Origin, Destination, and Transfer Inference (ODX)

- Using automatically collected data: AFC, AVL, APC
- Infers destinations in open systems
- Infers transfers
- Only captures existing demand
- Does not make inferences for all fare transactions
  - only one tap
  - cash
  - fare evasion
  - trips on other modes
- Validated with surveys
- Needs to be scaled up to full demand

Key Automated Data Collection Systems

- Automatic Vehicle Location (AVL)
- Automatic Fare Collection (AFC)
- Automatic Passenger Counting (APC)

OD Matrix Estimation

Route Level

- APC provides “control totals”

Network Level

Full Intermodal Journey Inference

Route Level OD Estimation with APC
Iterative Proportional Fitting (IPF)

- Also known as biproportional fitting and matrix scaling
- Scales cell values of a sampled origin-destination matrix so that row and column sums equal marginal target values (counted boardings and alightings)
- If all values are strictly positive, IPF converges to a unique MLE solution
- Zeroes affect the solution

Initialization

<table>
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<tr>
<th></th>
<th>A</th>
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Total Alightings: 1 2 3
Target Alightings: 30 20 40

Step 1

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Total Alightings: 13.3 28.3 48.3
Target Alightings: 30 20 40

Step 2

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Total Alightings: 30 20 40
Target Alightings: 30 20 40
Factor: 2.3 0.7 0.8

Step 3

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Total Alightings: 23.8 21.3 44.9
Target Alightings: 30 20 40

Step 4

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Total Alightings: 30 20 40
Target Alightings: 30 20 40
Factor: 1.3 0.9 0.9

Step 5

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Total Alightings: 26.8 20.5 42.7
Target Alightings: 30 20 40

Step 6

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Total Alightings: 30 20 40
Target Alightings: 30 20 40
Factor: 1.1 1.0 0.9
Iterative Proportional Fitting (IPF)

**Step 7**

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Total Alightings: 28.2 20.3 41.6
Target Alightings: 30 20 40

**Step 8**

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Total Alightings: 30 20 40
Target Alightings: 30 20 40
Factor: 1.1 1.0 1.0

Iterative Proportional Fitting (IPF)

**Step 9**

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Total Alightings: 28.9 20.2 40.9
Target Alightings: 30 20 40

**Step 10**

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Total Alightings: 30 20 40
Target Alightings: 30 20 40
Factor: 1.0 1.0 1.0

Iterative Proportional Fitting (IPF)

**Step 11**

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Total Alightings: 29.3 20.1 40.6
Target Alightings: 30 20 40

**Step 12**

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Total Alightings: 30 20 40
Target Alightings: 30 20 40
Factor: 1.0 1.0 1.0

Route Level ODX with AFC and AVL

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<td>AVL</td>
<td>iBus</td>
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<td>APC (sample)</td>
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<tr>
<td>Gatelines (Rail stations)</td>
<td>some</td>
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Closed, Detailed, Including transfers
Origin Inference

Matching the AFC transactions with the AVL data to infer boarding stops

Destination Inference: Closest Stop

Key Assumptions
- The destination of many trip segments is close to the origin of the following trip segment.
- No intermediate private transportation mode trip segment
- Passengers will not walk a long distance
- Last trip of a day ends at the origin of the first trip of the day (symmetry assumption)

Origin Inference Results: London

- 10 weekdays, 6.1 to 6.5 million Oyster bus boardings per day
- 96% of boarding locations inferred within ± 5 min
  - 96% within ± 2 min
  - 93% within ± 1 min
  - 28% between arrival and departure times
- 2.6% beyond ± 5 min.
- 1.4% not matched to iBus route or trip

Destination Inference

Bus

Rail

Time

Space

transfer

non-transportation activity

transfer
Destination Inference

Feasibility Tests
- distance and time between alighting and next boarding stop
- relative location

Destination Inference Results: London

Ten-weekday average: 6-10 and 13-17 June 2011
- 15.6 to 16.1 million Oyster transactions
- 9.5 to 10.1 million journey stages
- 3.0 to 3.1 million Oyster cards
- 74.5% of bus alighting times and locations inferred within 1 km of subsequent Oyster tap
- 5% are the only transaction that day
- 6.7% beyond maximum distance (750 m)
- 3.2% of buses heading away from first origin of day
- 3.6% of buses heading away from next origin
- 2.5% origin or next origin not inferred
- 2.5% beyond origin-error tolerance
- 2.5% subsequent origin beyond origin-error tolerance

Comparison to Other Sources
- Small stop-by-stop differences between estimated OD and results from the Bus OD Survey (BODS)
- BODS underestimated the ridership in peak periods and midday, especially when BODS survey return rates are low (50%-80%).
- Value for transportation planning
Destination Inference: Minimum Cost Path

- Tap Location
- Next Tap Location
- Walk

Destination Inference: MBTA

- Inferred
- No Target Location
- Target Location Too Far
- Non-Feasible Path
- Unknown Origin
- Next Origin Reached Too Fast
- Circuitous

Inference Probability

- destination
- inferable destination
- bus destination
- green line surface destination
- rail destination
Interchange (Transfer) Inference

Journey stage: any portion of a rider's journey that is represented by a single Oyster bus record or by a rail entry/exit pair.

Interchange (Transfer): a transition between two consecutive journey stages that does not contain a trip-generating activity. Its primary purpose, rather, is to connect a previous stage’s origin to a subsequent stage’s destination.

Full journey: a sequential set of journey stages connected exclusively through interchanges.

Trip-Linking Assumptions

Examples:
- Maximum interchange distance
- Circuity between stages
- Ending journey near origin

Temporal conditions

Spatial conditions

Logical conditions

Examples:
- Interchange time (distance)
- Maximum bus wait time (headways)
- Must not continue at same station, same route, etc.

Interchange Inference Results

Ten-day average: 6-10 and 13-17 June 2011

- Link status inferred for 91% of journeys stages
  - Link status could not be inferred for remaining 9% of stages: assumed not linked

- Stages per journey:
  - One stage: 4 million (66%)
  - Two stages: 1.5 million (25%)
  - Three stages: 400,000 (7%)
  - Four or more stages: 170,000 (3%)

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Comparison to Travel Surveys (LTDS)

Trip-Level Scaling with Transfer Information and without APC

- AFC, AVL, and ODX give an OD matrix, but only for a sample of passenger trips.
- APC gives full count of boardings and alightings:
  - for all vehicles, a fraction of vehicles, or none.
- Iterative Proportional Fitting (IPF) can be used to assign remaining destinations in probability:
  - control totals are APC boardings and alightings minus ODX boardings and alightings.

Trip-Level Scaling

- The complete OD matrix $R$ can be divided into an inferred part $I$ and a missing part $M$.
  
  $$R = I + M$$

- The missing part can be divided into trips with uninferrred destinations $U$ and trips not observed $N$.
  
  $$M = U + N$$

- Therefore
  
  $$R = I + U + N$$

  and we want to estimate $R$ as
  
  $$\hat{R} = I + \tilde{U} + \tilde{N}$$
Trip-Level Scaling with Transfer Information and without APC

- A portion of trips \( N \) is not observed.
  - Trips with uninferrable origins
  - Trips without farebox interaction
- They can be estimated by combining ODX with passenger counts, e.g., APC data.
- Let \( \tilde{n} \) be a vector of boarding scaling factors.
- Assuming destinations are distributed like observed trips,

\[
\tilde{N} = \tilde{n} \left( I + \tilde{U} \right)
\]

Journey Matrix Scaling

- Problem
  - Estimate expansion factors to scale Oyster-inferred full-journeys to represent non-Oyster and incompletely documented Oyster journeys.
- Challenges
  - Control totals available for stations, routes, but not itineraries
  - Large number of unique itineraries observed per day (if bus activity is aggregated to the route level)
  - Trillions of solutions can satisfy control totals
- Approach
  - Scale all full-journey itineraries to satisfy control totals

\[
\tilde{R} = I + \tilde{U} + \tilde{N}
\]

\[
= I + \tilde{U} + \tilde{n} \left( I + \tilde{U} \right)
\]

\[
= (1 + \tilde{n}) \left( I + \tilde{U} \right)
\]

\[
= (1 + \tilde{n}) \left( I + u\tilde{L} \right)
\]
Journey Matrix Scaling

1. Initialize:
\[ \hat{a}_i \leftarrow 1.0 \quad \forall i \in I \]

2. Update:
\[ \hat{\Delta}_n \leftarrow \sum_{i \in I} b_{n,i} \hat{a}_i t_i \quad \forall n \in N \]
\[ \hat{a}_i \leftarrow \frac{\hat{\Delta}_n}{\sum_{n \in N} b_{n,i} \Delta_n} \quad \forall i \in I \]

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\[ \alpha = 1.0 \]
\[ \alpha(1 + \alpha) = 1.0 \]

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<th>Movement</th>
<th>AB</th>
<th>ABC</th>
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<th>CB</th>
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<th>DE</th>
<th>Totals</th>
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<th>Control</th>
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</table>

\[ \alpha(1 + \alpha) = 1.0 \]
Journey Matrix Scaling

Initialize:
\[ \tilde{a}_i \leftarrow 1.0 \quad \forall i \in I \]

Update:
\[ \Delta_n \leftarrow \frac{\sum_{i \in I} b_{n,i} \tilde{a}_i t_i}{\sum_{n \in N} b_{n,i}} \quad \forall n \in N \]
\[ \tilde{a}_i \leftarrow \tilde{a}_i + \Delta_n \quad \forall i \in I \]

Count Location
<table>
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<tr>
<th>Station/Stop Movement</th>
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<th>ABDE</th>
<th>CB</th>
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<tr>
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<td>0</td>
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<td>0</td>
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<td>1</td>
</tr>
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\[
\alpha = \frac{0.34}{100} + \frac{0.33}{101} + \frac{0.35}{199} + \frac{0.34}{51} + \frac{0.35}{99} = 0.34, \ 0.33, \ 0.35, \ 0.34, \ 0.35
\]

\[
\alpha (1+\alpha) = \frac{26}{100} + \frac{25}{101} + \frac{51}{199} + \frac{25}{51} + \frac{13}{99} = 26, \ 25, \ 51, \ 25, \ 13
\]

Journey Matrix Scaling

Convergence of Journey Matrix Scaling Heuristic vs. Standard Deviation of \( \alpha \) Across Itineraries

0 5 10 15 20

STDDEV(\( \alpha \)) RMSE
0.01 0.66
0.05 3.36
0.15 10.72

Victoria Underground Station
Wednesday, 29 October 2011

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Scaling Factor Results

Journey Scaling vs. IPF (rail links only)

Full-Journey Scaling Results

References
