Smart Cities

SESSION II: Lecture 2: The Smart City
as a Communications Mechanism: Transit Movements

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Outline of the Lecture

1. The Context Again: New Data for and from the Smart City: Illustrating Smart Cities with Movement Data

2. Why London?

3. A Partial View of London's Network

4. Three Approaches, Three Problems –

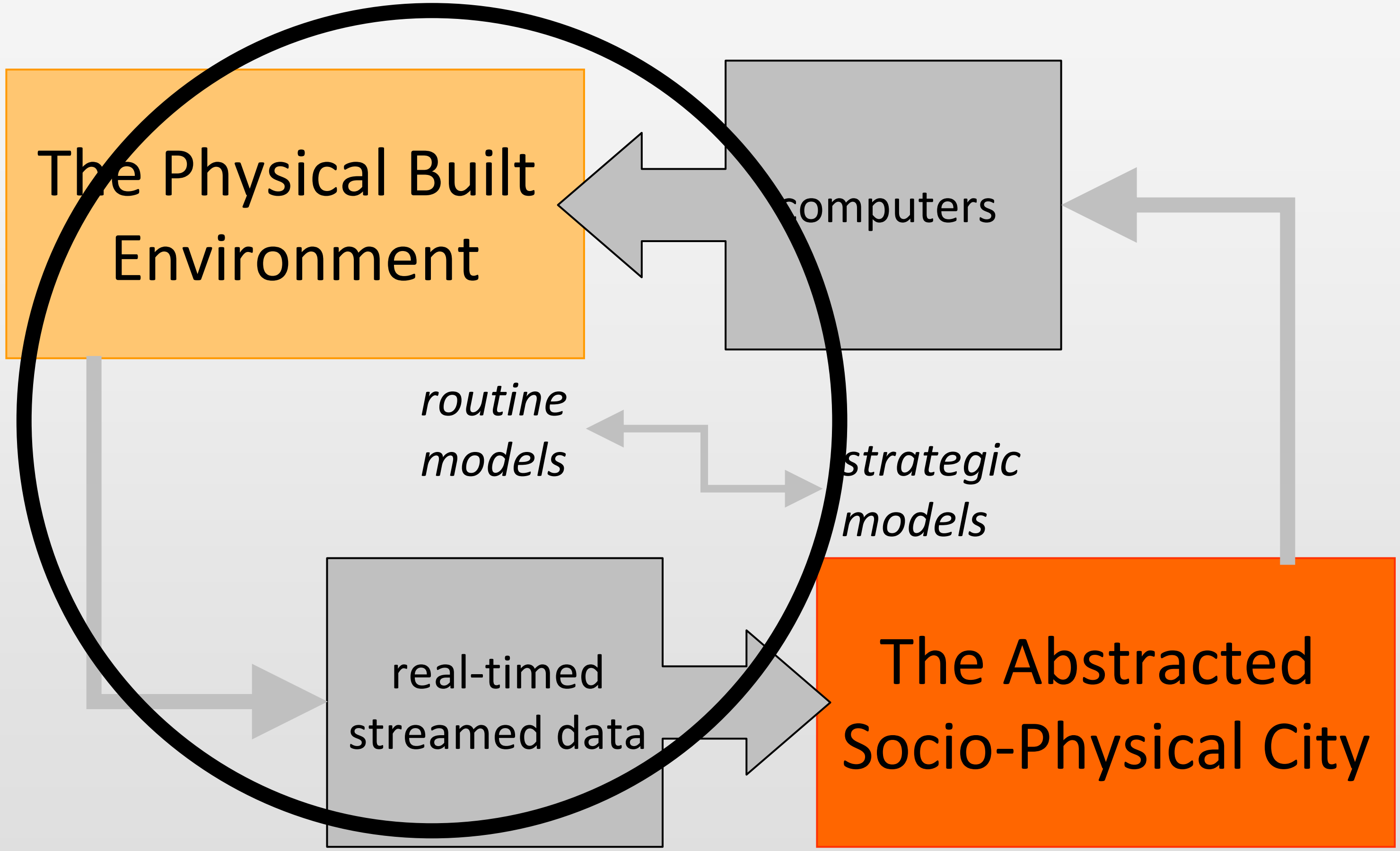
a. Problem 1: Flows on the Tube Lines – by trains; some buses

b. Problem 2: Representing Networks

And the 3rd problem we will leave until next time

c. Problem 3: 'Shortest'-Path Problems and Disruption

Our focus on transport and communications mainly affect the routine aspects of smart cities over short time periods



Context: New Data for and from the Smart City

Here we are going to move directly to networks in the literal sense, Remember Metcalfe's Law, so we will look also at flows on networks

Our understanding of urban flows tends to be based almost exclusively on single-mode systems and each mode is handled separately; arguably we need to look an integrated networks – multiplex networks

The increasing availability of large behavioural data sets from Public Transport Networks (PTNs), combined with the increasing power and sophistication of computational approaches, creates new ways of exploring travel demand: real time streamed day

Greater spatial resolution – down to station or bus stop, and greater temporal resolution – down to the minute, and greater coverage – centralised collection of data means a single data store for an entire city

PTN-derived data also avoids many of the privacy issues associated with mobile network data because the user becomes invisible as soon as they leave the system.

Why London?

Transport for London's (TfL) RFID-based 'Oyster Card' is particularly attractive because users typically need to use their card at both ends of a trip, providing us with detailed origin and destination data for more than 3 million daily users.

The system is particularly large and complex:

Approximately 640 stations across all modes

340 stations with Oyster Card readers served by National Rail trains

80 stations served by Overground trains

270 stations served by Underground trains

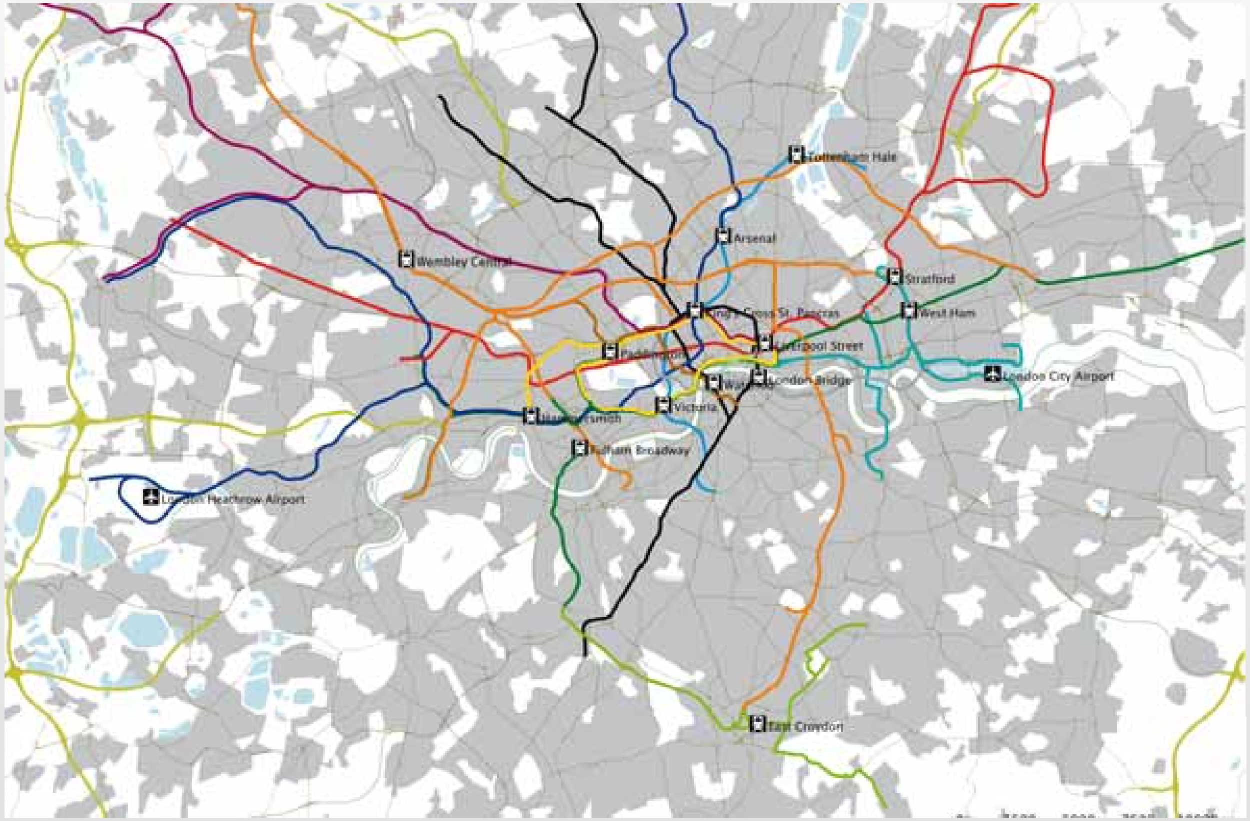
45 stations served by Docklands Light Rail

39 stations served by Tram

147 stations with some kind of interchange (between line or mode)

Aboveground coverage by Open Street Map (OSM) is also particularly good, allowing us to model walking behaviour using open source tools that respect pedestrian preferences for balancing directness with quieter streets.

A Partial View of London’s Network



Although many users – especially visitors – are used to thinking about London in terms of the Beck schema, the combination of an online Journey Planner and regular travel on the network enable many to identify the quickest route *even if* it doesn’t appear to be the most direct.

Three Approaches, Three Problems

1. To explore what is happening to actual movements of trains – to compute delays – currently Transport for London TfL have an API for tubes and buses that enables the user to query the location and of all trains/buses on the network and to examine how they move – from this we can calculate delay and compute a variety of measures. This is what Richard Milton, one of my colleagues has done and I will show some of this – it is very preliminary
2. Use of classic graph measures to show how the network can be disrupted – this is largely a topological graph/network approach that shows how betweenness centrality or accessibilities is disturbed – I am responsible for this and will show some work
3. Fully fledged flow and graph measures in a multimodal context – tube, overground, walk so far – where we are computing changes in flow – this work that Jon Reades is doing – we will look at this next time and focus on disruption.

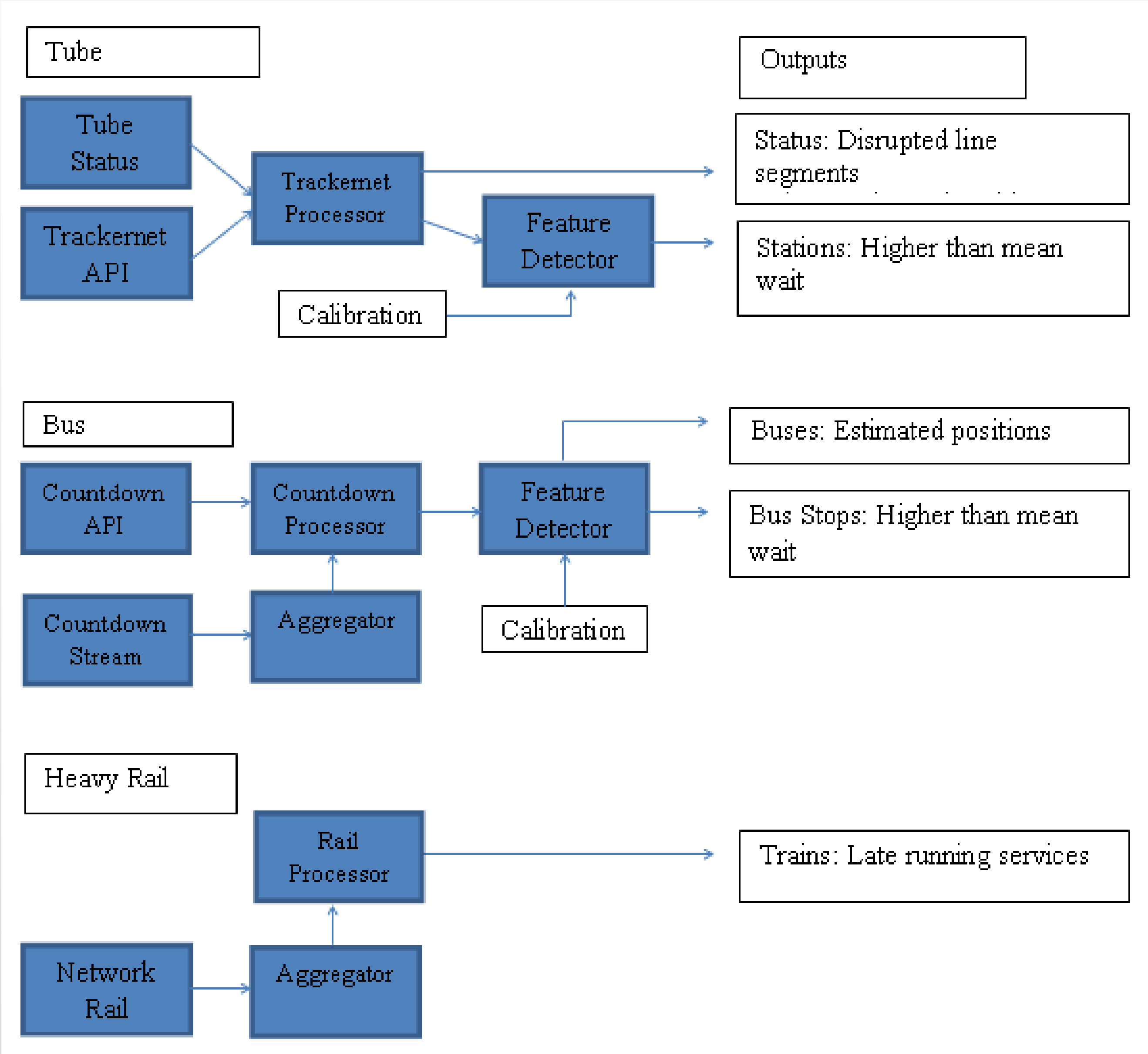
Problem 1: Flows on the tube lines – by trains

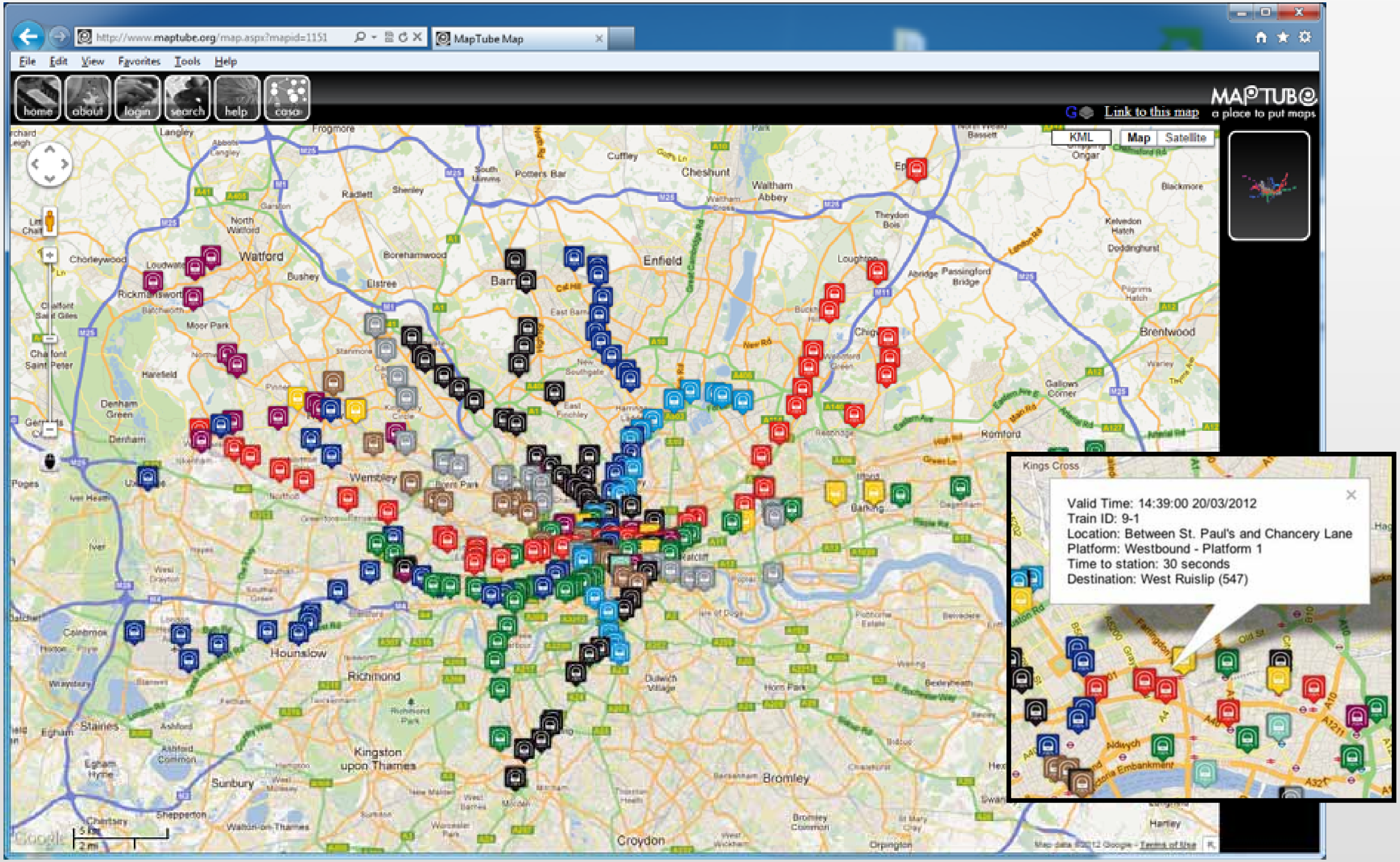
As we will demonstrate, through the "Trackernet" system for London Underground and the "Countdown" system for buses, it is now possible to collect and visualise the positions of vehicles in real-time.

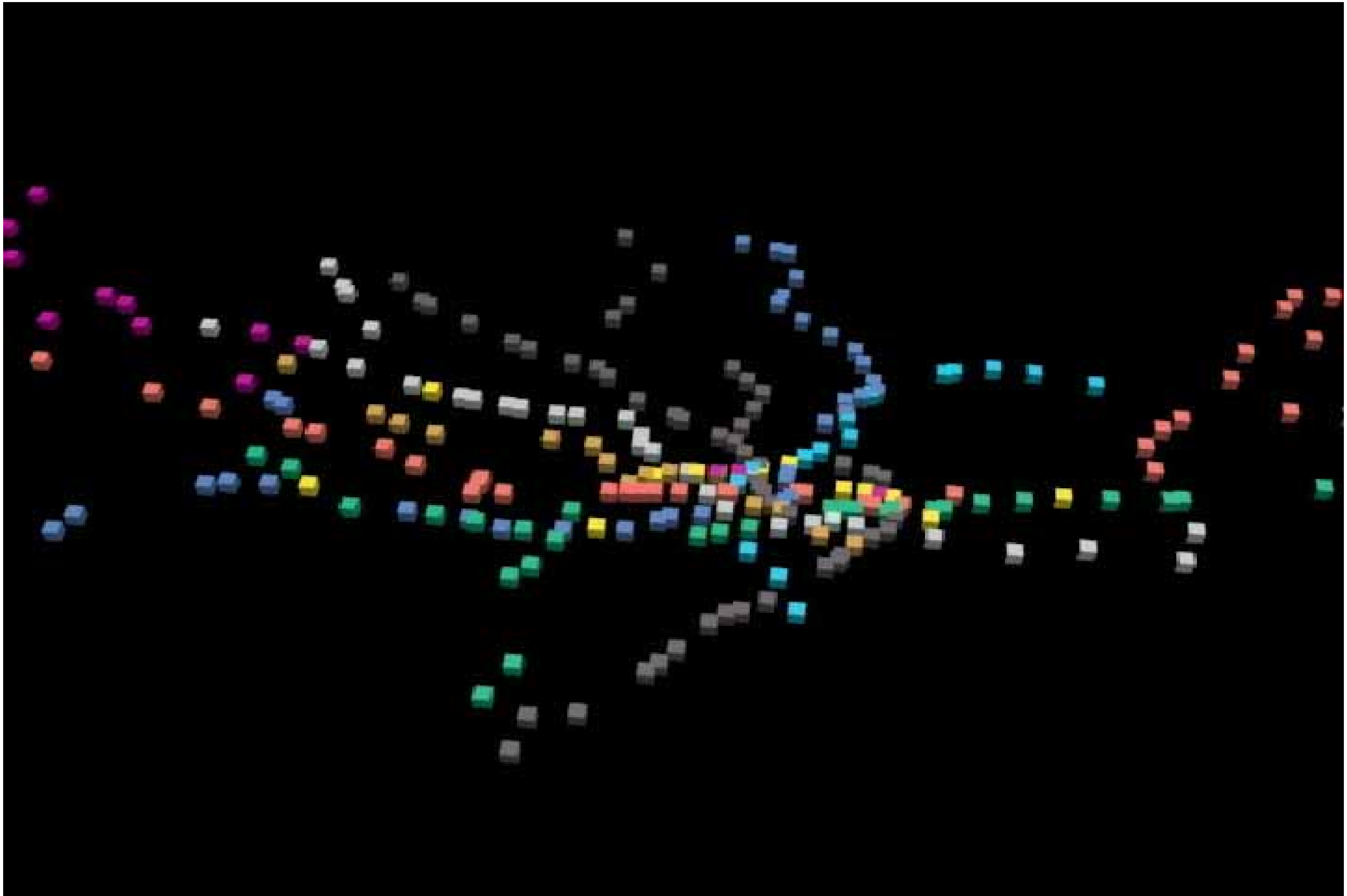
At peak periods there can be 7000 buses, 900 trains and 450 tubes running on the system. 270 underground stations.

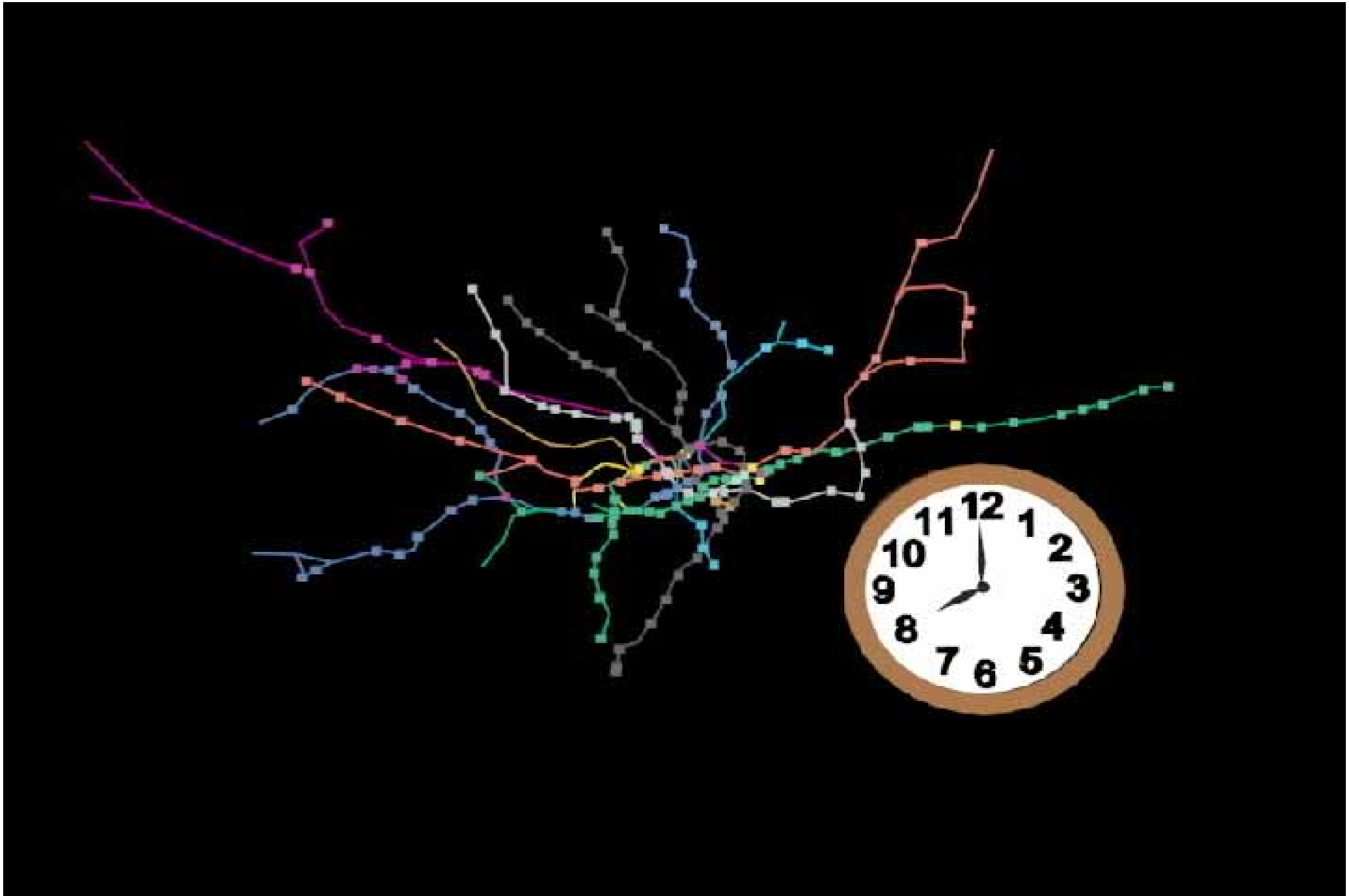
Delays for these transport systems were calculated by using an archive of historic data to find the mean wait time for every hour and every station or bus stop.

This can then be visualised in real time or after the event for further analysis. We show a mix of these visualisations in the figures that follow – as yet we have not developed an integrated analysis but all the ideas are there. We show the analysis first for the tube but here is the block diagram showing how we are assembling the data.


Tube
Tube Status
Trackernet API
Trackernet Processor
Feature Detector
Calibration
Outputs
Status: Disrupted line segments
Stations: Higher than mean wait
Bus
Countdown API
Countdown Processor
Feature Detector
Countdown Stream
Aggregator
Calibration
Buses: Estimated positions
Bus Stops: Higher than mean wait
Heavy Rail
Rail Processor
Network Rail
Aggregator
Trains: Late running services


http://www.maptube.org/map.aspx?mapid=1151
MapTube Map
File Edit View Favorites Tools Help
home
about
login
search
help
casa
Link to this map
MAPTUBE
a place to put maps
KML
Map
Satellite
Watford
Enfield
Cheshunt
Waltham Abbey
Brentwood
Romford
Wembley
Hounslow
Richmond
Kingston upon Thames
Bromley
Croydon
Staines
Kings Cross
Valid Time: 14:39:00 20/03/2012
Train ID: 9-1
Location: Between St. Paul's and Chancery Lane
Platform: Westbound - Platform 1
Time to station: 30 seconds
Destination: West Ruislip (547)




12
1
2
3
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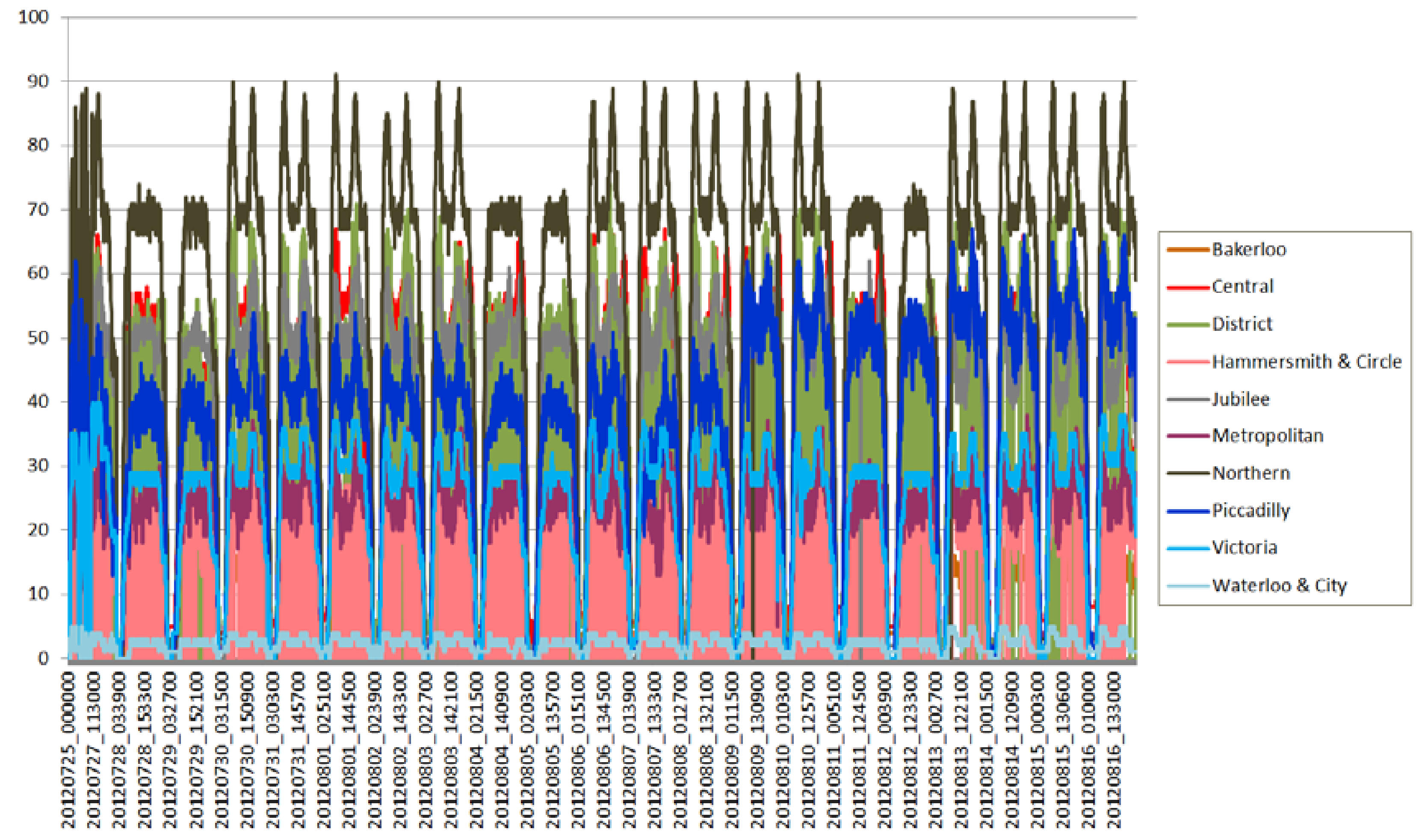
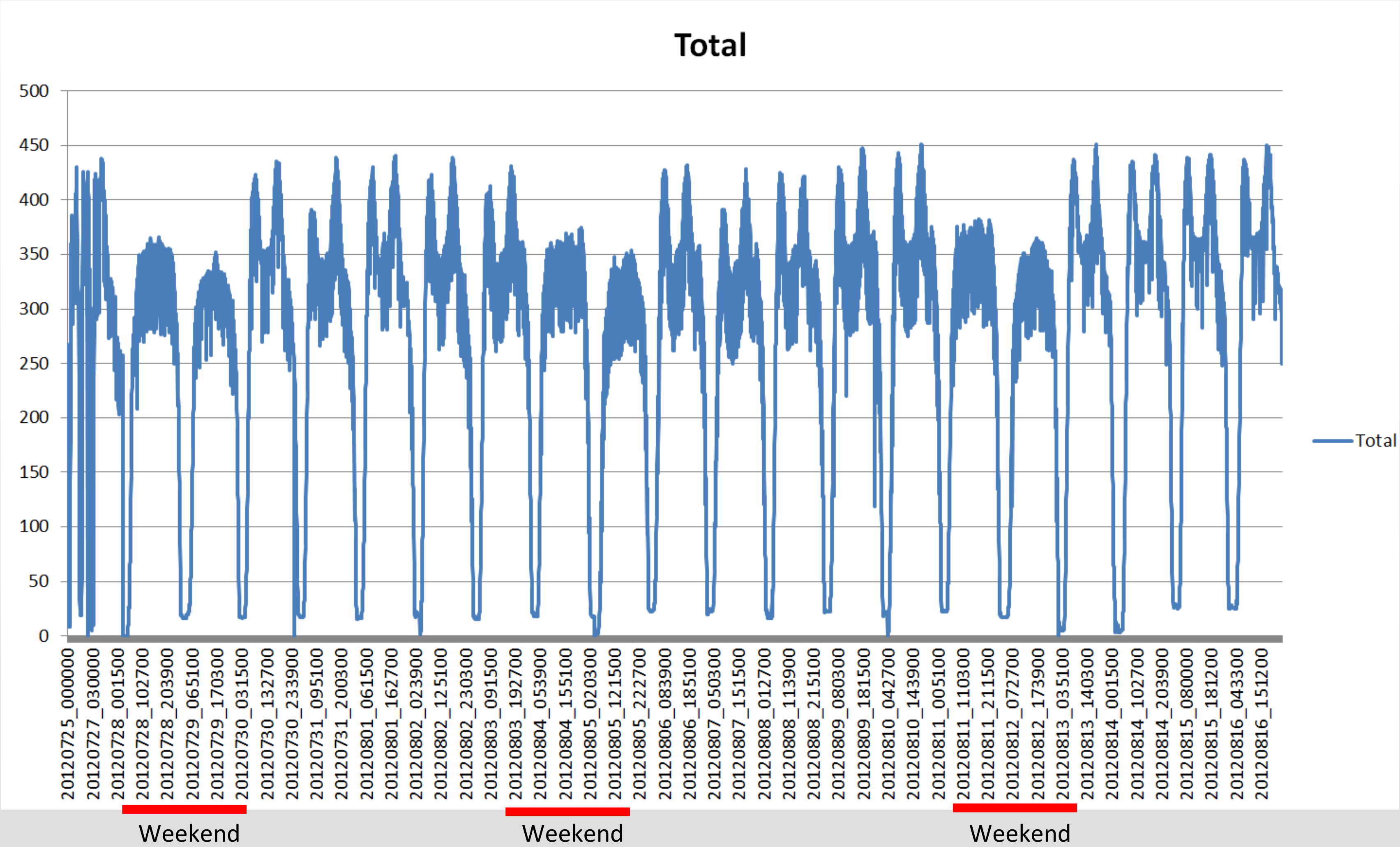
11

Flows During the Olympics – we are looking at this as a case study




Total
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200
150
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20120725_000000
20120727_030000
20120728_001500
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20120728_203900
20120729_065100
20120729_170300
20120730_031500
20120730_132700
20120730_233900
20120731_095100
20120731_200300
20120801_061500
20120801_162700
20120802_023900
20120802_125100
20120802_230300
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20120808_215100
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20120811_005100
20120811_110300
20120811_211500
20120812_072700
20120812_173900
20120813_035100
20120813_140300
20120814_001500
20120814_102700
20120814_203900
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20120815_181200
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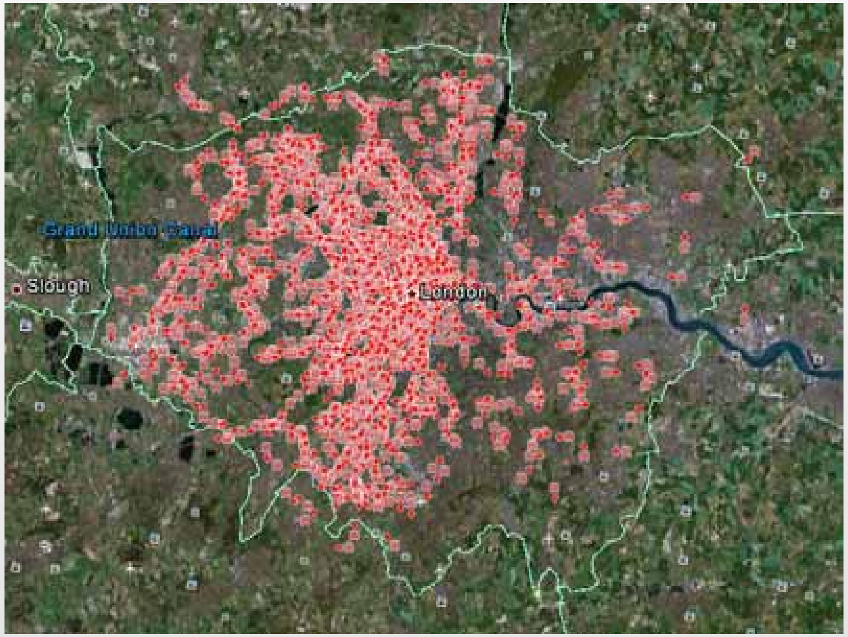
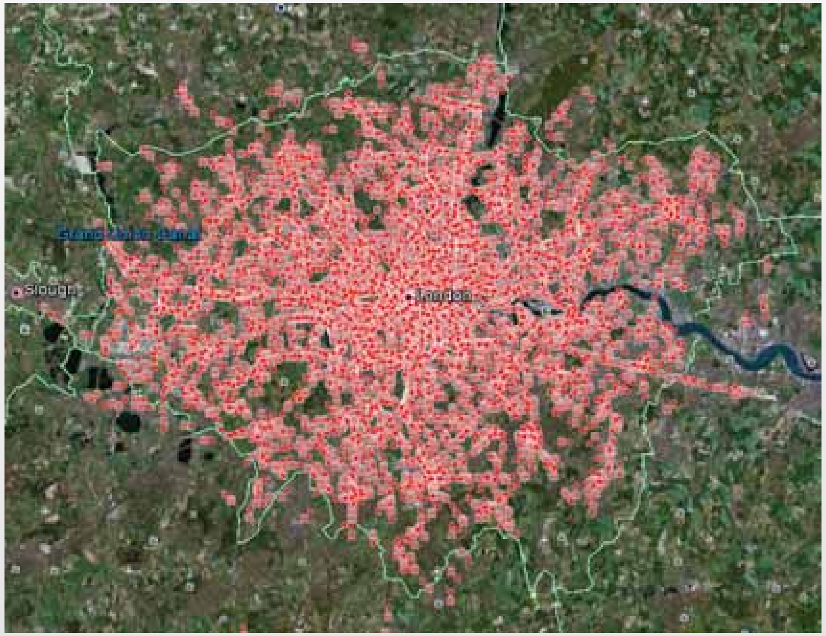
Total
Weekend
Weekend
Weekend

The Effect of Bus Strike



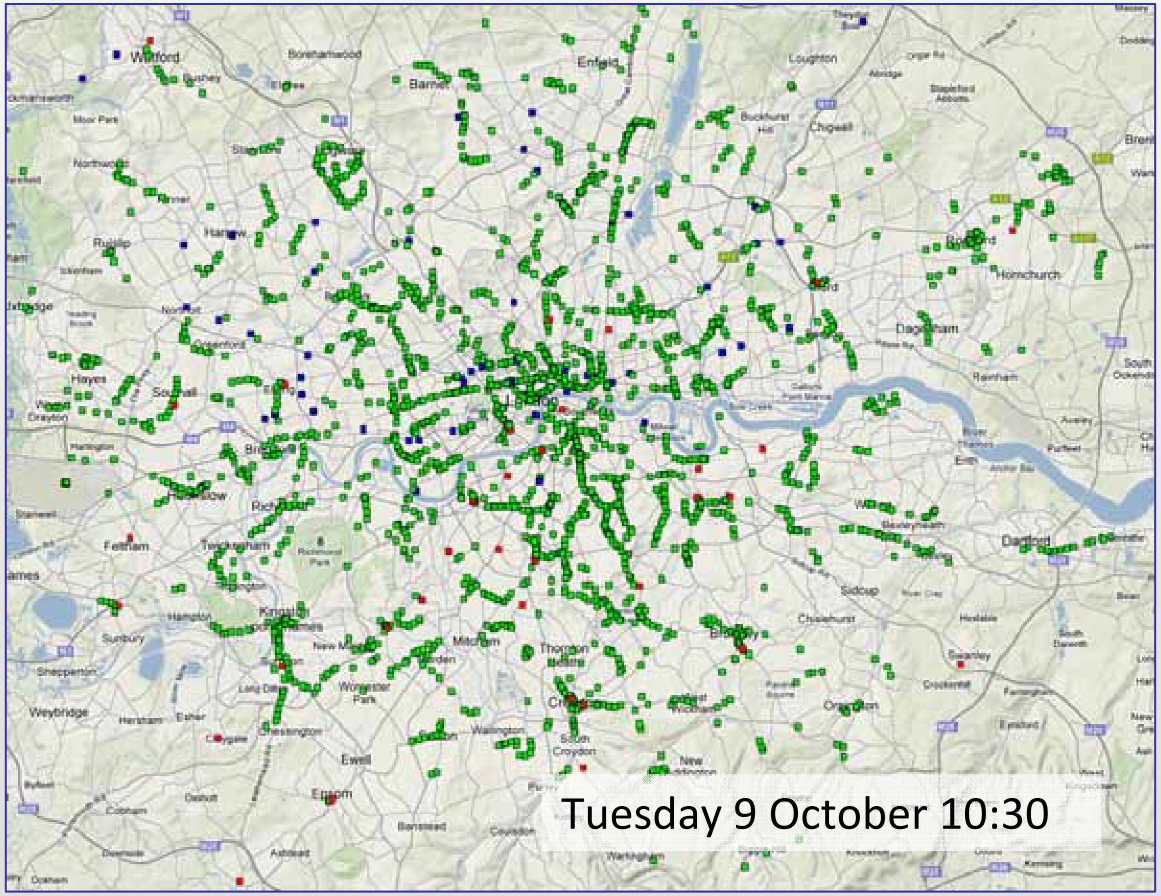
Tuesday 22nd May 2012, 09:00



Wednesday 23rd May 2012, 09:00

The left image shows the effect of the bus strike on 22nd May 2012, while the image on the right shows a normal day.

Delays from Tube, National Rail and Bus Fused



Key

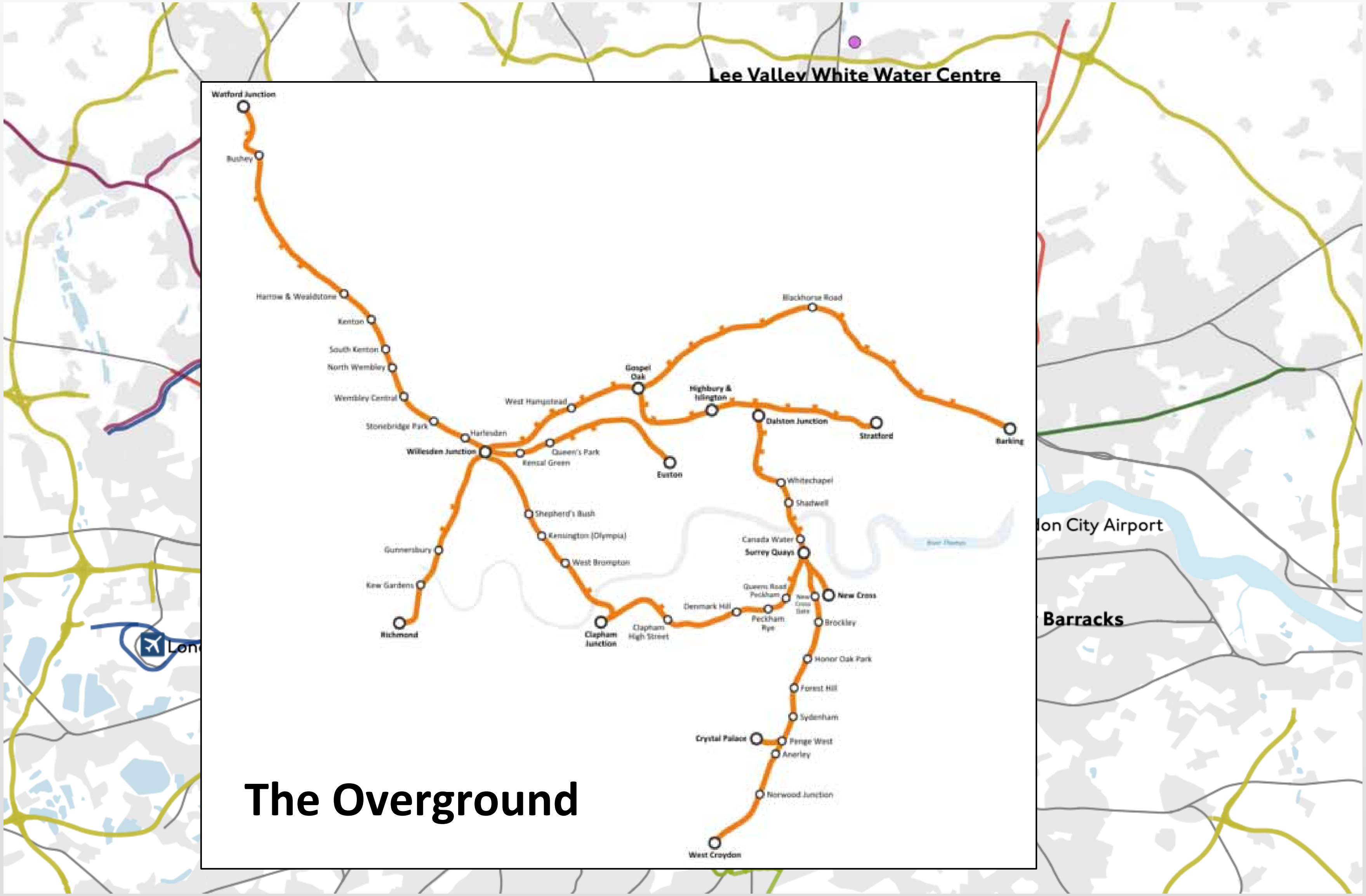
- National Rail more than 5 minutes late (red)
- Tube stations showing a wait time 15% above expected (blue)
- Bus stops showing a wait time 20% above expected (green)

Tube delays from the TfL status feed are also plotted as lines

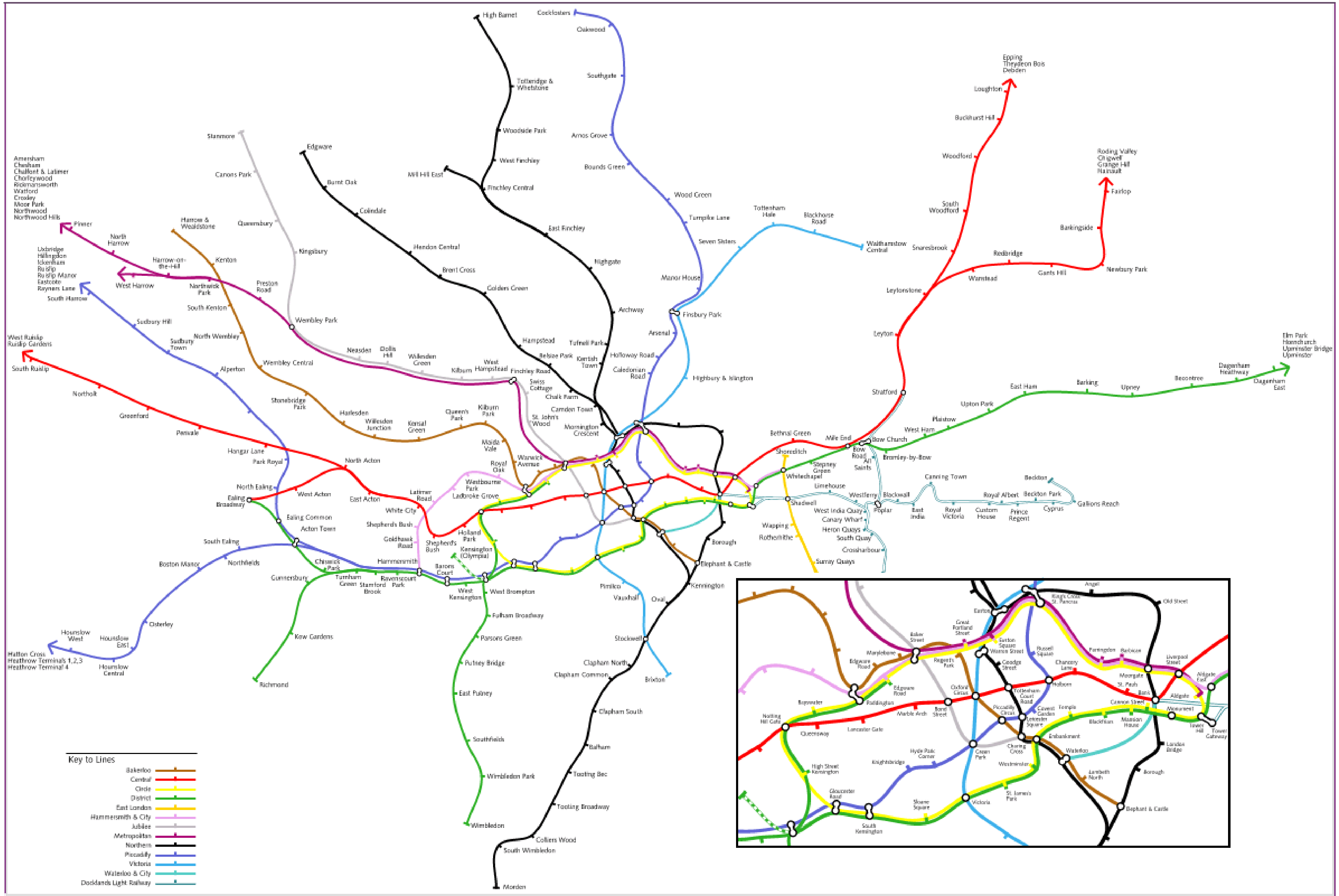
I want to introduce a little more background on the automated scheme in London that we are discussing – some history first and then a map of the network

It is quite confusing because so many networks overlap so we should be clear about the core network – the underground which has 270 stations; the Docklands Light railway has 45; the overground has 83 but this extends outside of Greater London: then national rail is more complicated because it dovetails with overground and underground stations also coincide but are not the same as national rail stations.

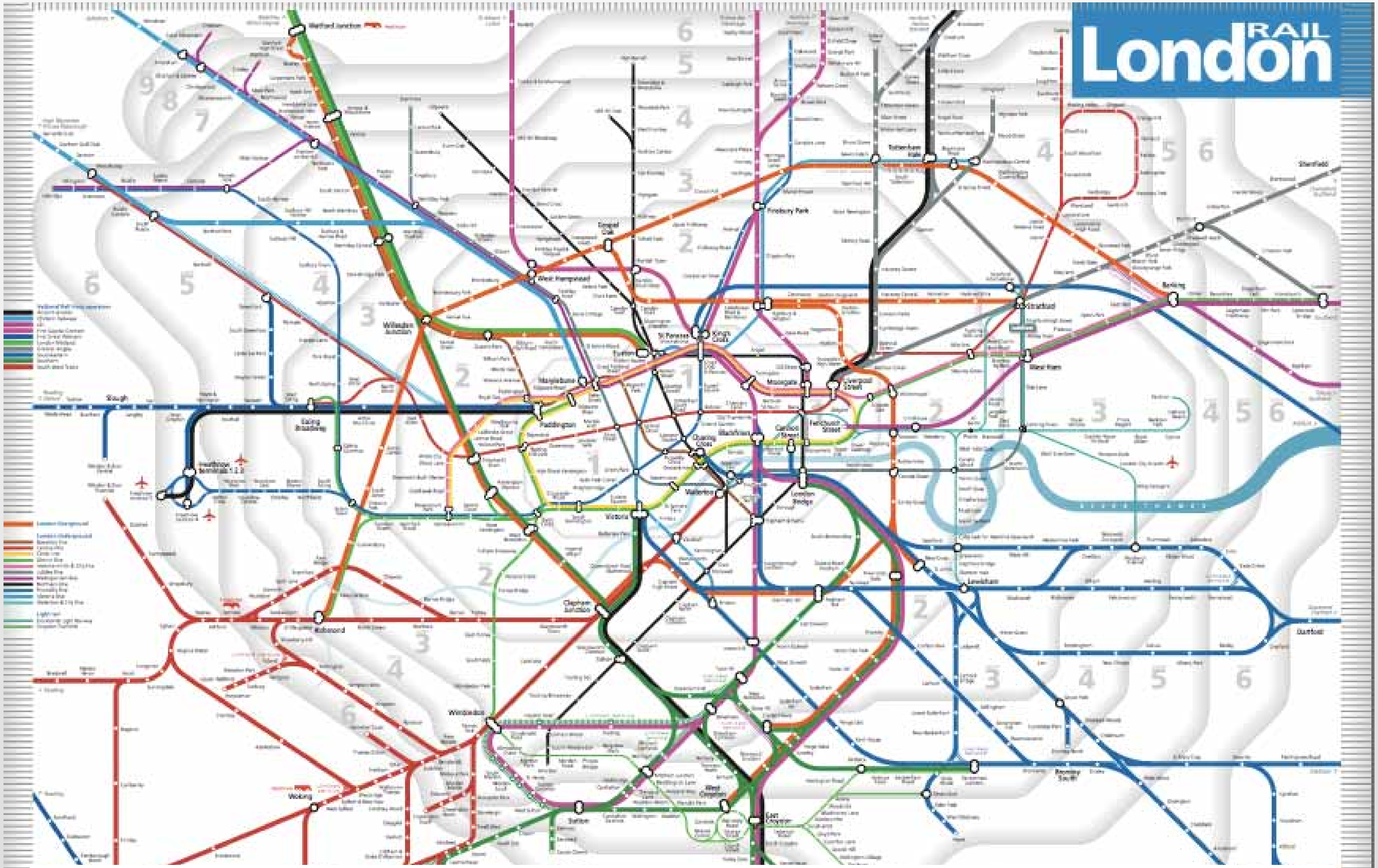
We are mainly going to deal here with the greater London networks but the touch card data is for a much bigger area and also for the bus system and it can also be related to national rail.



Centre for Advanced Spatial Analysis

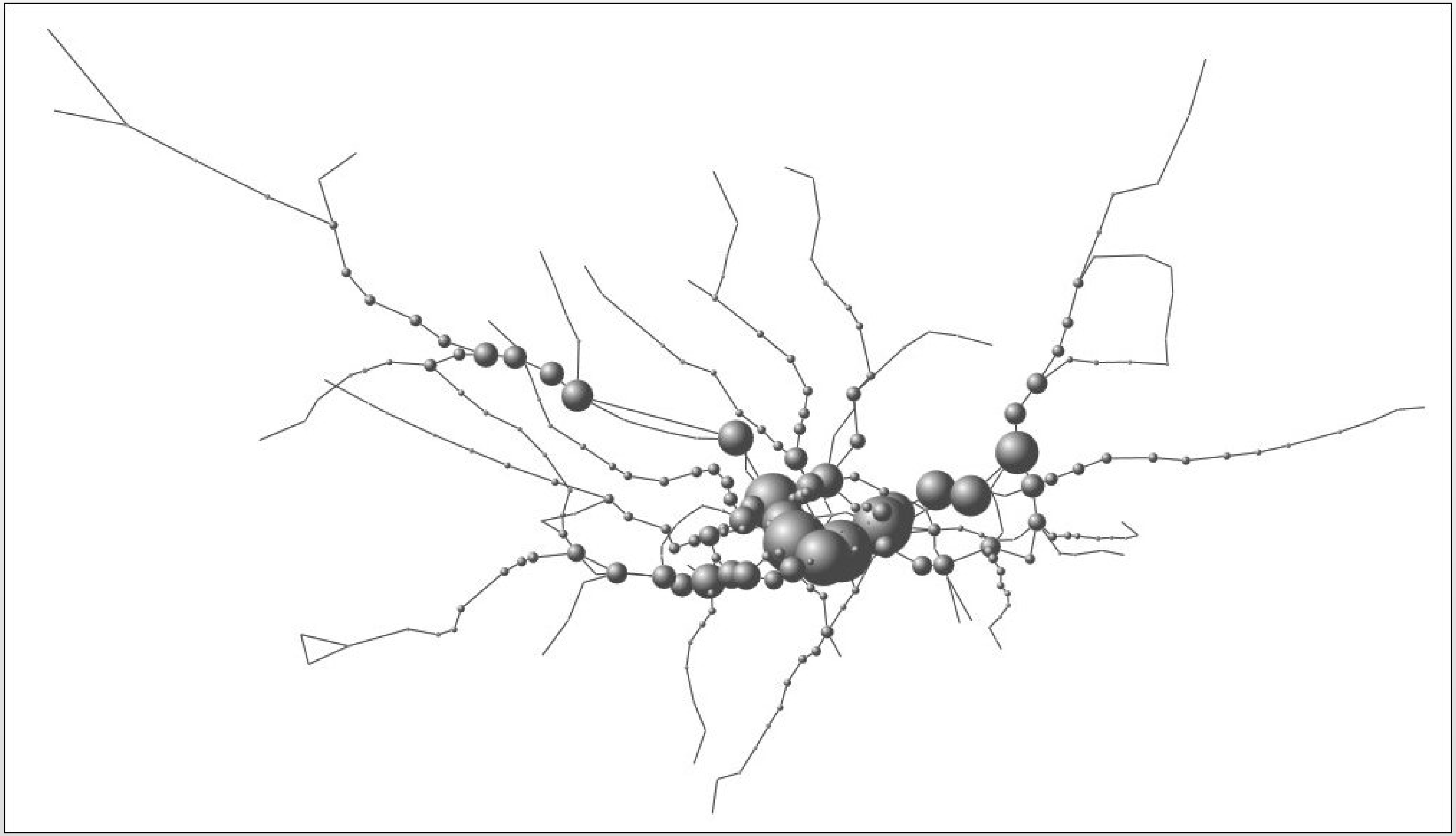


Key to Lines
Bakerloo
Central
Circle
District
East London
Hammersmith & City
Jubilee
Metropolitan
Northern
Piccadilly
Victoria
Waterloo & City
Docklands Light Railway
High Barnet
Cockfosters
Oakwood
Southgate
Totteridge & Whetstone
Woodside Park
West Finchley
Arnos Grove
Bounds Green
Wood Green
Turnpike Lane
Seven Sisters
Tottenham Hale
Blackhorse Road
Walthamstow Central
Epping
Theydon Bois
Debden
Loughton
Buckhurst Hill
Woodford
South Woodford
Snaresbrook
Leytonstone
Leyton
Stratford
Roding Valley
Chigwell
Grange Hill
Hainault
Fairlop
Barkingside
Newbury Park
Gants Hill
Redbridge
Wanstead
Stanmore
Canons Park
Edgware
Burnt Oak
Colindale
Mill Hill East
Finchley Central
East Finchley
Highgate
Archway
Hendon Central
Brent Cross
Golders Green
Hampstead
Belsize Park
Chalk Farm
Camden Town
Kentish Town
Tufnell Park
Holloway Road
Caledonian Road
Arsenal
Finsbury Park
Manor House
Highbury & Islington
Amersham
Chesham
Chalfont & Latimer
Chorleywood
Rickmansworth
Watford
Croxley
Moor Park
Northwood
Northwood Hills
Pinner
North Harrow
Harrow-on-the-Hill
Harrow & Wealdstone
Queensbury
Kingsbury
Kenton
Uxbridge
Hillingdon
Ickenham
Ruislip
Ruislip Manor
Eastcote
Rayners Lane
South Harrow
West Harrow
Northwick Park
Preston Road
South Kenton
North Wembley
Wembley Park
Wembley Central
Sudbury Hill
Sudbury Town
Alperton
West Ruislip
Ruislip Gardens
South Ruislip
Northolt
Greenford
Perivale
Hanger Lane
Park Royal
North Acton
North Ealing
Ealing Broadway
West Acton
East Acton
Ealing Common
Acton Town
South Ealing
Northfields
Boston Manor
Osterley
Hounslow West
Hounslow East
Hounslow Central
Hatton Cross
Heathrow Terminals 1,2,3
Heathrow Terminal 4
Gunnersbury
Kew Gardens
Richmond
Chiswick Park
Turnham Green
Stamford Brook
Ravenscourt Park
Hammersmith
Barons Court
West Kensington
West Brompton
Fulham Broadway
Parsons Green
Putney Bridge
East Putney
Southfields
Wimbledon Park
Wimbledon
Neasden
Dollis Hill
Willesden Green
Kilburn
West Hampstead
Finchley Road
Swiss Cottage
St. John's Wood
Stonebridge Park
Harlesden
Willesden Junction
Kensal Green
Queen's Park
Kilburn Park
Maida Vale
Warwick Avenue
Royal Oak
Westbourne Park
Ladbroke Grove
Latimer Road
White City
Shepherd's Bush
Goldhawk Road
Holland Park
Kensington (Olympia)
Mornington Crescent
Bethnal Green
Mile End
Bow Road
Bow Church
Bromley-by-Bow
All Saints
Shoreditch
Whitechapel
Stepney Green
Limehouse
Shadwell
Wapping
Rotherhithe
Surrey Quays
Westferry
Blackwall
Poplar
West India Quay
Canary Wharf
Heron Quays
South Quay
Crossharbour
East India
Canning Town
Royal Victoria
Custom House
Prince Regent
Royal Albert
Beckton Park
Beckton
Cyprus
Gallions Reach
West Ham
Plaistow
Upton Park
East Ham
Barking
Upney
Becontree
Dagenham Heathway
Dagenham East
Elm Park
Hornchurch
Upminster Bridge
Upminster
Borough
Elephant & Castle
Kennington
Pimlico
Vauxhall
Oval
Stockwell
Brixton
Clapham North
Clapham Common
Clapham South
Balham
Tooting Bec
Tooting Broadway
Colliers Wood
South Wimbledon
Morden
Angel
King's Cross St. Pancras
Old Street
Euston
Great Portland Street
Euston Square
Warren Street
Baker Street
Marylebone
Edgware Road
Regent's Park
Russell Square
Goodge Street
Chancery Lane
Farringdon
Barbican
Liverpool Street
Moorgate
St. Paul's
Bank
Aldgate
Aldgate East
Bayswater
Paddington
Oxford Circus
Tottenham Court Road
Holborn
Notting Hill Gate
Queensway
Lancaster Gate
Marble Arch
Bond Street
Piccadilly Circus
Covent Garden
Leicester Square
Temple
Cannon Street
Monument
Tower Hill
Tower Gateway
Blackfriars
Mansion House
Embankment
Charing Cross
London Bridge
Hyde Park Corner
Green Park
Knightsbridge
Waterloo
Westminster
Lambeth North
High Street Kensington
Gloucester Road
South Kensington
Sloane Square
Victoria
St. James's Park



Tube, DLR, Overground and National Rail Networks in London

The simplest network for the first problem, based on an analysis of the network, not the flows: shown below are the degrees



Problem 2: Representing Networks

We use standard graph algebra to represent the network where we define three indices of centrality

Degrees of the graph

$$\left.\begin{aligned}\sigma_i &= \sum_j a_{ij} \\ \sigma_j &= \sum_i a_{ij}\end{aligned}\right\} \quad \sigma = \sum_i \sigma_i = \sum_j \sigma_j = \sum_i \sum_j a_{ij}$$

Betweenness Centrality

$$C_k = \sum_i \sum_j \frac{\sigma_{ikj}}{\sigma_{ij}}$$

Closeness Centrality

$$L_i = KD_i^{-1} = K\left(\sum_j d_{ij}\right)^{-1}$$

Representing Flows

Trip Volume

Entries and Exits

$$T_i = \sum_j T_{ij}$$

$$T_j = \sum_i T_{ij}$$

$$T = \sum_i T_i = \sum_j T_j = \sum_i \sum_j T_{ij}$$

Changes in

Trip Volumes

$$\Delta_i = T_i - T_i'$$

$$\Delta_j = T_j - T_j'$$

$$\sum_i \Delta_i = \sum_i \Delta_j = 0$$

Weighted Betweenness

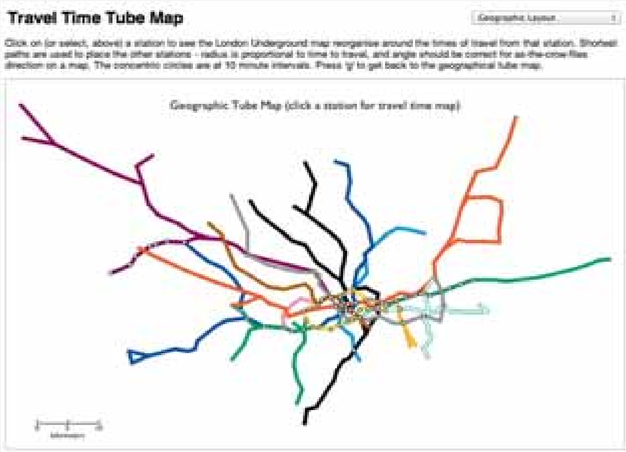
Centrality

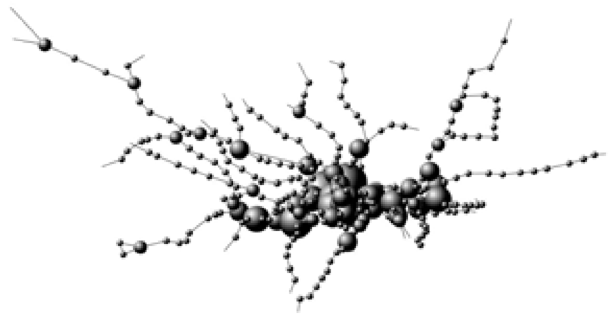
$$p_{ijk} = \frac{\sigma_{ikj}}{\sigma_{ij}} = \frac{\sigma_{ikj}}{\sum_\ell \sigma_{i\ell j}} \quad , \quad \sum_k p_{ikj} = 1$$

$$\tilde{C}_k = \sum_i \sum_j T_{ij} p_{ikj} = \sum_i \sum_j T_{ij} \frac{\sigma_{ikj}}{\sigma_{ij}}$$

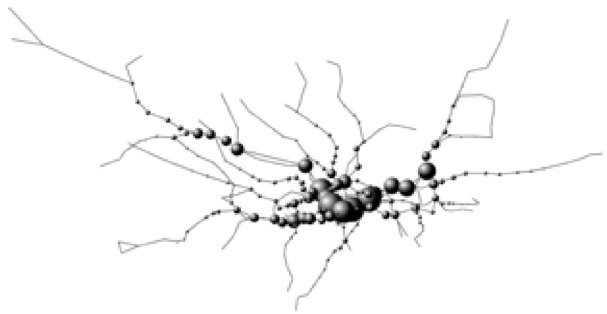
A Preliminary Analysis (1)

The Minimal Tube Network and the Three Centrality Indices





Degree



Betweenness

Closeness

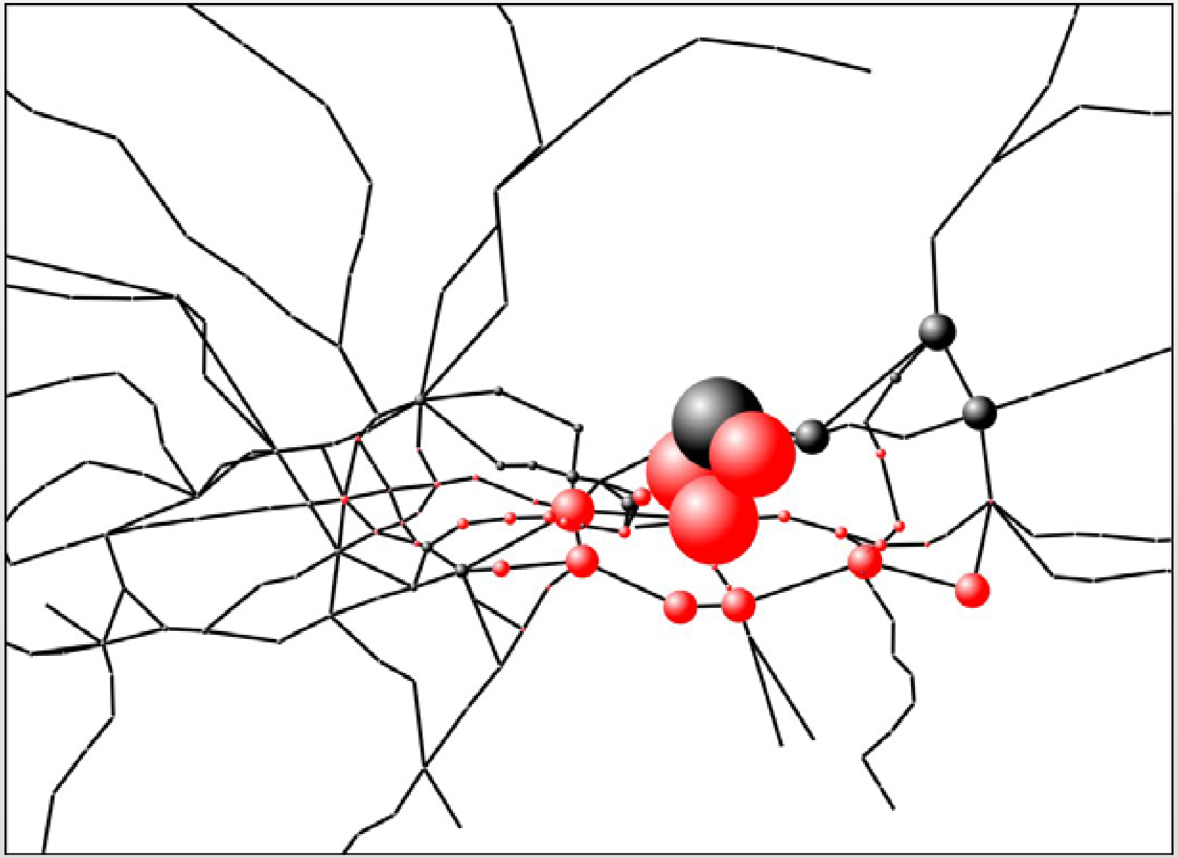
A Preliminary Analysis (2)

- Top Stations
- By Centrality

Station	d_i	Station	$\hat{C}_i$	Station	$\hat{L}_i$
Baker Street	7	*Green Park*	16399	*Green Park*	2.137
King's Cross	7	Waterloo	15644	Westminster	2.107
Bank	6	Bank	15008	Bond Street	2.101
Earl's Court	6	Baker Street	14441	Oxford Circus	2.089
Green Park	6	Westminster	14139	Waterloo	2.089
Oxford Circus	6	Bond Street	11429	Bank	2.074
Waterloo	6	***Liverpool Street***	11186	Baker Street	2.071
Canning Town	5	Stratford	10814	Victoria	2.065
Liverpool Street	5	Mile End	10302	Hyde Pk Corner	2.053
Paddington	5	Bethnal Green	10017	Embankment	2.041
Shadwell	5	Finchley Road	8905	Piccadilly Circus	2.041
Turnham Green	5	Earl's Court	8706	St. James's Park	2.035
Acton Town	4	King's Cross	8679	Regent's Park	2.032
Bond Street	4	Wembley Park	7968	King's Cross	2.029
Camden Town	4	South Ken	7182	***Liverpool Street***	2.026
Canada Water	4	Euston	7156	Marble Arch	2.026
Canary Wharf	4	Gloucester Rd	7042	Tottenham Ct Rd	2.026
Embankment	4	Paddington	7028	Moorgate	2.020
Euston	4	Victoria	6558	Charing Cross	2.017
Finchley Road	4	Harrow-o-t-Hill	6253	Great Portland St	2.017

A Preliminary Analysis (3)

Closing Liverpool Street



A Preliminary Analysis (3)

Closing Green Park