Using Automated Data Sources to Improve the Performance of Public Transport Systems: A Framework and Applications

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Outline

- The changing environment and customer expectations
- Automated Data Collection Systems
- Framework for using Automated Data Sources (ADS)
- Analysis building blocks
  - OD Matrix Estimation
  - Inferring Train Loads
  - Measuring Service Reliability
- Future Prospects

The Changing Environment and Customer Expectations

- Many customers expect a personal relationship with service providers, e.g. Amazon
- Information technology advances raise expectations and provide new opportunities, e.g. mobile internet
- Rising incomes result in fewer captive riders
- Need to attract choice riders
- Challenges for public transport
  - Gap between customer expectations and current reality
  - Uber-type competition
  - AV in mid-term future

Automated Data Systems

- **Automatic Fare Collection Systems (AFC)**
  - increasingly based on contactless smart cards with unique ID
  - provides entry (exit) information (spatially and temporally) for individual passengers
  - traditionally not available in real-time
- **Automatic Vehicle Location Systems (AVL)**
  - bus location based on GPS
  - train tracking based on track circuit occupancy
  - available in real time
- **Automatic Passenger Counting Systems (APC)**
  - bus systems based on sensors in doors with channelized passenger movements
  - passenger boarding (alighting) counts for stops/stations with fare barriers
  - train load-weigh systems can be used to estimate number of passengers on board
  - traditionally not available in real-time

Public Transport Operators/Agencies are at a Critical Transition in Data Collection Technology

Manual	⟹	Automatic
• low capital cost		• high(er) capital cost
• high marginal cost		• low marginal cost
• small sample sizes		• large sample sizes
• "hard and soft"		• "hard"
• unreliable		• errors and biases can be estimated and corrected
• limited spatially and temporally		• ubiquitous
• not available immediately		• available in real-time or quasi real-time

ADS - Potential

- Integrated ADS database
- Models and software to support many agency decisions using database
- Monitoring and insight into normal operations, special events, unusual weather, etc.
- Large, long time-series disaggregate panel data to better understand customer experience and travel behavior

ADS - Reality

- Most ADS systems are implemented independently
- Data collection is ancillary to primary system function
  - AVL - emergency notification, stop announcements
  - AFC - fare collection and revenue protection
- Many problems to overcome:
  - not easy to integrate data
  - requires new resources and expertise

Opportunities

- ADS
  - monitoring system status
  - measuring reliability
  - understanding customer behavior
- Data + Computing
  - simulation-based predictive performance models
- Communications
  - real time information (demand)
  - operations management (supply)
- Systematic approaches for planning, operations, real-time control

Key Agency/Operator Functions

A. Off-Line Functions

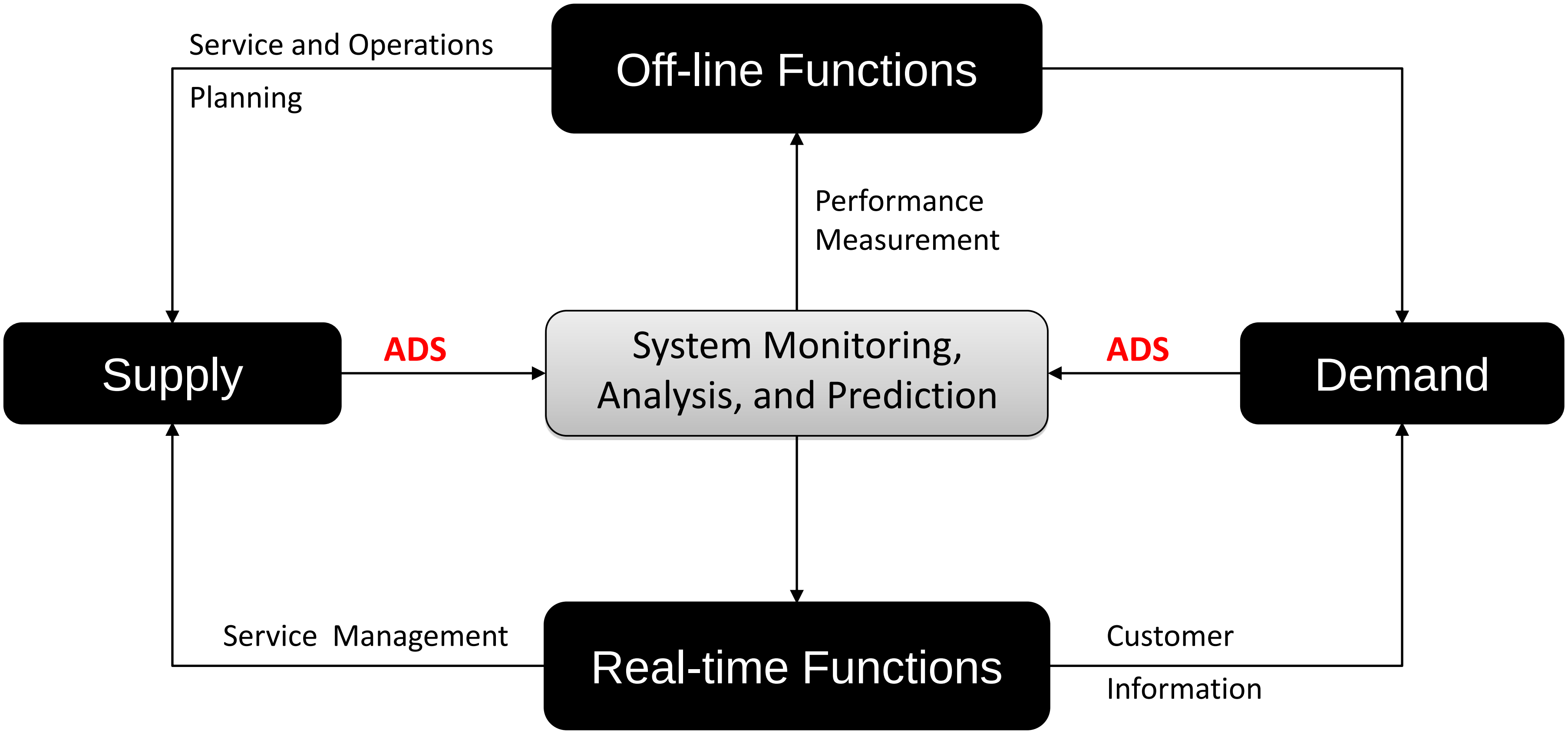
- Service and Operations Planning
  - Network and route design
  - Frequency setting and timetable development
  - Vehicle and crew scheduling
- Performance Measurement
  - Measures of operator performance against plans/contract specs
  - Measures of customer experience

Key Agency/Operator Functions

B. Real-Time Functions

- Service and Operations Control and Management
  - Dealing with deviations from plans, both minor and major
  - Dealing with unexpected changes in demand
- Customer Information
  - Information on routes, trip times, vehicle arrival times, etc.
  - Increasingly dynamic

Key Functions



Analysis Building Blocks

- OD Matrix Estimation
- Inferring train loads
- Measuring Service Reliability

OD Matrix Estimation

Objective:

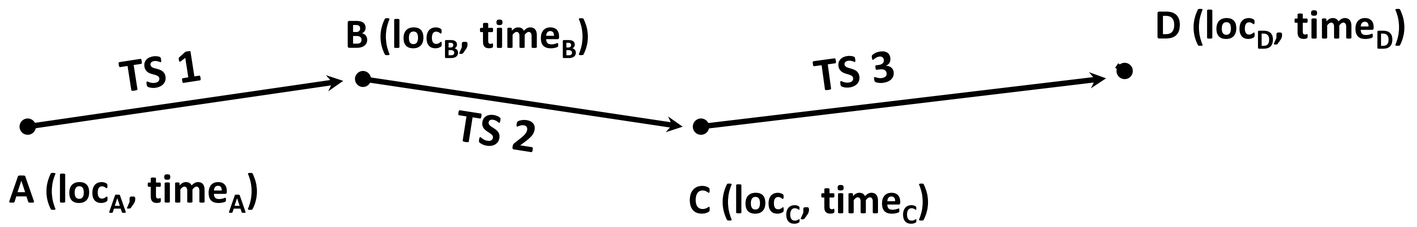
- Estimate passenger journey OD matrix at the network level using AFC and AVL data
  - Multimodal public transport passenger flows
- AFC characteristics
  - Open (entry fare control only)
  - Closed (entry+exit fare control)
  - Hybrid

Source:
"Intermodal Passenger Flows on London's Public Transport Network: Automated Inference of Full Passenger Journeys Using Fare-Transaction and Vehicle-Location Data. Jason Gordon, MST Thesis, MIT (September 2012).

Trip Chaining: Basic Idea

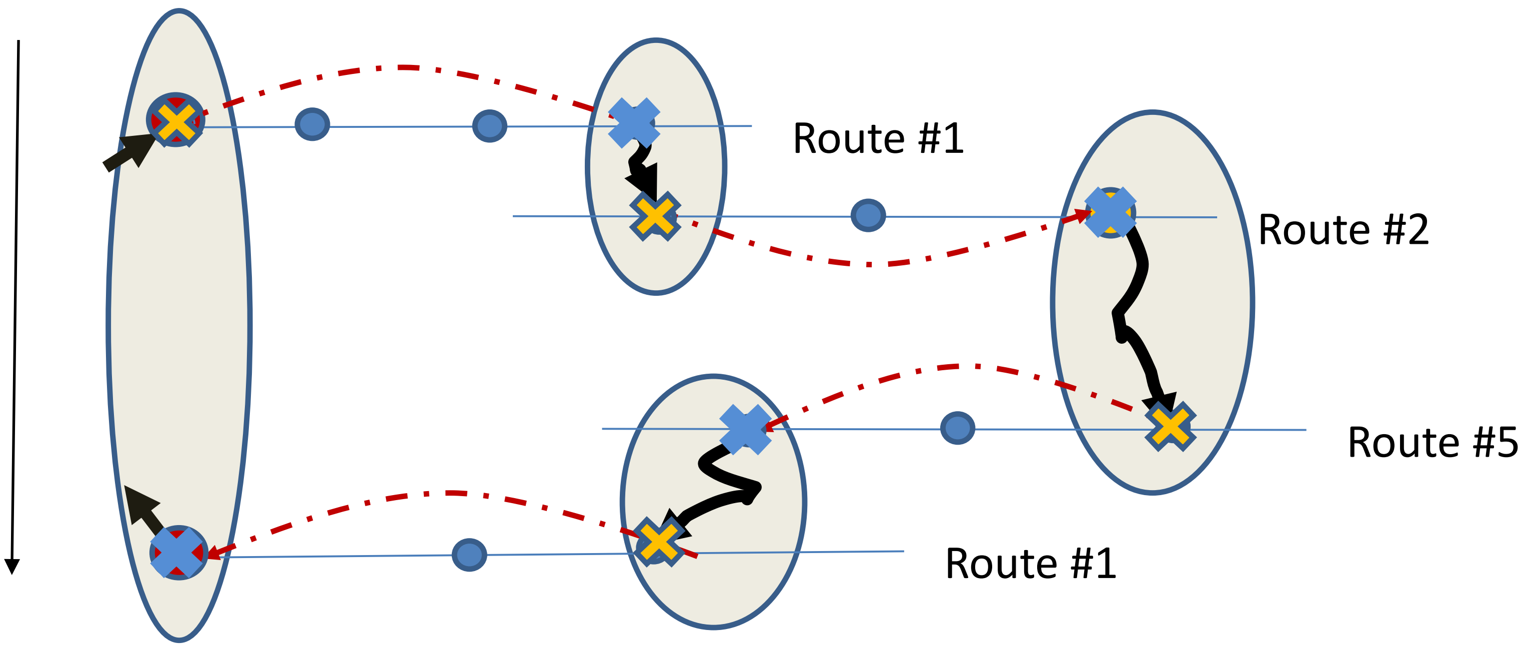
Each AFC record includes:

- AFC card ID
- transaction type
- transaction time
- transaction location: rail station or bus route and stop (either directly or based on time-matching with AVL data)

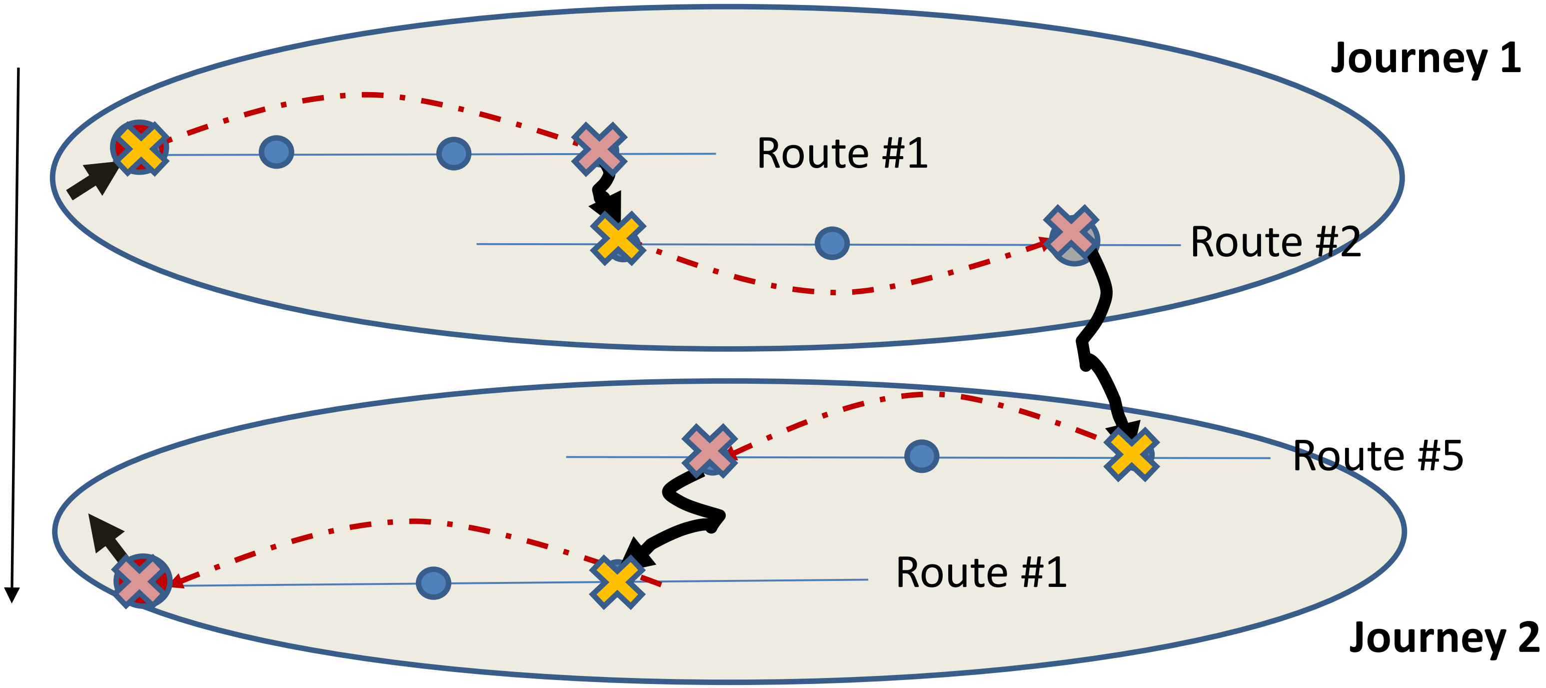


The destination of many trip segments (TS) is close to the origin of the following trip segment.

Destination Inference



Interchange Inference



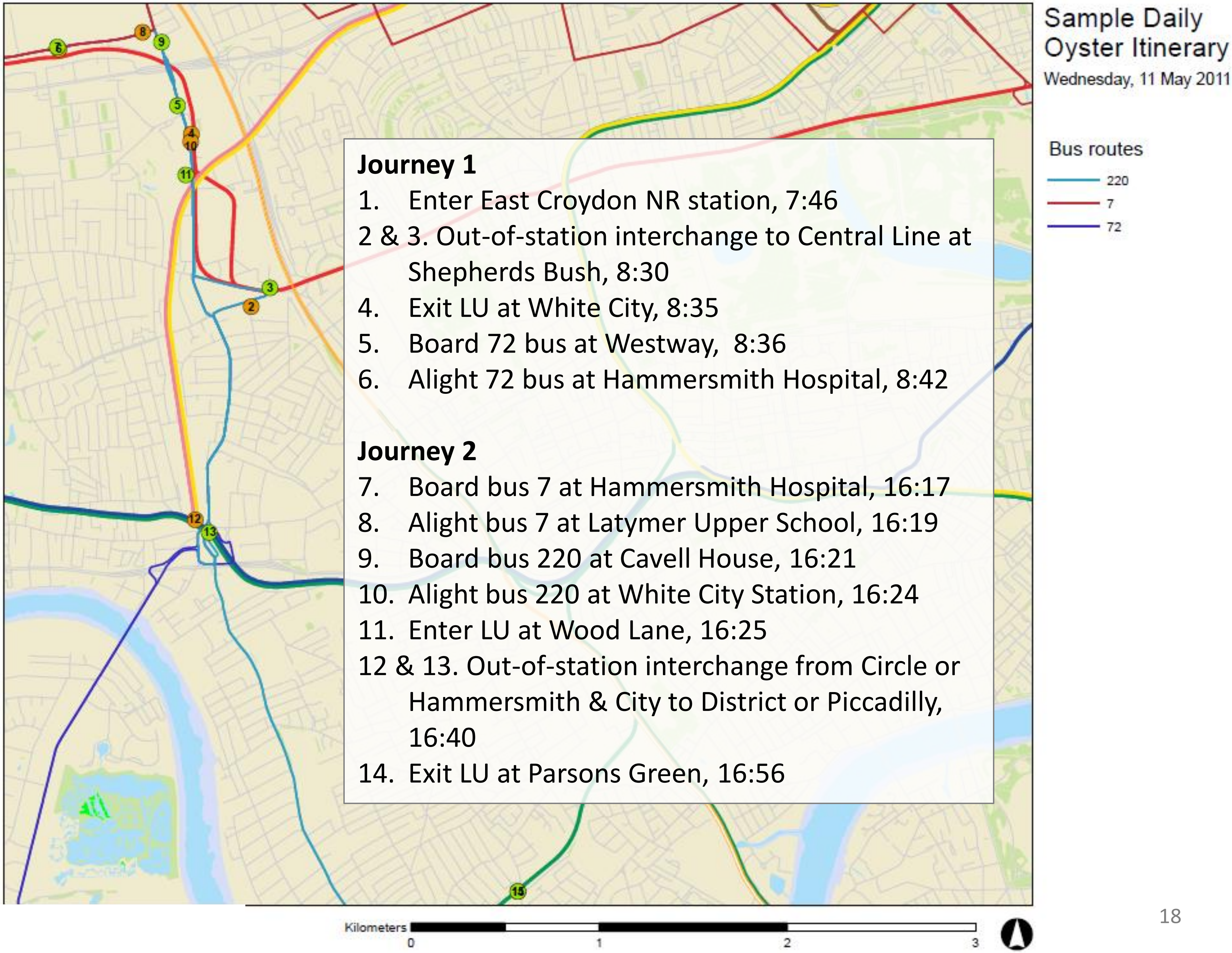
Trip-Chaining Method for OD Inference

Key Assumptions for Destination Inference to be correct:

- 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

Sample Daily Oyster Itinerary

Wednesday, 11 May 2011



Journey 1

1. Enter East Croydon NR station, 7:46

2 & 3. Out-of-station interchange to Central Line at Shepherds Bush, 8:30

4. Exit LU at White City, 8:35
5. Board 72 bus at Westway, 8:36
6. Alight 72 bus at Hammersmith Hospital, 8:42

Journey 2

7. Board bus 7 at Hammersmith Hospital, 16:17
8. Alight bus 7 at Latymer Upper School, 16:19
9. Board bus 220 at Cavell House, 16:21
10. Alight bus 220 at White City Station, 16:24
11. Enter LU at Wood Lane, 16:25

12 & 13. Out-of-station interchange from Circle or Hammersmith & City to District or Piccadilly, 16:40

14. Exit LU at Parsons Green, 16:56

Trip-Chaining Method Steps

- Infer start and end of each trip segment for individual AFC cards
- Link trip segments into complete (one-way) journeys
- Integrate individual journeys to form seed OD matrix (by time period)
- Expand to full OD matrix using available control totals
  - station entries and/or exits for rail
  - passenger entries and/or exits by stop, trip, or period for bus

Summary Information on London Application

- Oyster fare transactions/day:
  - Rail (Underground, Overground, National Rail): 6 million (entry & exit)
  - Bus: 6 million (entry only)
- For bus:
  - Origin inference rate: 96%
  - Destination inference rate: 77%
- For full public transport network:
  - 76% of all fare transactions are included in the seed matrix
- Computationally feasible (30 mins on Intel PC for full London public transport OD Matrix for entire day, including both seed matrix and scaling)

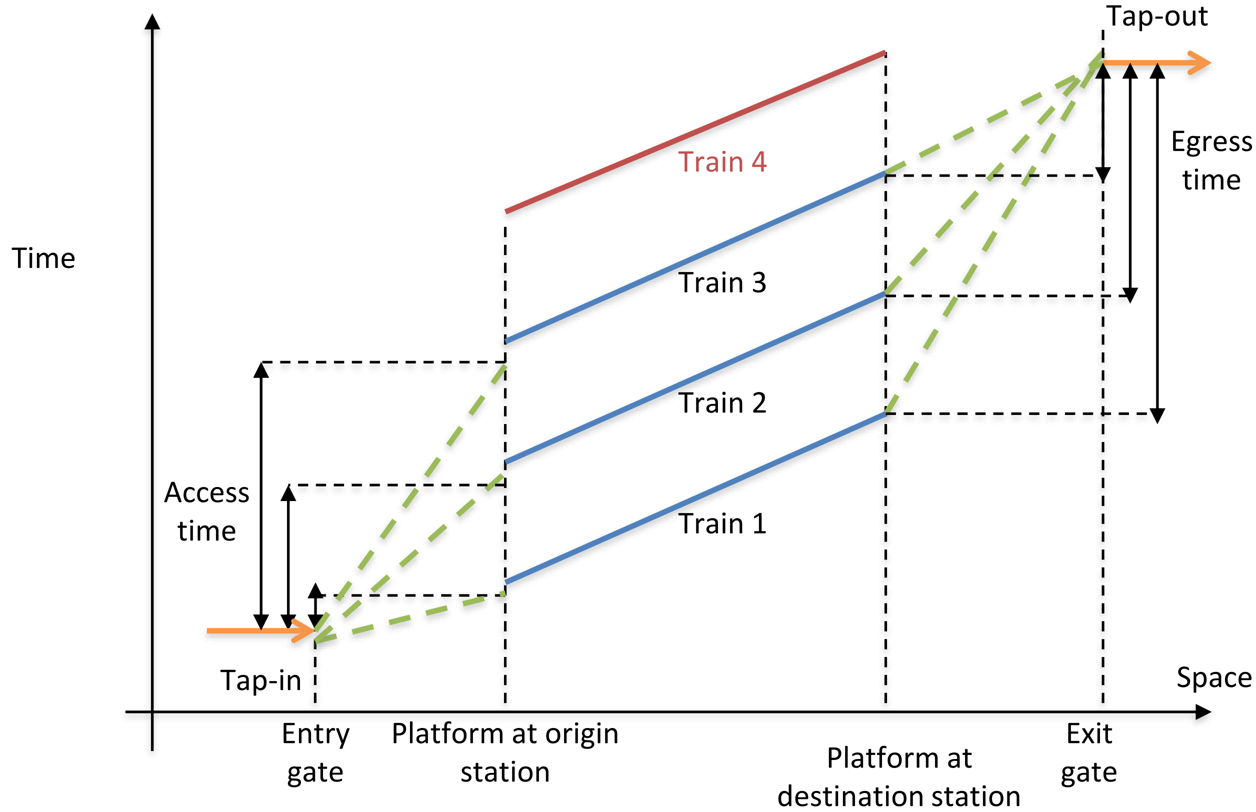
Inferring Train Loads

- Develop a methodology to “assign” passengers to trains through the use of AFC, ATR data
- The methods support:
  - Assessment of service utilization
  - Service quality metrics from the customers’ point of view
    - Crowding on trains and in stations
    - Number of passengers denied boarding
    - More detailed journey time metrics

Source: "Passenger-to-Train Assignment Model Based on Automated Data."
Yiwen Zhu, Master of Science in Transportation thesis (MIT, 2014)

Feasible Train Itineraries

- Given: AFC & ATR data
- A train itinerary is feasible if:
  - It departs after the passenger taps in, and
  - Arrives before the passenger taps out



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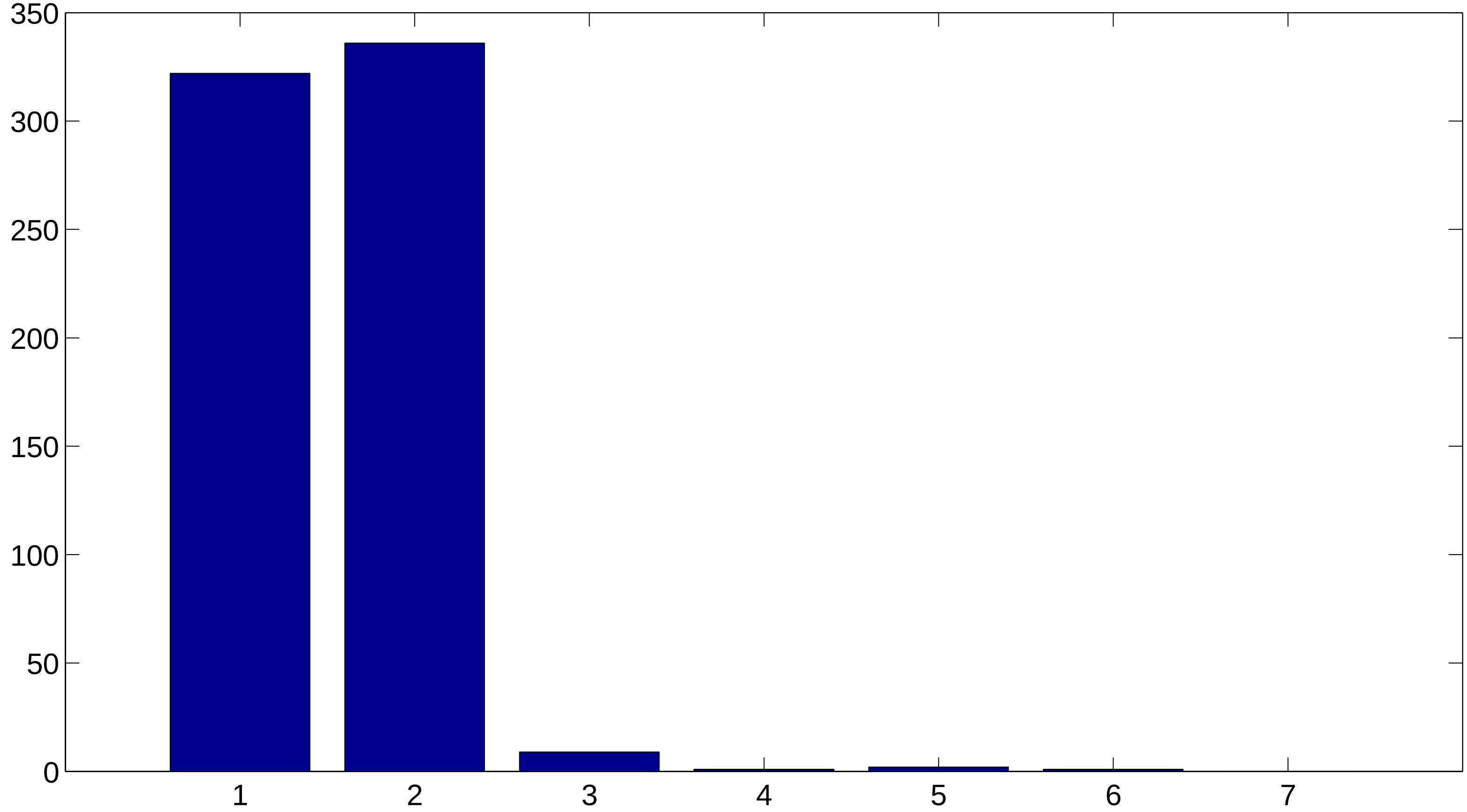
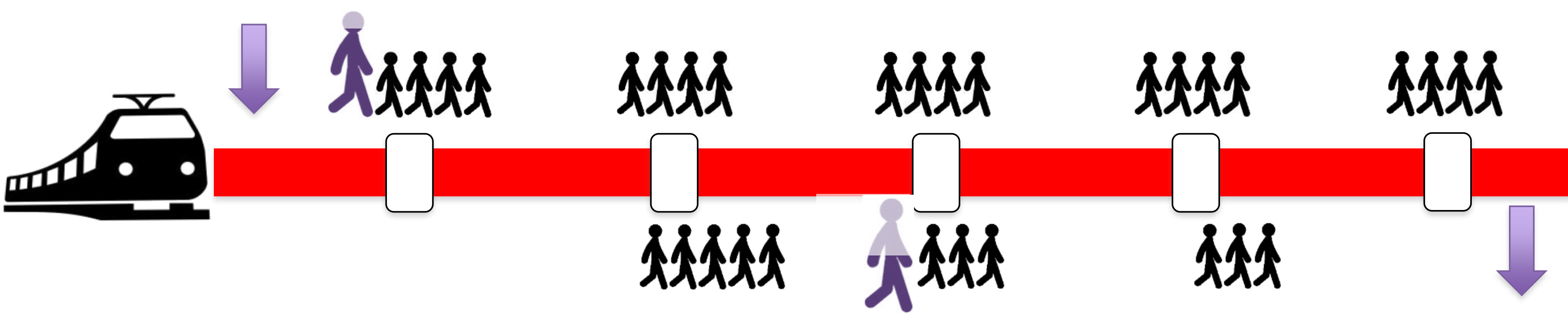
Feasible Train Itineraries Example



Passenger Assignment Model (PAM)

- Each station is examined in sequence starting from the terminal.
- At each station, the trainload is calculated from the corresponding probabilities of passengers whose feasible itinerary set includes this train.



Recent Extensions

- Relaxing assumptions:
  - Denied boardings due to capacity constraints
  - Interchange demand

Future Work

- Advanced customer information, such as expected crowding at stations and in trains
- Real time model and application

Measuring Service Reliability

Objective:

- Define a customer-centric measure to capture effects of reliability

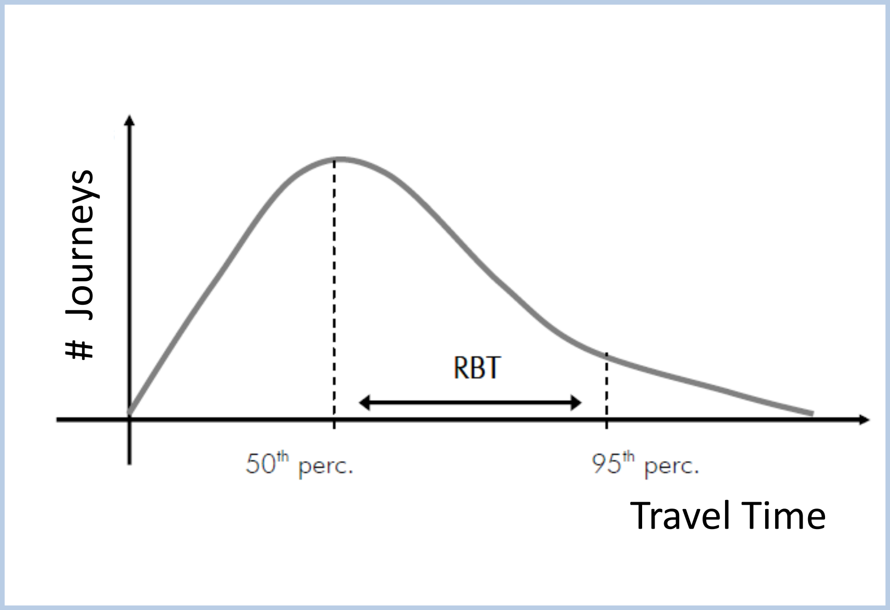
Expected benefits:

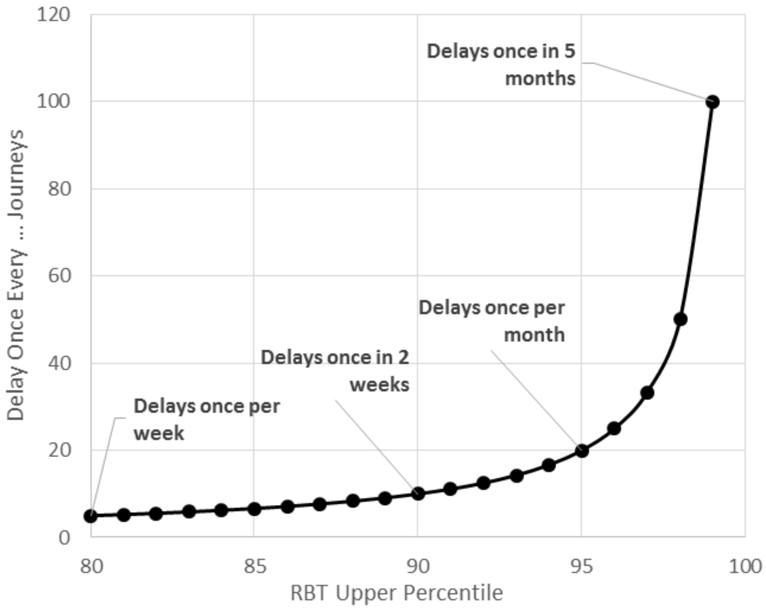
- Improve customer communication
- Capture the effects of strategies to improve service reliability

Reliability Buffer Time (RBT)

$$RBT_{OD} = JT(N^{th}) - JT(50^{th})$$

"How much additional time should I budget, beyond my typical travel time, to ensure an on time arrival N% of the time?"





Calculating the RBT

- Calculated for **each hour** of the day over some **period of time**
- RBT measures the **total** variation from all portions of a journey:

Access Time + Wait Time + In Vehicle Time + Egress Time

Variants of the RBT

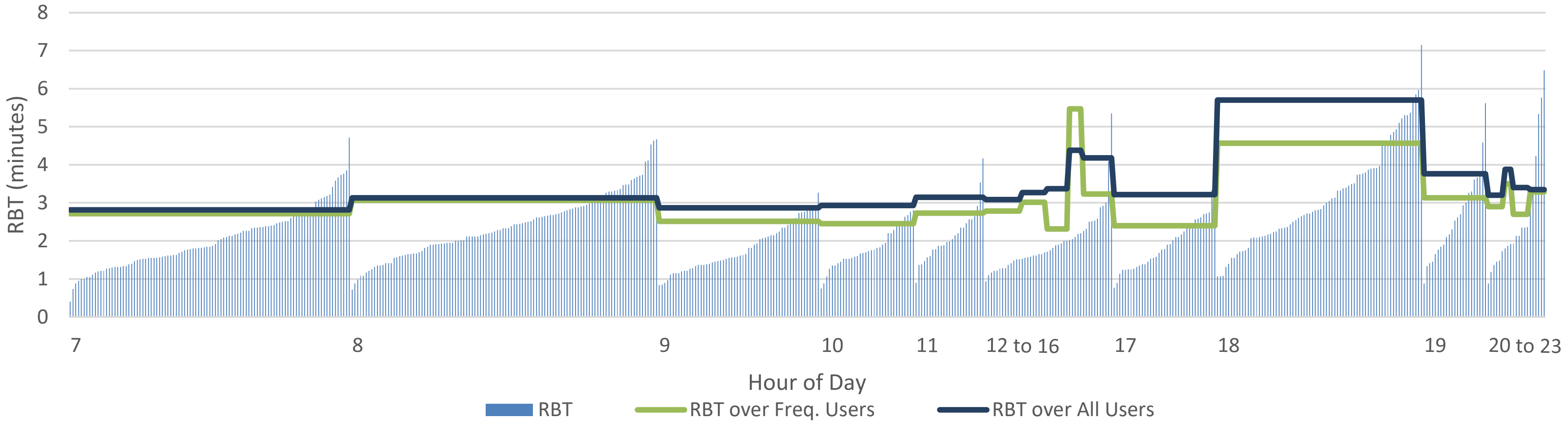
Journey Component Variants

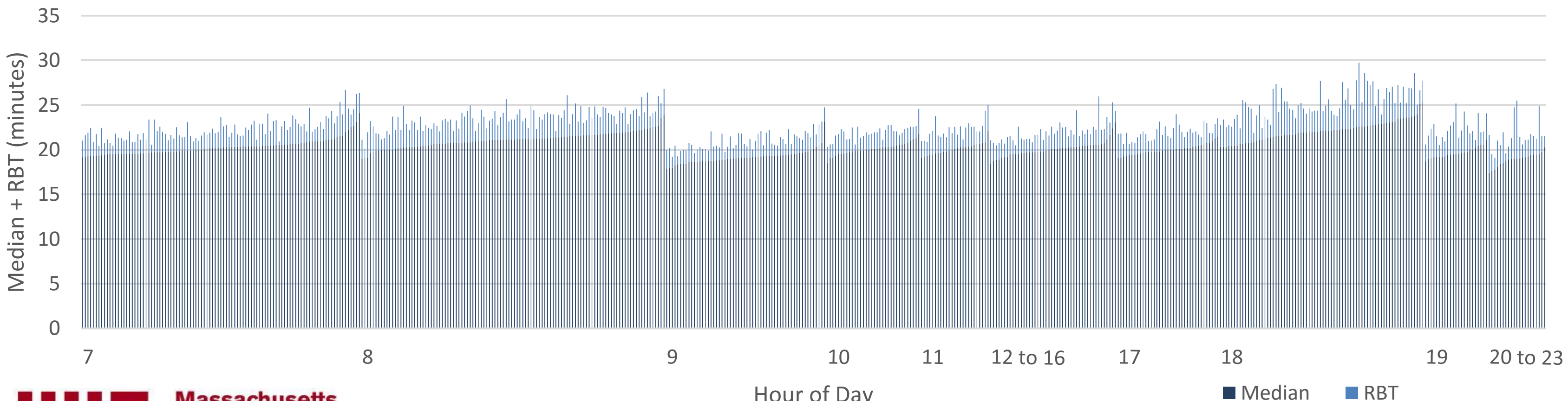
- Full Journey Time
- Platform to Platform Time
- In-vehicle Time

Passenger Variants

- All Customers
- Groups of Passengers
- Individual Passengers

Individual vs Group RBTs Example: Single OD Pair, 2 Months Data





Summary

- Complete Journey OD Estimation practical with ADS
  - foundation for many analyses related to customer experience
- Realistic to assess service reliability for individuals and journeys
  - most critical aspect of customer experience
- Targeted on-line surveys an efficient alternative to other survey methods
- Customer classification is critical in understanding the customer experience
- Developing predictive models is a critical research need

Future Prospects

- Panel data combined with full journey OD estimation and journey time provides the basis for extensive customer experience and behavior analysis including:
  - understanding impacts of changes in service and price
  - understanding customer attraction, retention, and attrition
  - informing "information push" customer information strategies
  - documenting the impacts of marketing and promotional strategies
- Strategies in light of Uber-type service and AV technology