Urban Public Transport Connectivity

OUTLINE

1. A Framework for Improving Connectivity[1]
2. Assessing the Transfer Penalty[2, 3]

1. Crockett, C., "A Process for Improving Transit Service Connectivity," MST (Master of Science in Transportation) Thesis, MIT, September 2002
2. Guo, Z., "Assessment of the Transfer Penalty for Transit Trips: A GIS-based Disaggregate Modeling Approach," MCP (Master in City Planning) Thesis, MIT, June 2003
3. 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).

INTRODUCTION

- Interchanges/Transfers are a basic characteristic of public transport
- They are necessary for area coverage
    - typically 30-60% of urban public transport trips involve 2 (or more) public transport vehicles
- A major source of customer dis-satisfaction contributing:
    - uncertainty
    - discomfort
    - waiting time
    - cost
- Often ignored in service evaluation and planning practice

A Framework For Improving Connectivity

Service connectivity is affected by:

- System elements
- Transfer facility elements
- Service elements

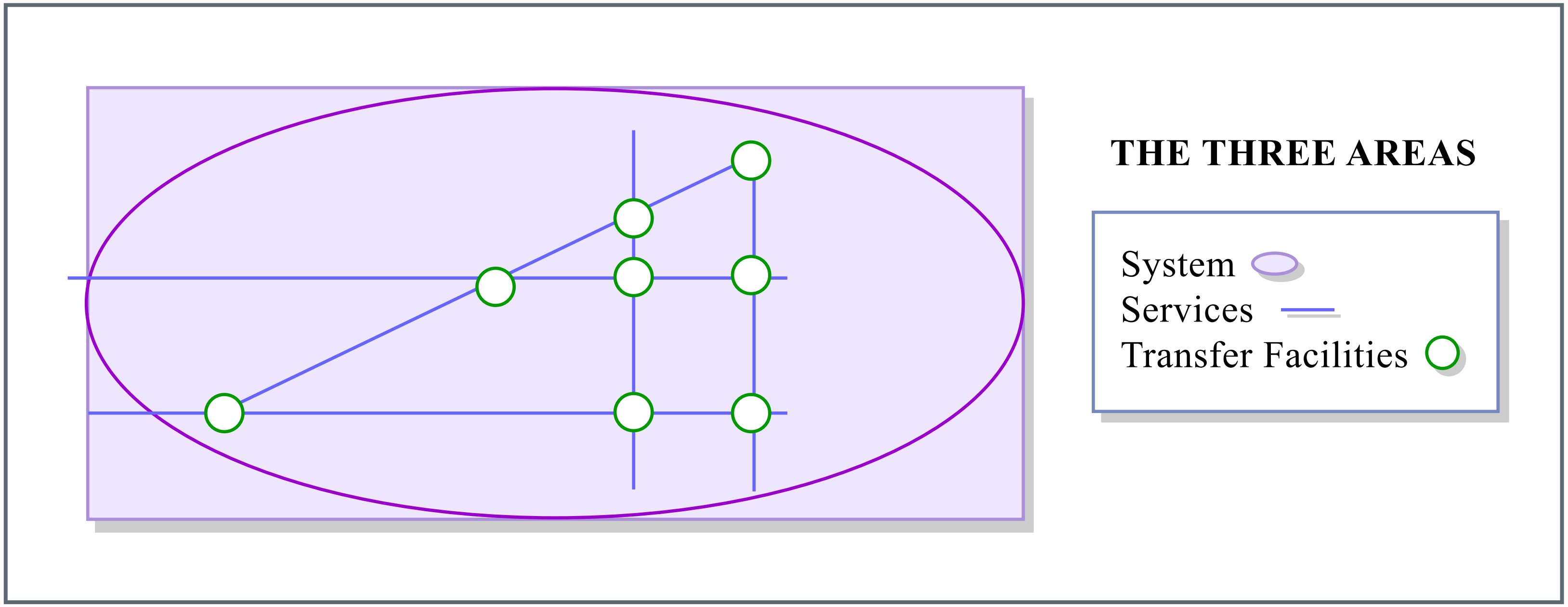


Figure by MIT OCW.

System Elements

Transfer Price	Pre-Trip Information	Fare Media	In-vehicle Information	Fare Control
Free	System Information with Trip Planner	Same	Real-time Connecting Route Info, Transfer Announcements	No Validation Needed and Can Leave Public Transportation Space
Discounted	System Information		Connecting Route Info, Transfer Announcements	No Validation Needed if Remain in Public Transportation Space
	Route Information		Connecting Route Information	Validation Needed, but No Delay Added to Trip
Full Additional Fare	No Information	Different	No Information	Validation Adds Delay to Trip

Transfer Facility Elements

Weather Protection	**En-Route Information**	**Changing Levels**	**Road Crossings**	**Walking Distance**	**Concessions**
Fully Protected Connection	Real time, System, Facility, and Schedule Information	No Vertical Separation	No Road Crossing Required	No Walking Required	Large Selection
Covered Connection	System, Facility, and Schedule Information				
Covered Waiting Area	Facility, and Schedule Information	Vertical Separation with Assistance	Road Crossing Required, but Assisted	Short Walk Required	Small Selection
	Schedule Information				
Open Waiting Area	No Information	Vertical Separation without Assistance	Unassisted Road Crossing	Long Walk Required	None.

Service Elements

Transfer Waiting Time	Span of Service
High Frequency	Matched
Matched Headways and Coordinated Arrivals and Departures	
Coordinated Arrivals and Departures	
No Coordination	Unmatched

Assessing the Transfer Penalty: a GIS-based Disaggregate Modeling Approach

Outline

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

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

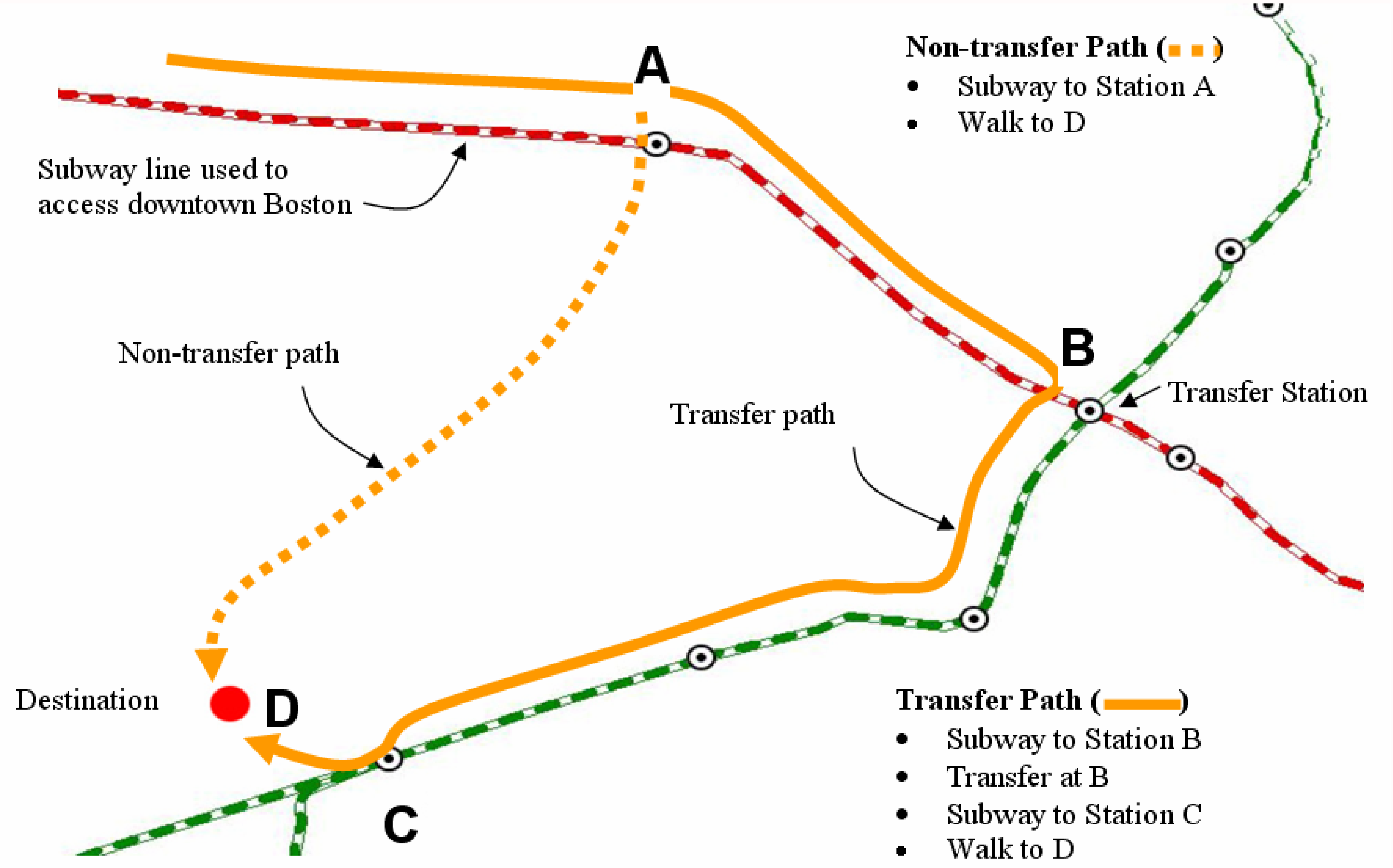
- **Define transfer and non-transfer paths to destination from subway line accessing downtown area**
- **For each path define attributes:**

  -- walk time -- transfer walk time

  -- in-vehicle time -- transfer wait time

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

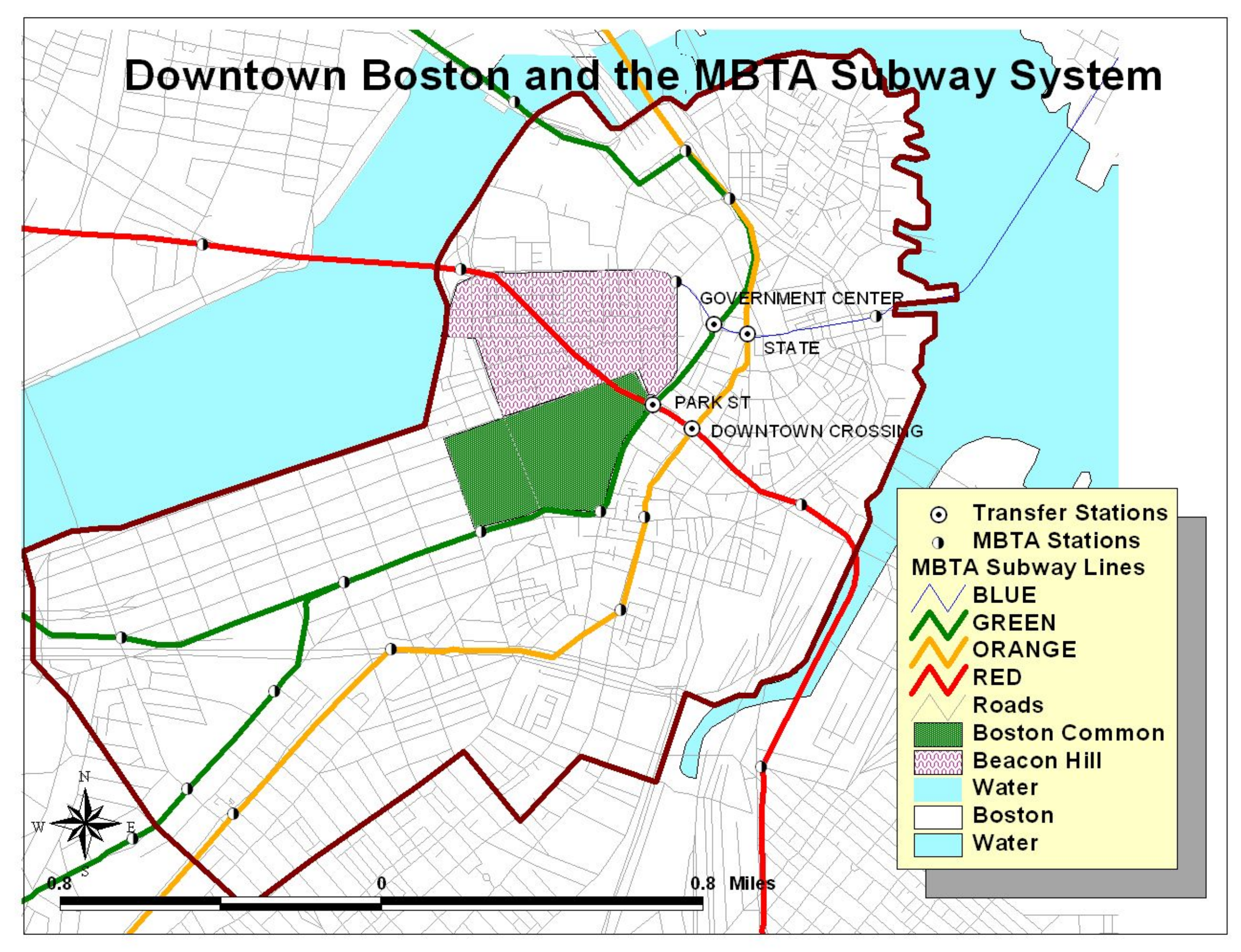
Two Options to Reach the Destination



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



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

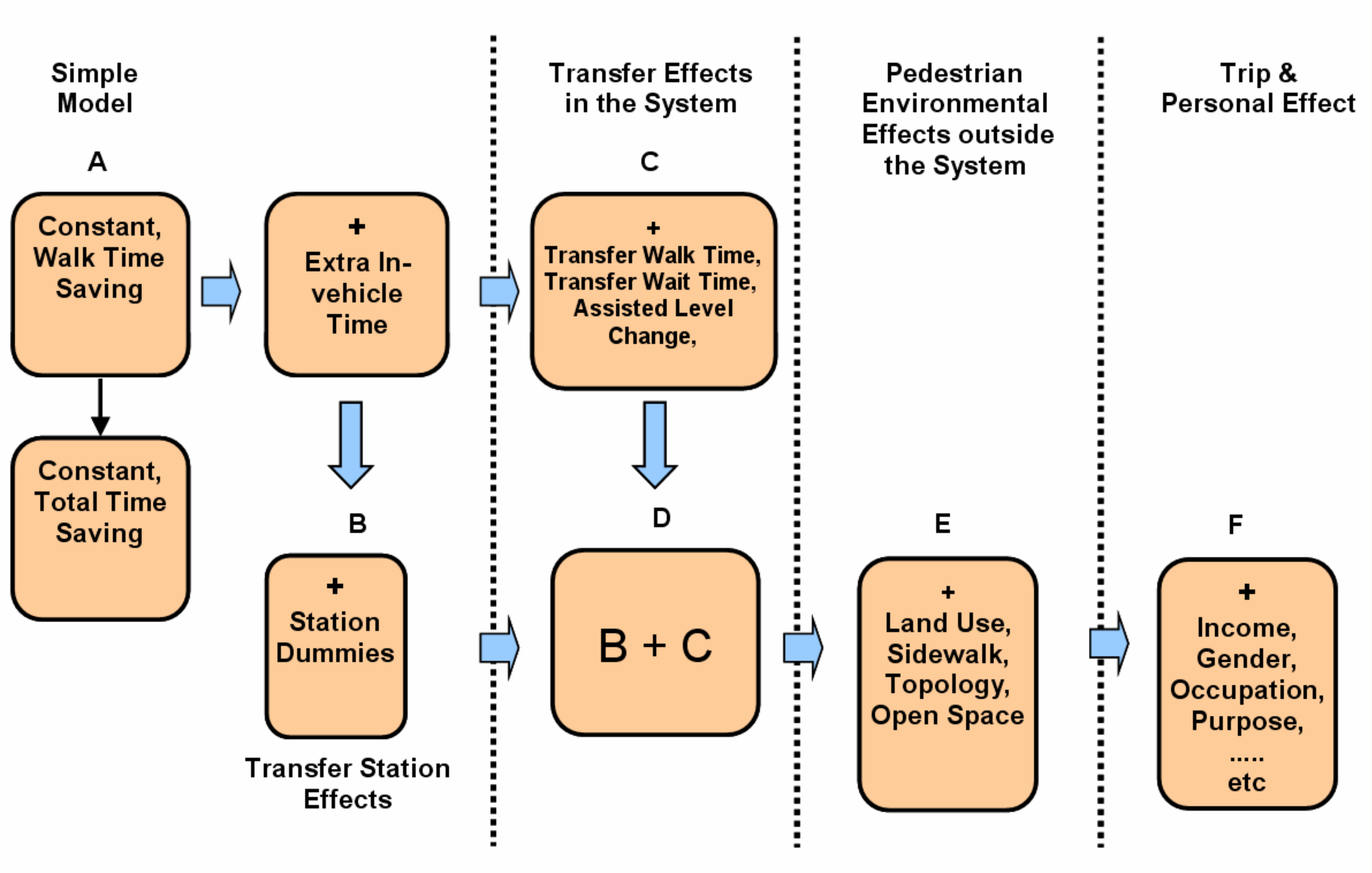
Variables (continued)

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



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	-2.39	-28.57
•Walk Time Savings (minute)	0.25	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