 31.8

* Minutes of in-vehicle time

LIMITATIONS OF RESEARCH

- Findings relate only to current transit riders
- Only subway-subway transfer studied

  -- no transfer payment involved

  -- transfers are protected from weather

  -- headways are very low

- Weather variable not included

SOURCES OF DATA ON USER BEHAVIOR

- Revealed Preference Data
  - Travel Diaries
  - Field Tests
- Stated Preference Data
  - Surveys
  - Simulators

STATED PREFERENCES / CONJOINT EXPERIMENTS

- **Used for product design and pricing**
  - -- For products with significantly different attributes
  - -- When attributes are strongly correlated in real markets
  - -- Where market tests are expensive or infeasible

Uses data from survey “trade-off” experiments in which attributes of the product are systematically varied

Applied in transportation studies since the early 1980s

AGGREGATION AND FORECASTING

- **Objective is to make aggregate predictions from**
  - -- **A disaggregate model, $P(i \mid X_n)$**
  - -- **Which is based on individual attributes and characteristics, X_n**
  - -- **Having only limited information about the explanatory variables**

THE AGGREGATE FORECASTING PROBLEM

- The fraction of population *T* choosing alt. *i* is:

$$W(i) = \int_X P(i \mid X) p(X) dX$$, *p*(*X*) is the density function of *X*

$$= \frac{1}{N_T} \sum_{n=1}^{N_T} P(i \mid X_n)$$, N_T is the # in the population of interest

- Not feasible to calculate because:
  - -- We never know each individual's complete vector of relevant attributes
  - -- *p*(*X*) is generally unknown

- The problem is to reduce the required data

SAMPLE ENUMERATION

- **Use a sample to represent the entire population**
- **For a random sample:**

$$\hat{W}(i) = \frac{1}{N_s} \sum_{n=1}^{N_s} \hat{P}(i \mid x_n)$$

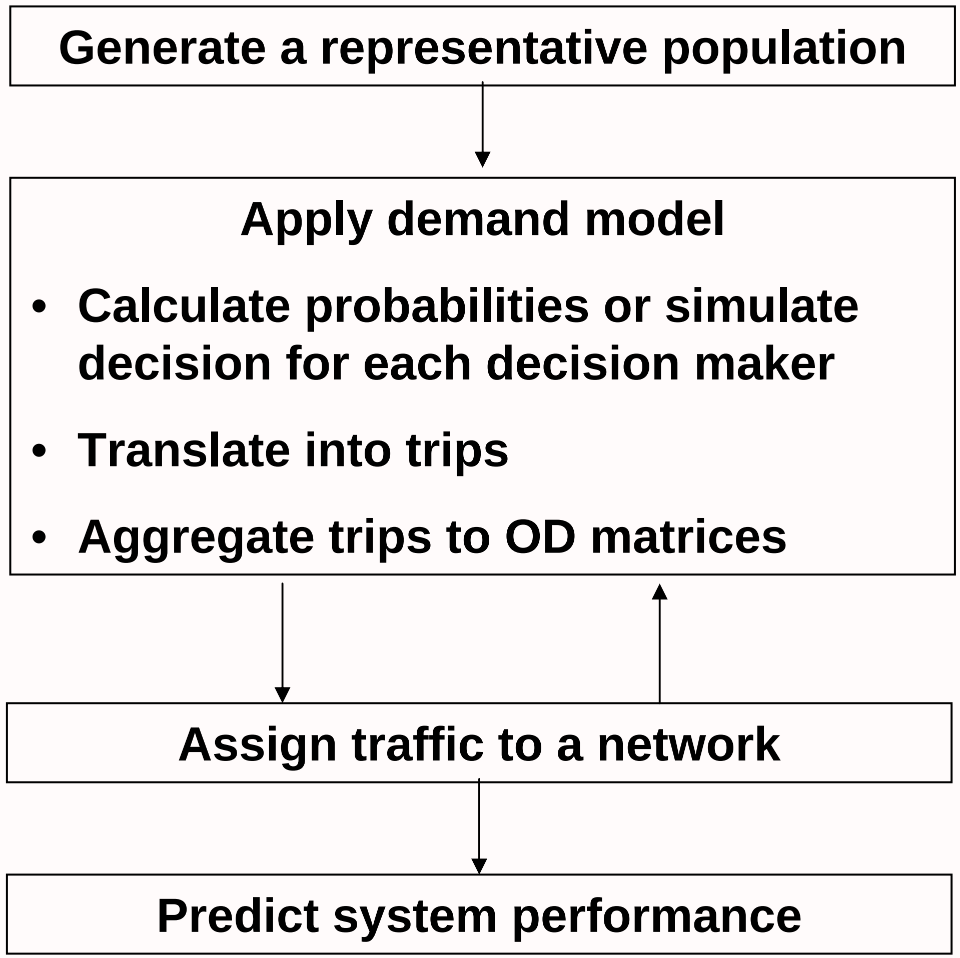
where N_s is the # of obs. in sample

- **For a weighted sample:**

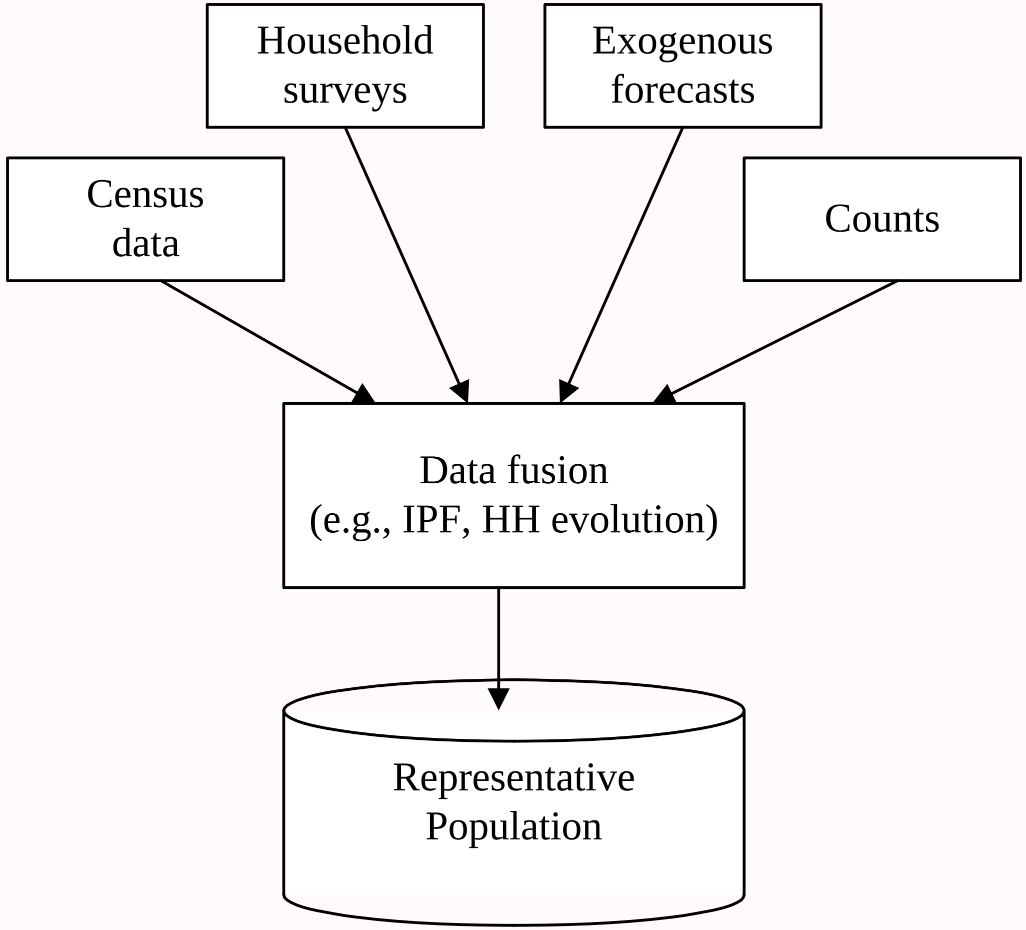
$$\hat{W}(i) = \sum_{n=1}^{N_s} \frac{w_n}{\sum_n w_n} \hat{p}(i \mid x_n) \text{ ,where } \frac{1}{w_n} \text{ is } x_n\text{'s selection prob.}$$

- **No aggregation bias, but there is sampling error**

DISAGGREGATE PREDICTION



GENERATING DISAGGREGATE POPULATIONS



LOGIT MODEL PROPERTY AND EXTENSION

- Independence from Irrelevant Alternatives (IIA) property -- Motivation for Nested Logit
- Nested Logit - specification and an example

INDEPENDENCE FROM IRRELEVANT ALTERNATIVES (IIA)

- **Property of the Multinomial Logit Model**
  - ε_{jn} **independent identically distributed (i.i.d.)**
  - $\varepsilon_{jn} \sim \textit{ExtremeValue}(0,\mu) \quad \forall j$
  - $$P_n(i \mid C_n) = \frac{e^{\mu V_{in}}}{\sum_{j \in C_n} e^{\mu V_{jn}}}$$

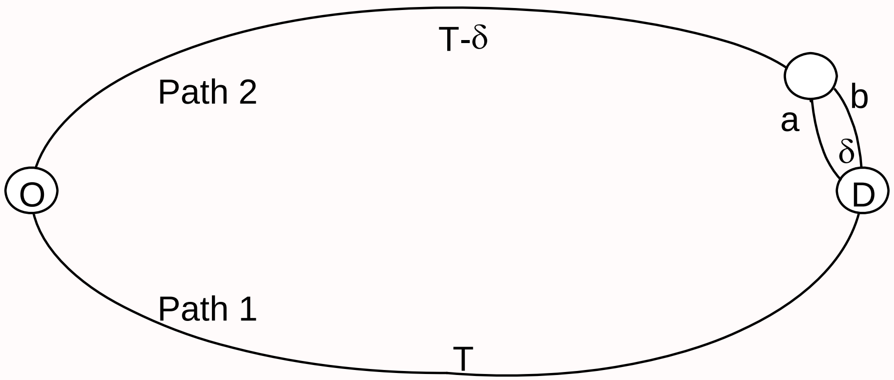
so

$$\frac{P(i \mid C_1)}{P(j \mid C_1)} = \frac{P(i \mid C_2)}{P(j \mid C_2)} \qquad \forall\ i, j, C_1, C_2$$

such that $i, j \in C_1$, $i, j \in C_2$, $C_1 \subseteq C_n$ *and* $C_2 \subseteq C_n$

EXAMPLES OF IIA

- **Route choice with an overlapping segment**



$$P(1 \mid \{1,2a,2b\}) = P(2a \mid \{1,2a,2b\}) = P(2b \mid \{1,2a,2b\}) = \frac{e^{\mu T}}{\sum_{j \in \{1,2a,2b\}} e^{\mu T}} = \frac{1}{3}$$

RED BUS / BLUE BUS PARADOX

- **Consider that initially auto and bus have the same utility**
  - C_n = {auto, bus} *and* $V_{auto} = V_{bus} = V$
  - P(auto) = P(bus) = 1/2
- **Now suppose that a new bus service is introduced that is identical to the existing bus service, except the buses are painted differently (red vs. blue)**
  - C_n = {auto, red bus, blue bus}; $V_{\text{red bus}} = V_{\text{blue bus}} = V$
  - MNL now predicts
    P(auto) = P(red bus) = P(blue bus) =1/3
  - We'd expect
    P(auto) =1/2, P(red bus) = P(blue bus) =1/4

IIA AND AGGREGATION

- **Divide the population into two equally-sized groups: those who prefer autos, and those who prefer transit**
- **Mode shares before introducing blue bus:**

Population	Auto Share	Red Bus Share	
Auto people	**90%**	**10%**	**P(auto)/P(red bus) = 9**
Transit people	**10%**	**90%**	**P(auto)/P(red bus) = 1/9**
Total	50%	50%	

- **Auto and red bus share ratios remain constant for each group after introducing blue bus:**

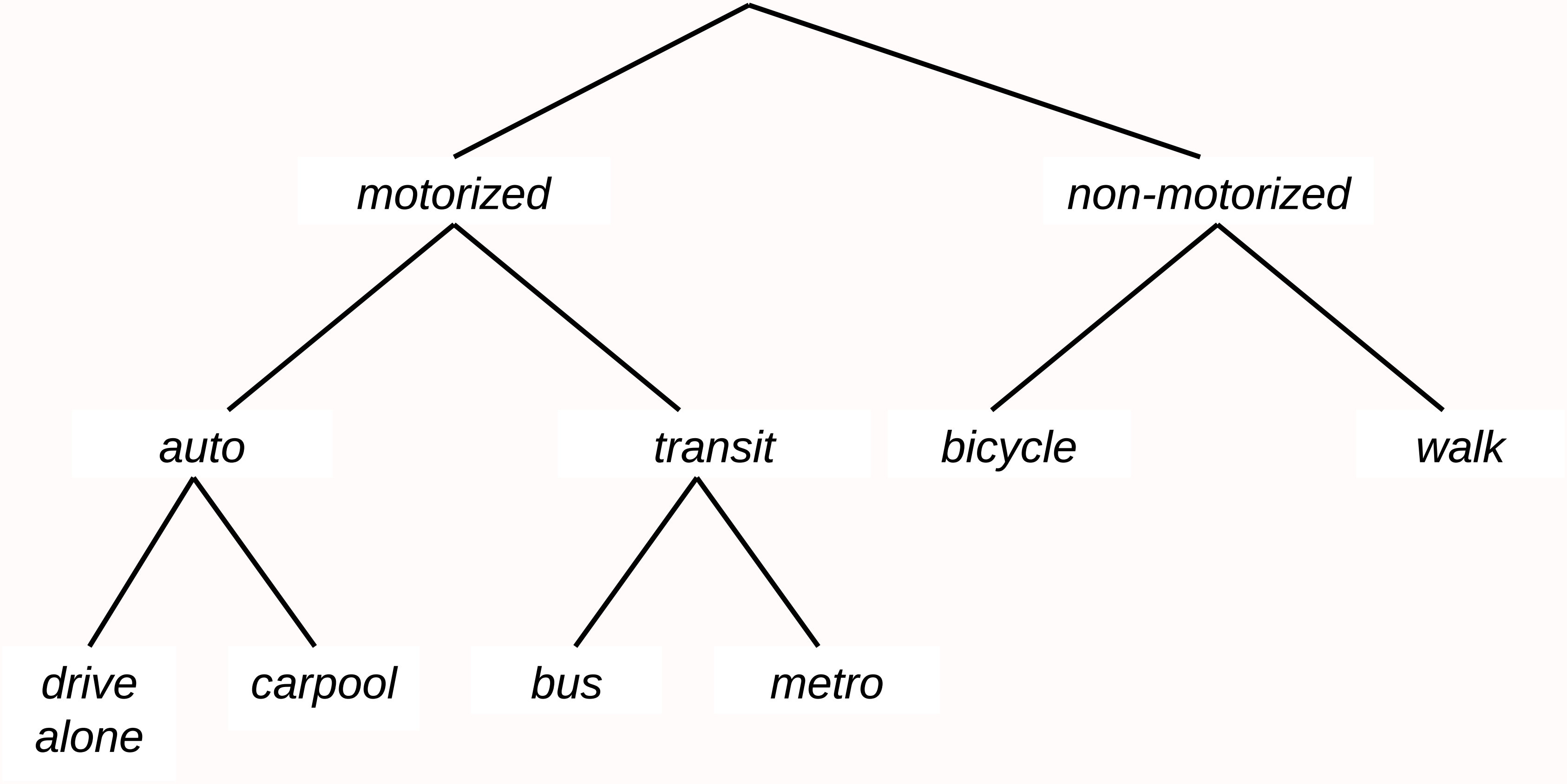
Population	Auto Share	Red Bus Share	Blue Bus Share
Auto people	**81.8%**	**9.1%**	**9.1%**
Transit people	**5.2%**	**47.4%**	**47.4%**
Total	43.5%	28.25%	28.25%

MOTIVATION FOR NESTED LOGIT

- **Overcome the IIA Problem of Multinomial Logit when**
  - **-- Alternatives are correlated**
    (e.g., red bus and blue bus)
  - **-- Multidimensional choices are considered**
    (e.g., departure time and route)

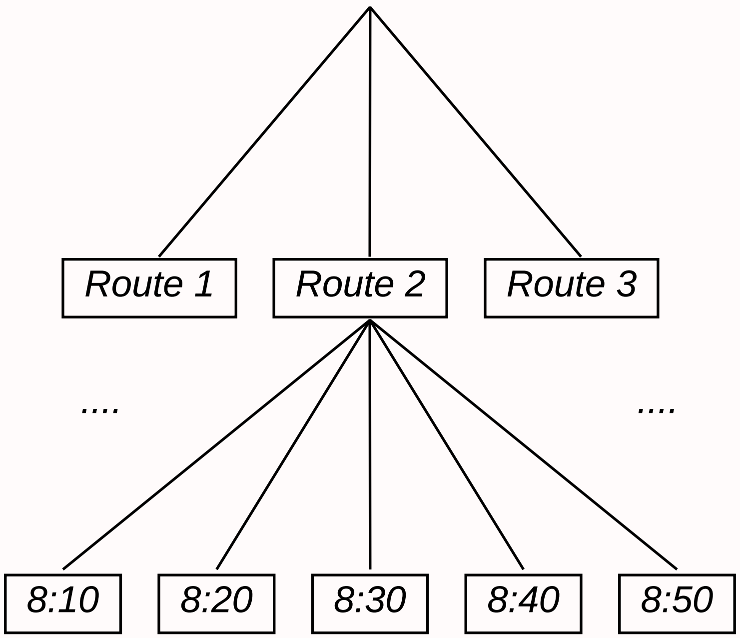
TREE REPRESENTATION OF NESTED LOGIT

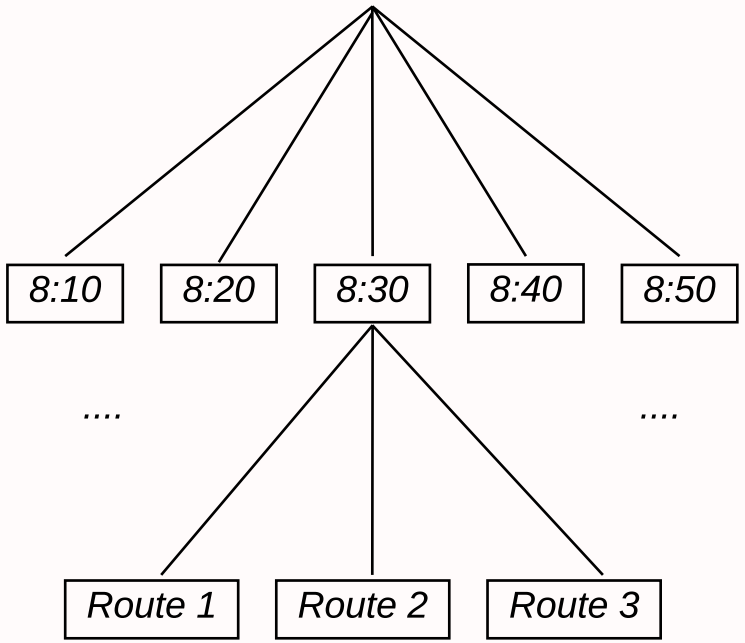
- **Example: Mode Choice (Correlated Alternatives)**



TREE REPRESENTATION OF NESTED LOGIT

- **Example: Route and Departure Time Choice (Multidimensional Choice)**

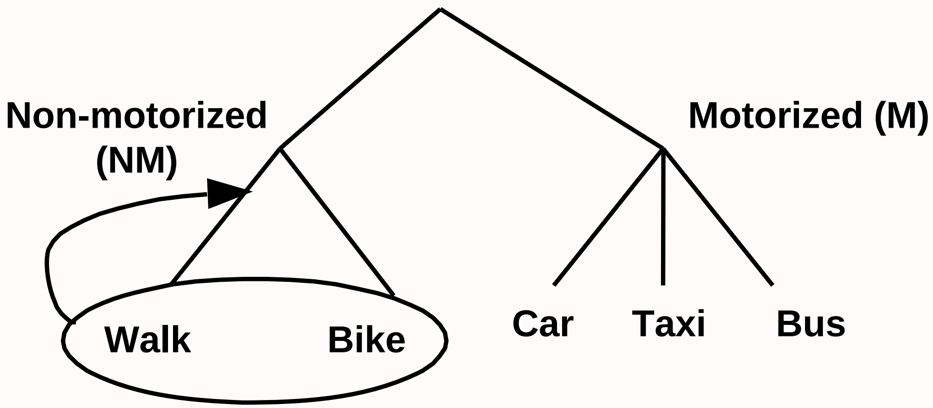




NESTED MODEL ESTIMATION

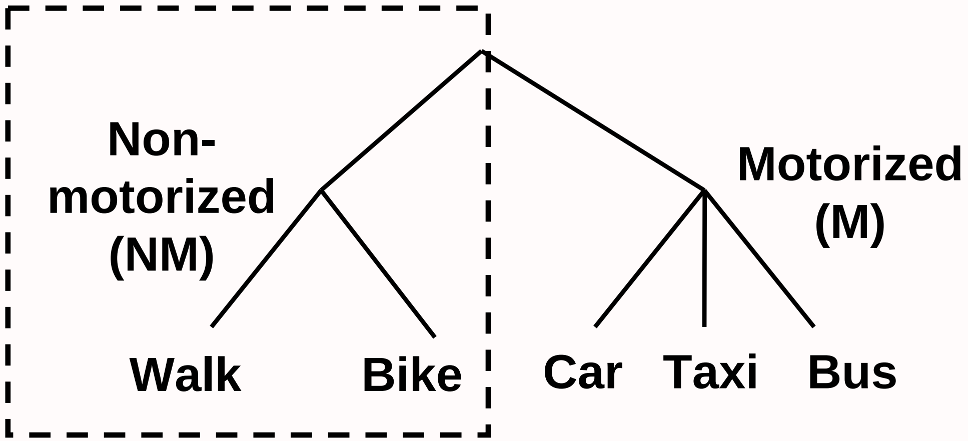
- **Logit at each node**
- **Utilities at lower level enter at the node as the *inclusive* value**

$$I_{NM} = \ln\left(\sum_{i \in C_{NM}} e^{V_i}\right)$$



- **The inclusive value is often referred to as *logsum***

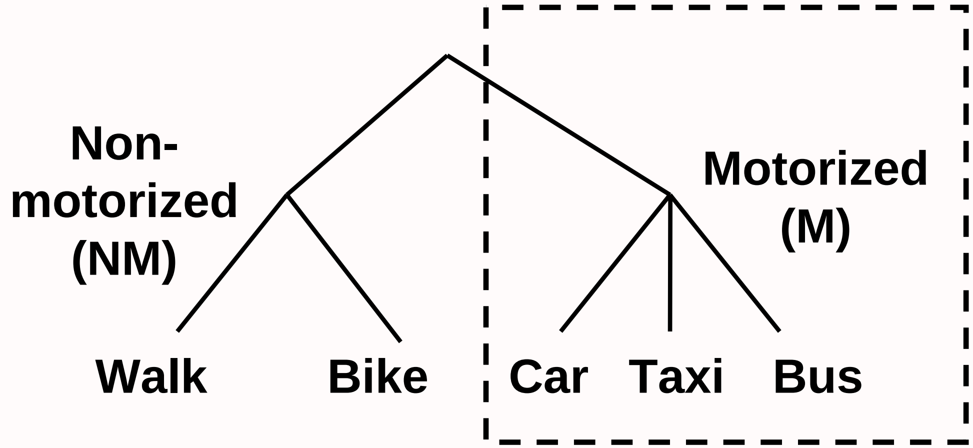
NESTED MODEL - EXAMPLE



$$P(i \mid NM) = \frac{e^{V_i}}{e^{V_{Walk}} + e^{V_{Bike}}} \qquad i = Walk, Bike$$

$$I_{NM} = \ln(e^{V_{Walk}} + e^{V_{Bike}})$$

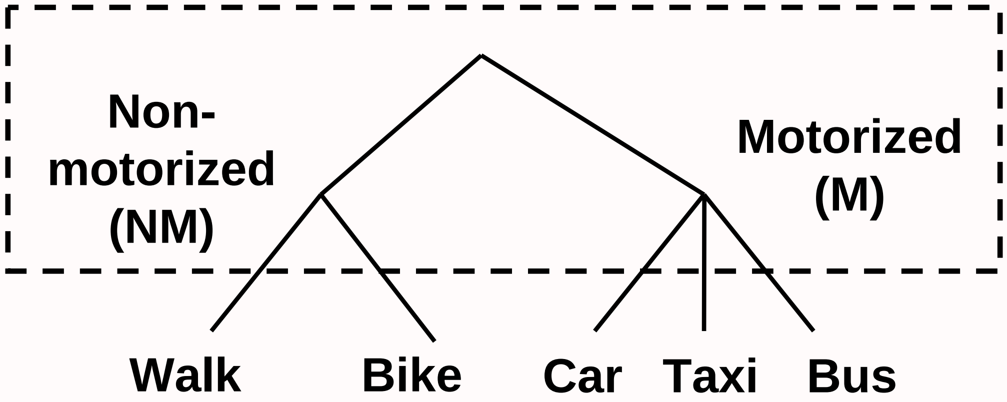
NESTED MODEL - EXAMPLE



$$P(i \mid M) = \frac{e^{V_i}}{e^{V_{Car}} + e^{V_{Taxi}} + e^{V_{Bus}}} \qquad i = Car, Taxi, Bus$$

$$I_M = \ln(e^{V_{Car}} + e^{V_{Taxi}} + e^{V_{Bus}})$$

NESTED MODEL - EXAMPLE



$$P(NM) = \frac{e^{a_{NM} + \gamma I_{NM}}}{e^{a_{NM} + \gamma I_{NM}} + e^{\gamma I_M}}$$

$$P(M) = \frac{e^{\gamma I_M}}{e^{a_{NM} + \gamma I_{NM}} + e^{\gamma I_M}}$$

NESTED MODEL - EXAMPLE

- **Calculation of choice probabilities**

$$\mathrm{P}(Bus) = P(Bus \mid M) \cdot P(M)$$

$$= \left[\frac{e^{V_{Bus}}}{e^{V_{Car}} + e^{V_{Taxi}} + e^{V_{Bus}}} \right] \cdot \left[\frac{e^{\gamma I_M}}{e^{a_{NM} + \gamma I_{NM}} + e^{\gamma I_M}} \right]$$

$$= \left[\frac{e^{V_{Bus}}}{e^{V_{Car}} + e^{V_{Taxi}} + e^{V_{Bus}}} \right] \cdot \left[\frac{e^{\gamma \ln(e^{V_{Car}} + e^{V_{Taxi}} + e^{V_{Bus}})}}{e^{a_{NM} + \gamma \ln(e^{V_{Walk}} + e^{V_{Bike}})} + e^{\gamma \ln(e^{V_{Car}} + e^{V_{Taxi}} + e^{V_{Bus}})}} \right]$$