# 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).*

*Guo, Z., "Transfers and Path Choice in Urban Public transport Systems." PhD Dissertation (MIT, 2008).*



# TRANSFERS ARE IMPORTANT TO PUBLIC TRANSPORT

**Transfers are endemic in public transport**

**-- transfer: change of vehicle**

**-- public transport is unable to provide door-to-door service**

**Transfers are prevalent in major public transport networks**

**-- share of transfer trips in public transport**

**Boston: 43% (CTPS 1991)**
**London: 50% (LATS 2001)**
**New York: 33% (NYMTC 1997/98)**
**Chicago: 50%* (Crockett 2002 )**

## TRANSFERS ARE NOT WELL ANALYZED

**Understanding of the behavior is limited**

-- how are transfers perceived by passengers?

-- how do transfers affect the performance of public transport?

**Analysis methods are primitive**

-- lack of detail to improve understanding and applications

**Applications are sporadic and limited**

-- timed transfer: focuses on transfer waiting time

-- under-evaluate the impact of transfers and the benefit of transfer-related investments



## 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<br>Stockholm | Walking time to stop<br>Initial waiting time<br>Transit in-vehicle time<br>Transit cost | Subway-to-Subway<br>Rail-to-Rail<br>Bus-to-Rail<br>Bus-to-Bus | 4.4 minutes in-vehicle time<br>14.8 minutes in-vehicle time<br>23.0 minutes in-vehicle time<br>49.5 minutes in-vehicle time |
| Han, 1987<br>Taipei, Taiwan | Initial waiting time<br>Walking time to stop<br>In-vehicle time<br>Bus fare<br>Transfer constant | Bus-to-Bus<br>(Path Choice) | 30 minutes in-vehicle time<br>10 minutes initial wait time<br>5 minutes walk time |
| Hunt , 1990<br>Edmonton, Canada | Transfer Constant<br>Walking distance<br>Total in-vehicle time<br>Waiting time<br>Number of transfers | Bus-to-Light Rail<br>(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<br>New Jersey, NJ | Transfer Constant<br>In-vehicle time<br>Out-of-vehicle time<br>One way cost<br>Number of transfers | Auto-to-Rail<br>Rail-to-Rail<br>(Modal Choice) | 15 minutes in-vehicle time<br>1.4 minutes in-vehicle time |
| CTPS, 1997<br>Boston, MA | Transfer Constant<br>In-vehicle time<br>Walking time<br>Initial waiting time<br>Transfer waiting time<br>Out-of-vehicle time<br>Transit fare | All modes combined<br>(Path and Mode Choice) | 12-15 minutes in-vehicle time |
| Wardman, Hine and Stradling, 2001<br>Edinburgh, Glasgow, UK | Utility function not specified | Bus-to-Bus<br>Auto-to-Bus<br>Rail-to-Rail | 4.5 minutes in-vehicle time<br>8.3 minutes in-vehicle time<br>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

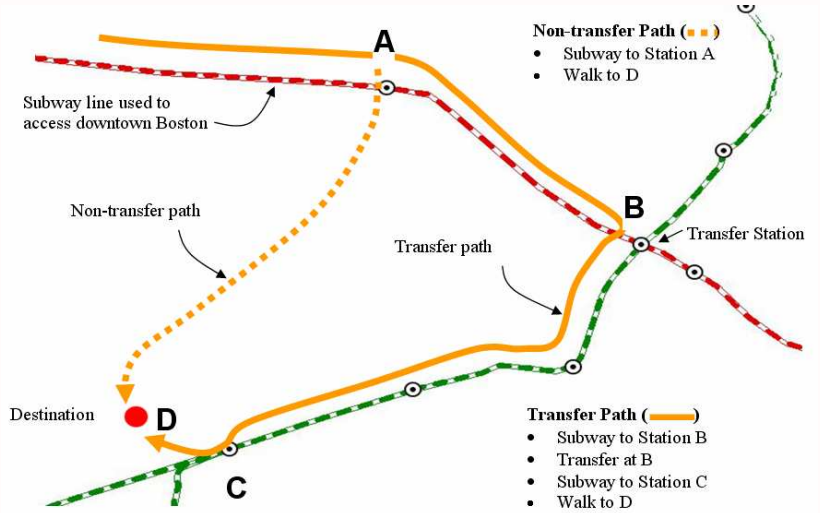
- Use standard on-board survey data including:
  - -- actual transit path including boarding and alighting locations
  - -- street addresses of origin and destination
  - -- demographic and trip characteristics
- Focus on respondents who:
  - -- travel to downtown Boston destinations by subway
  - -- 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**
  - **-- in-vehicle time**
  - **-- transfer walk 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

Map of Boston downtown subway system removed due to copyright restrictions.

## 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)

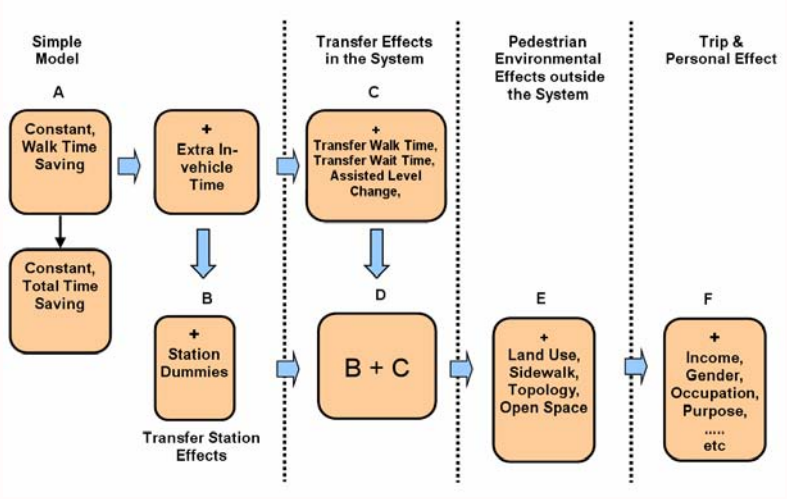
## C. Pedestrian Environment Variables

- **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**



# MODEL A RESULTS

| Variables | Coefficients | t statistics |
|---|---|---|
| Transfer Constant<br>Walk Time Savings (minutes) | -2.39<br>0.25 | -28.57<br>20.78 |
| # of Observations | 3140 | |
| Final log-likelihood | -1501.9 | |
| Adjusted $\rho^2$ | 0.309 | |

## Findings

- **A transfer is perceived as equivalent to 9.5 minutes of walking time, although about 2 minutes of this total is not actually part of the transfer, but the path chosen (i.e., average extra in-vehicle time for the transfer path)**

# 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



# 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 $\rho^2$ | 0.309 | | 0.369 | |

# MODEL B 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 C: TRANSFER ATTRIBUTES MODEL

## Specification

- Transfer attributes affect transfer perceptions:
  - -- transfer walk time
  - -- transfer wait time
  - -- assisted change in level

# 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 $\rho^2$ | 0.309 | | 0.369 | | 0.385 | |



# MODEL C 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 D: COMBINED ATTRIBUTE & STATION MODEL

## Specification

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



# 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 $\rho^2$ | 0.309 | 0.369 | 0.385 | 0.414 | 0.357 |

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

# MODEL D 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 E: PEDESTRIAN ENVIRONMENT MODEL

## Specification

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

# 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 $\rho^2$ | 0.309 | 0.369 | 0.385 | 0.414 | 0.357 | 0.425 | 0.376 |
| Note, ***: P < 0.001; **: P < 0.05; *: P < 0.1 | | | | | | | |



# MODEL E 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

# 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 $\rho^2$ | The Range of the Penalty (Equivalent Value of ) |
|---|---|---|---|
| A | Transfer constant | 0.309 | 7.5 minutes of walking time |
| B | Government Center<br>Downtown Crossing<br>State | 0.369 | 4.8 ~ 9.7 minutes of walking time |
| C | Transfer constant<br>• Transfer walk time<br>• Transfer wait time<br>• Assisted Level Change | 0.385 | 4.3 ~ 15.2 minutes of walking time |
| D | Transfer constant<br>• Transfer walk time<br>• Transfer wait time<br>• Assisted Level Change<br>• Government Center | 0.414 (Peak)<br>0.357 (Off-peak) | 4.4 ~ 19.4 minutes of walking time (Peak)<br><br>2.3 ~ 21.4 minutes of walking time (Off-peak) |

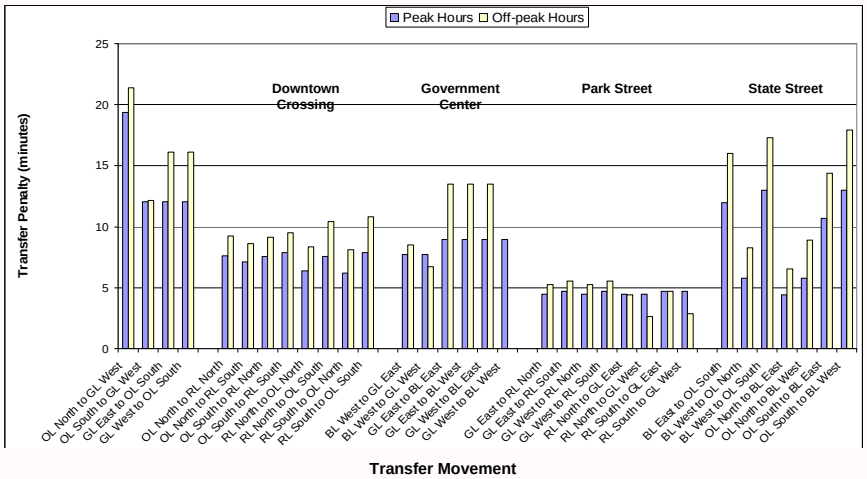
# COMPARISON OF THE TRANSFER PENALTY WITH PRIOR FINDINGS

| 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 |

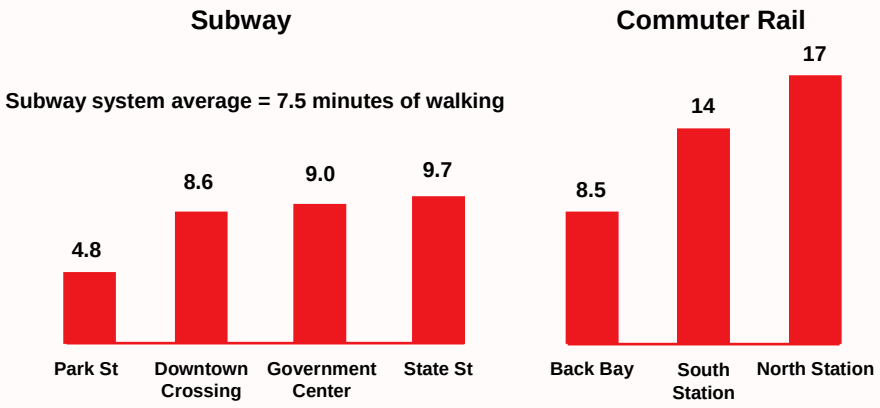
* Minutes of in-vehicle time



# TRANSFER PENALTY HAS GREAT VARIATION BY MOVEMENT



# BOSTON FINDINGS: TRANSFER PENALTY IS HIGH




- Transfers are perceived very negatively by passengers



# LONDON FINDINGS: TRANSFER PENALTY IS LOWER

One transfer equals 4.9 minutes of in-vehicle time (2.5 minutes of walking time)

Compare Boston subway with London Underground

-- transfer penalty is higher in Boston subway: 7.5 vs. 2.5 minutes of walking

-- but Boston subway has simple transfer environments

-- implies that Bostonians dislike transfers three times more than Londoners

# BIG VARIATION ACROSS LONDON STATIONS

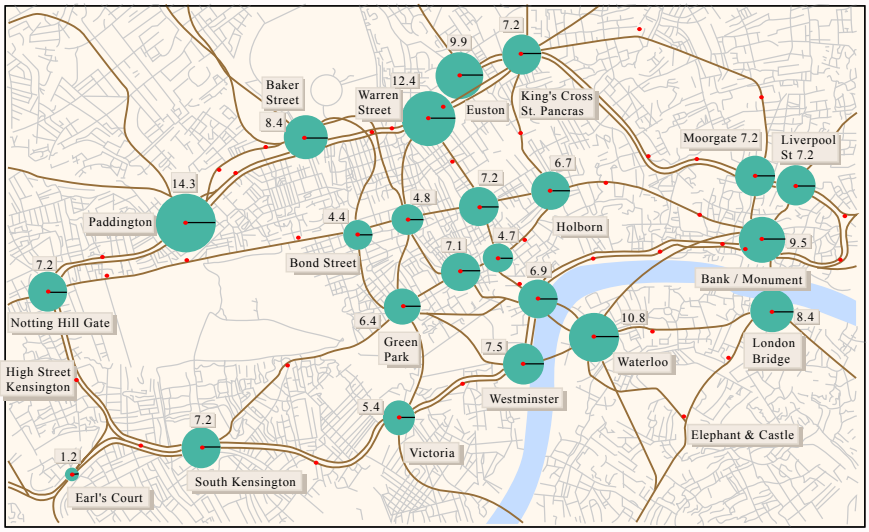



Figure by MIT OpenCourseWare.



# APPLICATION 1: MONITORING PASSENGER FLOW

**Crowding is a big concern in the Underground**

**Current treatment of transfer**

**One transfer = 3.5 minutes in-vehicle time, uniform across system**

**Update the treatment to reflect station and movement differences**

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# UPDATED PASSENGER FLOWS

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**Current method underestimates passenger flows on the circumferential service due to the under-estimated transfer penalty in the Underground**



# APPLICATION 2: EVALUATING TRANSFER-RELATED PROJECTS

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# CONCLUSIONS

## Methodology

-- Boston: captures the trade-off between one transfer and saving walk time

-- London: correct prediction = 80%

## Behavior

-- quantification of transfer experience

-- average as well as variations (station, movement, trip, people)

## Applications

-- monitoring system performance

-- project evaluation, prioritization, and justification



# APPENDIX:
# MBTA Commuter Rail to Subway Transfer Study

## EGRESS MODAL CHOICES IN THREE STATIONS

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## EGRESS PATH CHOICES FROM NORTH

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## EGRESS STATION CHOICES FROM SOUTH

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## POSSIBLE MODELING STRUCTURES

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# SEQUENCE OF MODEL DEVELOPMENT

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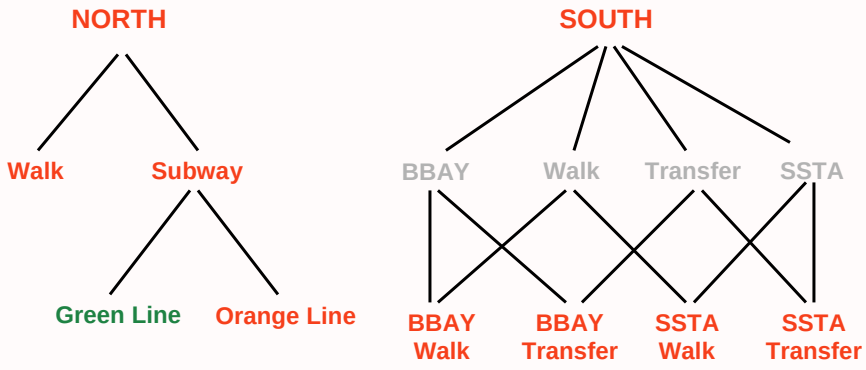
# POSSIBLE MODELING STRUCTURES



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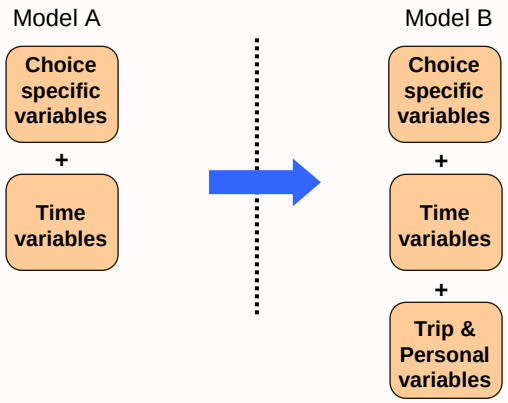





# RESULTS: NORTH COMMUTER RAIL

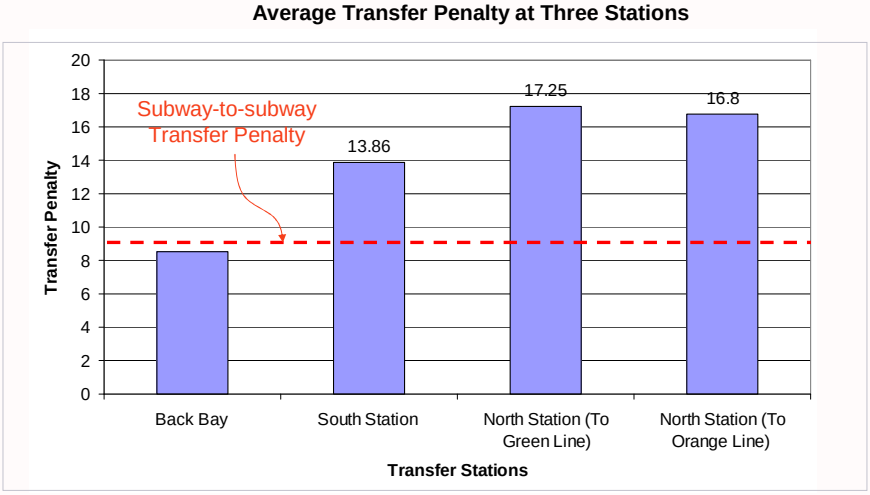
| Variables | | MNL | |
|---|---|---|---|
| | | Model A | Model B |
| **Intercept** | | | |
| Green Line | | -3.45 *** | -4.86 *** |
| Orange Line | | -3.36 *** | -4.72 *** |
| **Travel Time Attributes** (minutes) | | | |
| Walk Time (all three alternatives) | | -0.20 *** | -0.21*** |
| In-vehicle Time (2 transfer alternatives) | | -0.08 *** | -0.07 * |
| **Trip & Personal Attributes** (specific to non-transfer alternative) | | | |
| Fare Type: Monthly Pass | | | |
| Frequent Rider (>=3 days/week) | | | -0.81*** |
| Reliability Sensitive (rating=1) | | | -0.56 * |
| Reliability Insensitive (rating=5) | | | -1.08*** |
| Scale | | | -0.23* |
| Transfer Penalty (minutes of walk) | To Green Line | 17.3 | 23.1 |
| | To Orange Line | 16.80 | 22.5 |
| Adjusted $\rho^2$ | | 0.299 | 0.321 |

# RESULTS: SOUTH COMMUTER RAIL

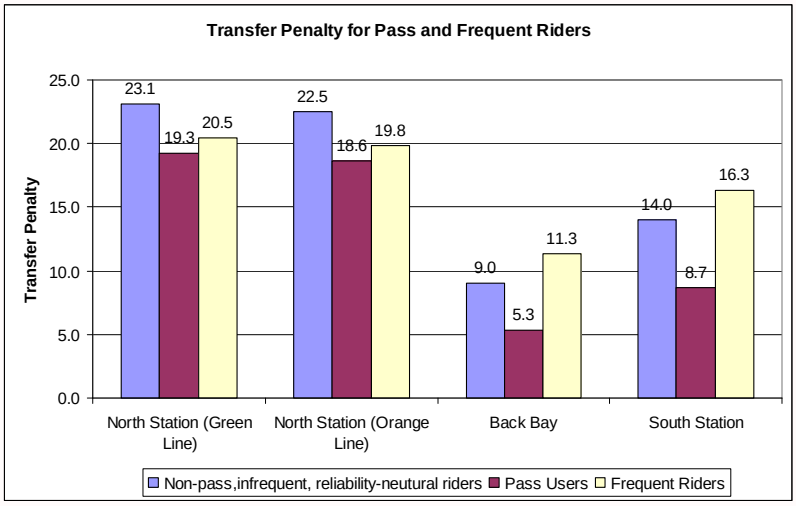
| Variables | | MNL | |
|---|---|---|---|
| | | Model A | Model B |
| **Intercept** | | | |
| Transfer from Back Bay | | -2.83 *** | -3.01 *** |
| Walk from South Station | | -1.05 *** | -1.04 *** |
| Transfer from South Station | | -4.49 *** | -4.69 *** |
| **Travel Time Attributes** (minutes) | | | |
| Walk Time (all four alternatives) | | -0.33 *** | -0.33 *** |
| Subway In-vehicle Travel Time (2 alternatives) | | -0.28 *** | 0.29 *** |
| **Trip & Personal Attributes** (2 alternatives) | | | |
| Fare Type: Monthly Pass | | | -1.21*** |
| Frequent Rider (>=3 days/week) | | | 0.76 ** |
| Reliability Sensitive (rating=1) | | | -0.51 |
| Reliability Insensitive (rating=5) | | | 0.04 |
| Transfer Penalty (minutes of walk) | Back Bay | 8.51 | 9.0 |
| | South Station | 13.86 | 14.0 |
| Adjusted $\rho^2$ | | 0.498 | 0.511 |



# TRANSFER PENALTIES ACROSS STATIONS



# TRANSFER PENALTIES ACROSS RIDER GROUPS



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