Airport ground movement:
Real world data sets and approaches to handling uncertainty

Sandy Brownlee[1], Jason Atkin[2], John Woodward[1], Una Benlic[1] & Edmund Burke[1]

[1] CHORDS Group, University of Stirling

[2] ASAP Group, University of Nottingham

CHORDS Computational Heuristics Operational Research Decision-Support

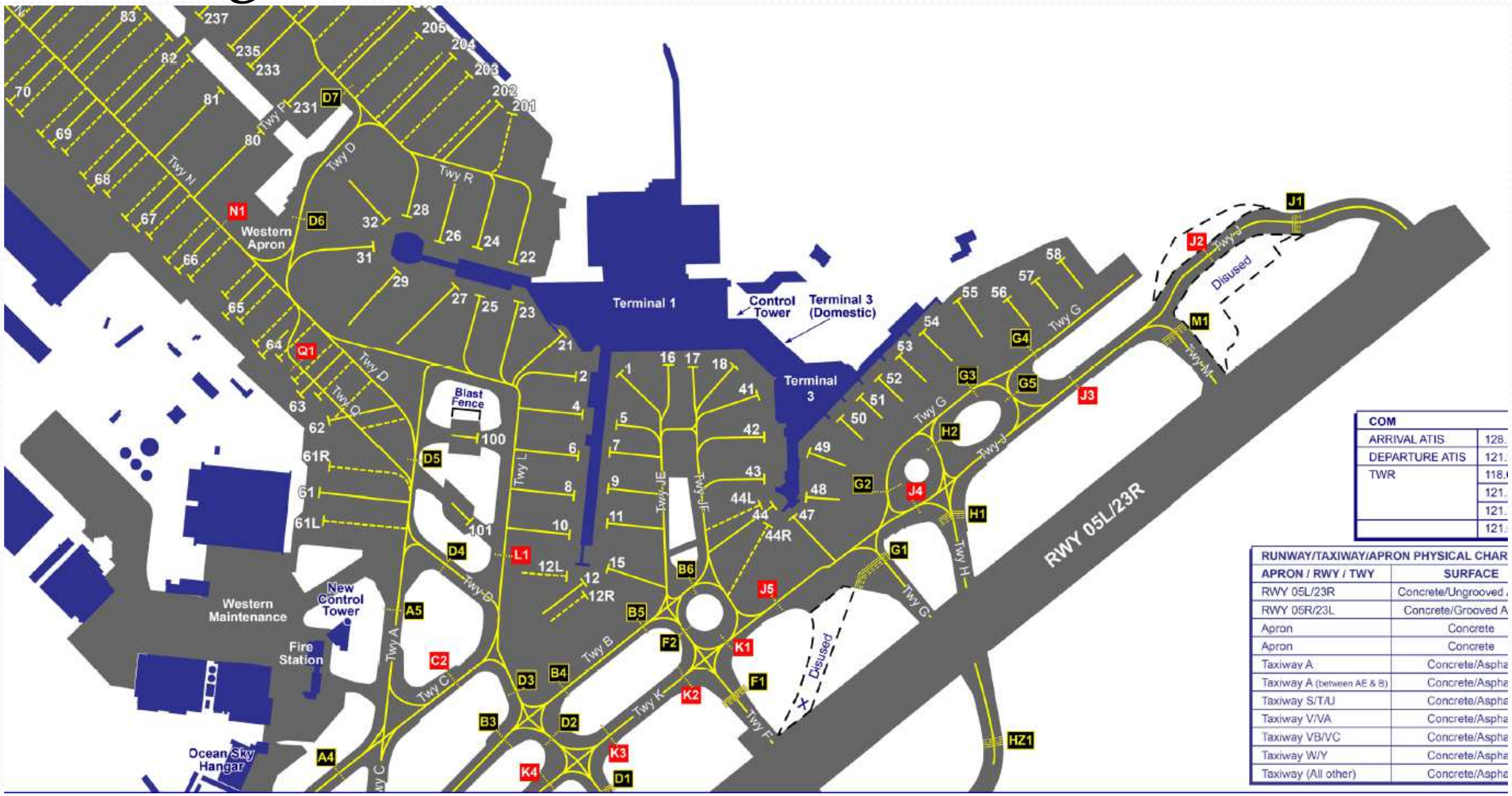
ASAP research group

Outline

- The ground movement problem
  - Introduction
  - The need for data
- Real world data sets
  - Sources
  - Benchmark problem
  - Cleaning and snapping raw data
- Tools for research

Ground movement

- Moving an aircraft from one point to another, in as quick and fuel-efficient way as possible, considering existing aircraft movements and route restrictions



Approaches to GM

- Mixture of routing and scheduling
- Many approaches
  - Mixed integer linear programming
  - Genetic algorithm
  - QPPTW (Quickest Path Problem with Time Windows)
    - Based on Dijkstra's algorithm – find quickest path, while respecting times reserved for other aircraft
- **Assumes that times and taxi speed estimates are correct and crisp**

QPPTW at Manchester

- Demo video

Handling uncertainty

- Uncertainty is a big issue: leads to increased conflicts and delays
- Currently adapting QPPTW, working on fuzzy and alternative approaches
- Need improved understanding and accurate modelling of real aircraft movements
- Crucial that we have access to good data
- Hard to get, particularly for multiple airports
- **Lack of data is a barrier to research**

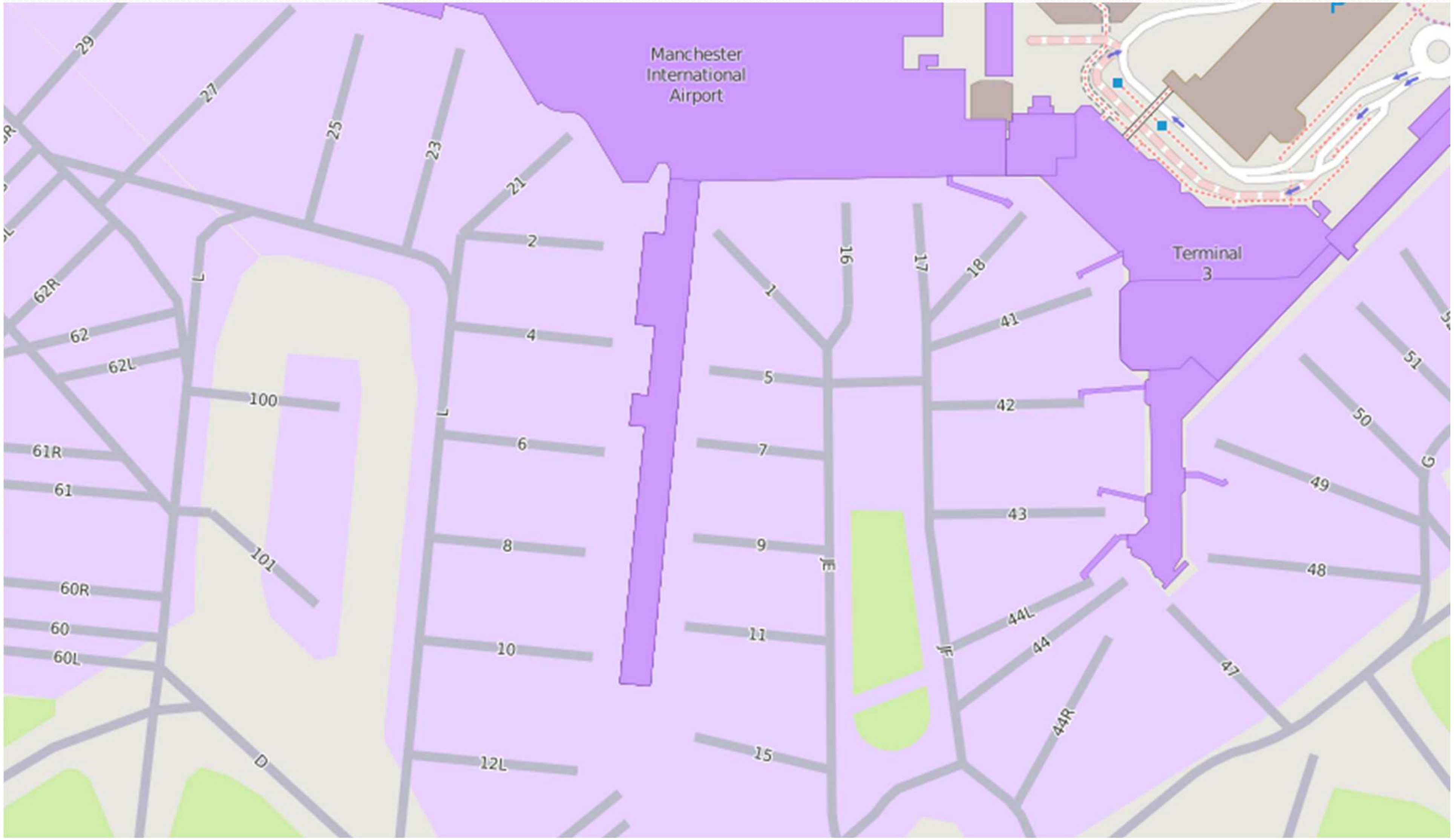
Data sets

- Required? Edge + node coordinates, aircraft timings
- Free sources: no substitute for good quality data direct from airports, but freely available (potential for benchmarking)
- Edge + Nodes:
  - Open street map
  - NATS / EUROCONTROL EAD AIS
- Movements:
  - FlightRadar 24

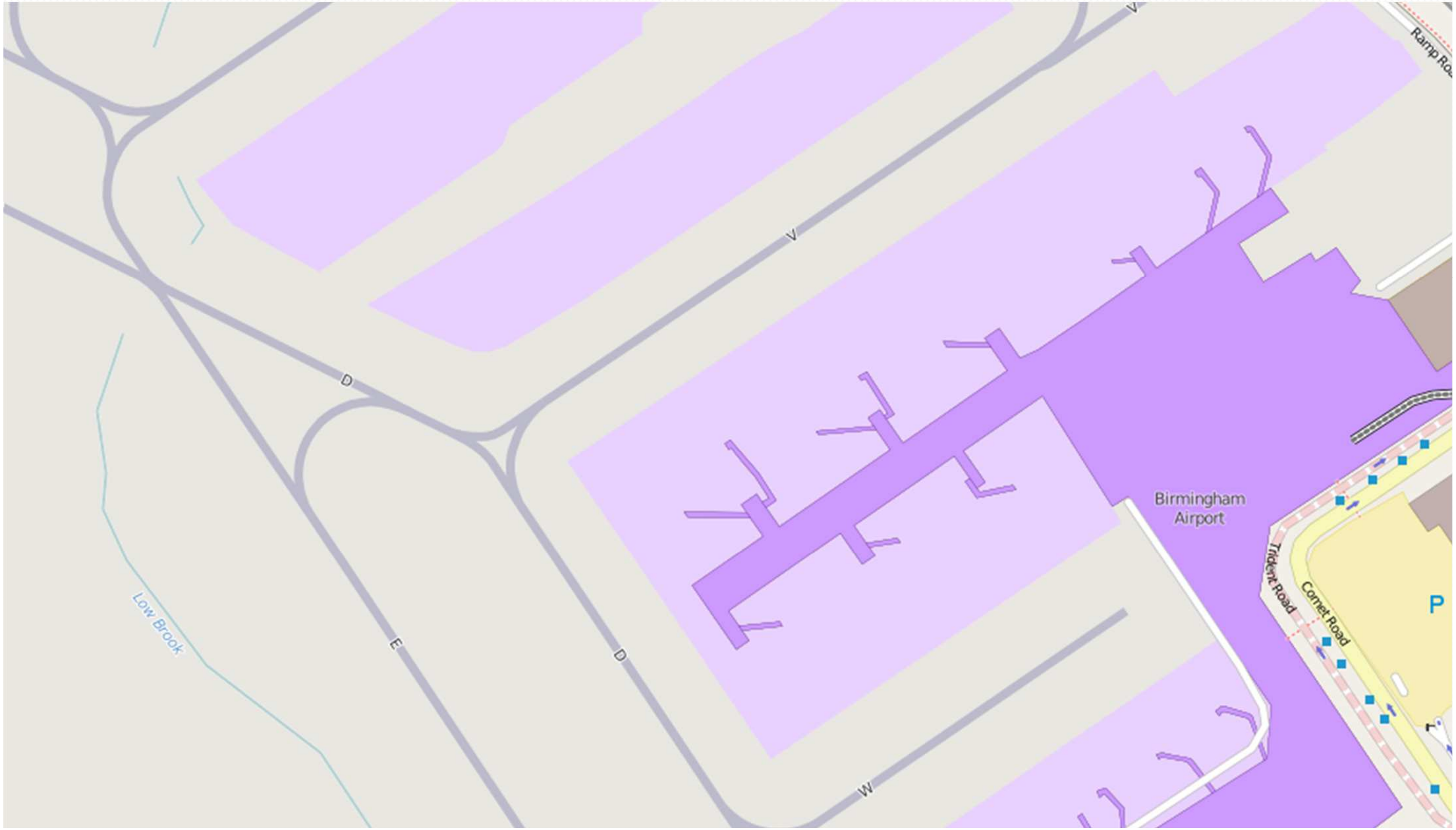
OpenStreetMap

- OSM – "free to copy, distribute, transmit and adapt our data, as long as you credit OpenStreetMap and its contributors" – so the following are © OpenStreetMap contributors
- Not perfect – but surprisingly accurate, and can be edited to fix imperfections
- Export to XML, taxiways, runways and (often) stands identified by type tags

OSM - Manchester



OSM - Birmingham



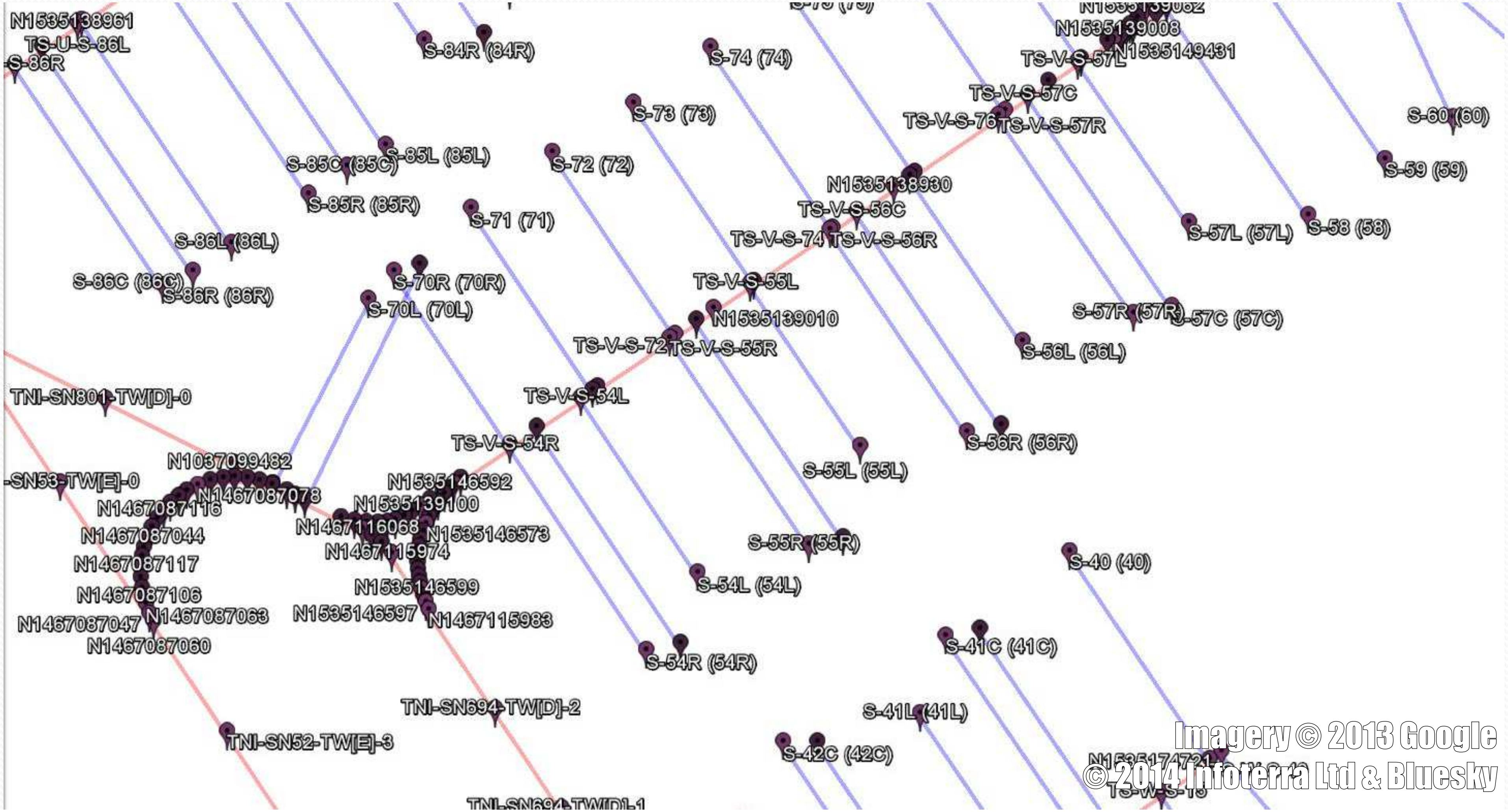
NATS & EUROCONTROL EAD AIS

- (Aeronautical information service)
- Charts and data for UK and European airports
- Includes coordinates of stands often missing from OSM

STAND	COORDINATE	STAND	COORDINATE	STAND	COORDINATE	STAND	COORDIN
	Terminal 1	28	532145.90N 0021642.40W		West Apron	69L	532148.72N 002
1	To be surveyed	29	532143.47N 0021643.17W	61L	532132.33N 0021648.46W	69	532149.07N 002
2	532138.77N 0021629.89W	31	532144.58N 0021644.84W	61	To be surveyed	69R	532149.54N 002
4	532137.10N 0021629.72W	32	532145.73N 0021643.95W	61R	532134.75N 0021648.16W	70L	532150.47N 002
5	532136.63N 0021626.85W		Terminal 3	62	532136.77N 0021648.20W	70	532150.94N 002
6	532135.22N 0021629.54W	41	532137.93N 0021616.22W	62L	532136.28N 0021646.83W	70R	532151.40N 002
7	532135.40N 0021627.33W	42	532136.08N 0021615.75W	62R	532137.20N 0021647.21W	71L	532152.34N 002
8	532133.47N 0021630.04W	43	532134.20N 0021615.73W	63	532137.91N 0021650.29W	71	532152.81N 002
9	532133.77N 0021627.44W	44L	532133.04N 0021615.99W	63L	532137.55N 0021649.49W	71R	532153.27N 002
10	532131.73N 0021630.16W	44	532133.03N 0021615.00W	63R	532138.52N 0021650.73W	72L	532154.02N 002
11	532132.25N 0021627.50W	44R	532132.11N 0021615.44W	64	532139.64N 0021653.14W	72	532154.57N 002
12	532129.39N 0021629.43W	47	532132.53N 0021613.60W	64L	532139.54N 0021651.90W	72R	532154.98N 002
12L	532129.75N 0021630.62W	48	532133.42N 0021612.63W	64R	532140.23N 0021653.61W	73L	532155.94N 002
12R	532128.91N 0021629.21W	49	532135.40N 0021612.42W	65R	532142.55N 0021656.23W	73	532156.44N 002
15	532130.37N 0021627.27W	50	532136.88N 0021610.00W	65	532141.60N 0021655.60W	73R	532156.91N 002
16	532139.29N 0021622.99W	51	532137.82N 0021608.49W	65L	532141.70N 0021654.77W	74L	532157.87N 002
17	532139.48N 0021620.95W	52	532138.67N 0021607.15W	66L	532143.02N 0021658.70W	74	532158.38N 002

Ground movement layouts

- Used these sources to generate layouts…



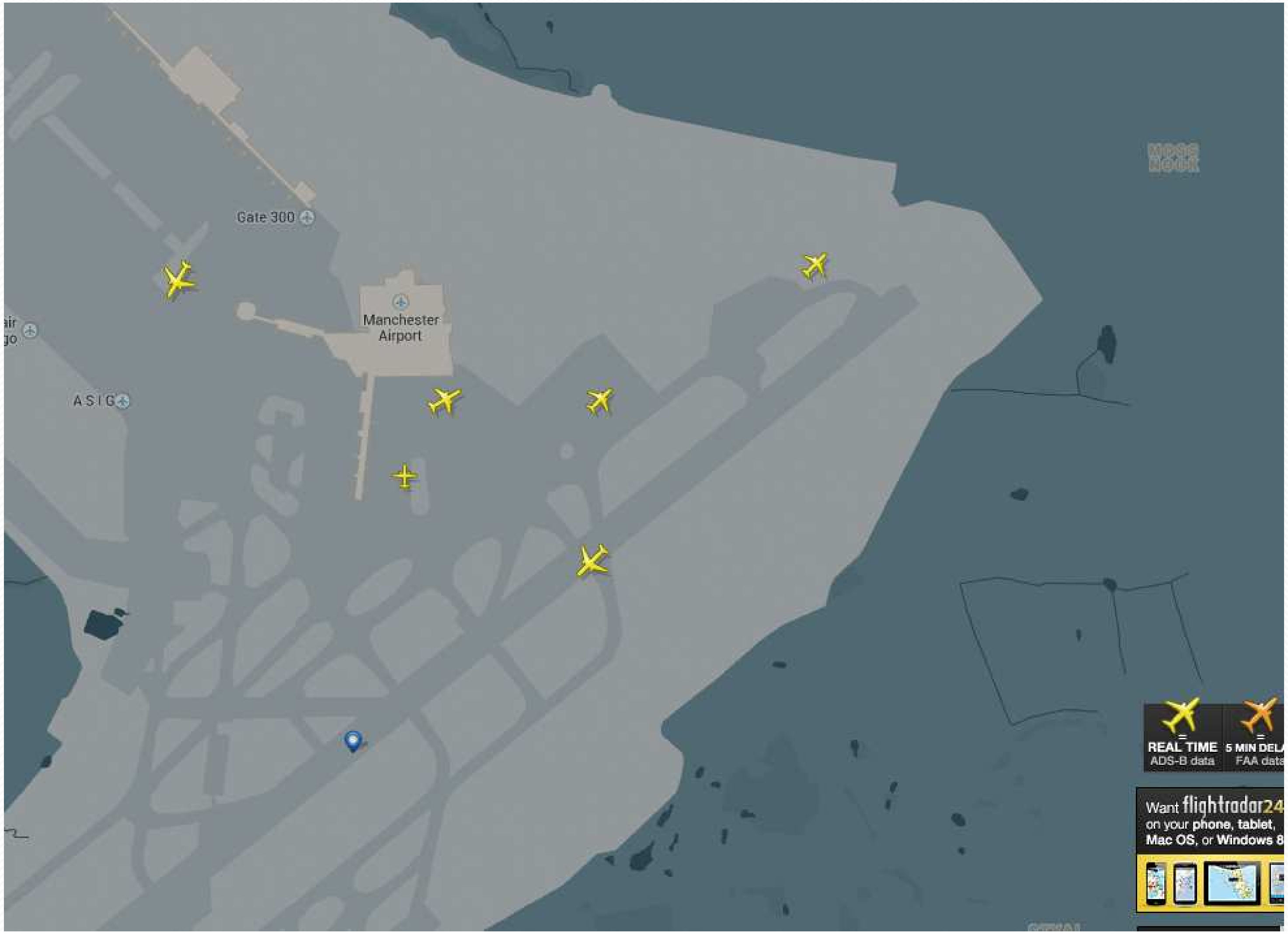
Benchmark

- Manchester Airport
- Third busiest in UK
- 2 runways, 148 stands
- 29 August – 4 September 2011
- 1855 arrivals, 1855 departures, 334 tows
- Available here:
- http://www.asap.cs.nott.ac.uk/external/atr/benchmarks/index.shtml

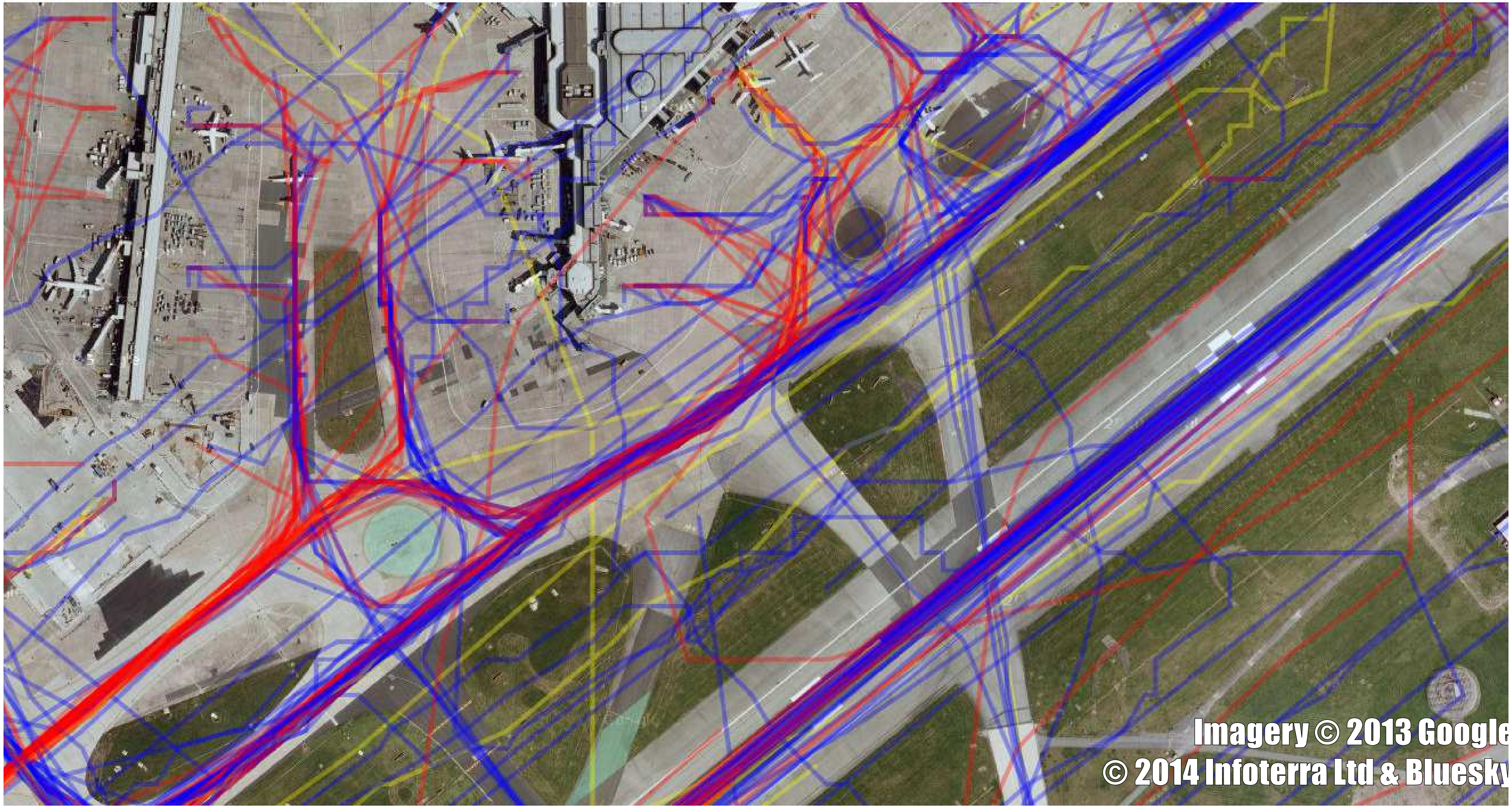
FlightRadar 24

- Real-time tracking of ADS-B transponder data
- Latitude / longitude / altitude every few seconds
- Covers most airports in Europe + USA, many elsewhere
- Includes 50-60% of flights, increasing
  - Can't be used to make benchmark problems, but suitable for analysis of real-world movements
- Noisy, needs cleaned
  - method applicable to other data sources too
- Already used in a handful of publications

FR24

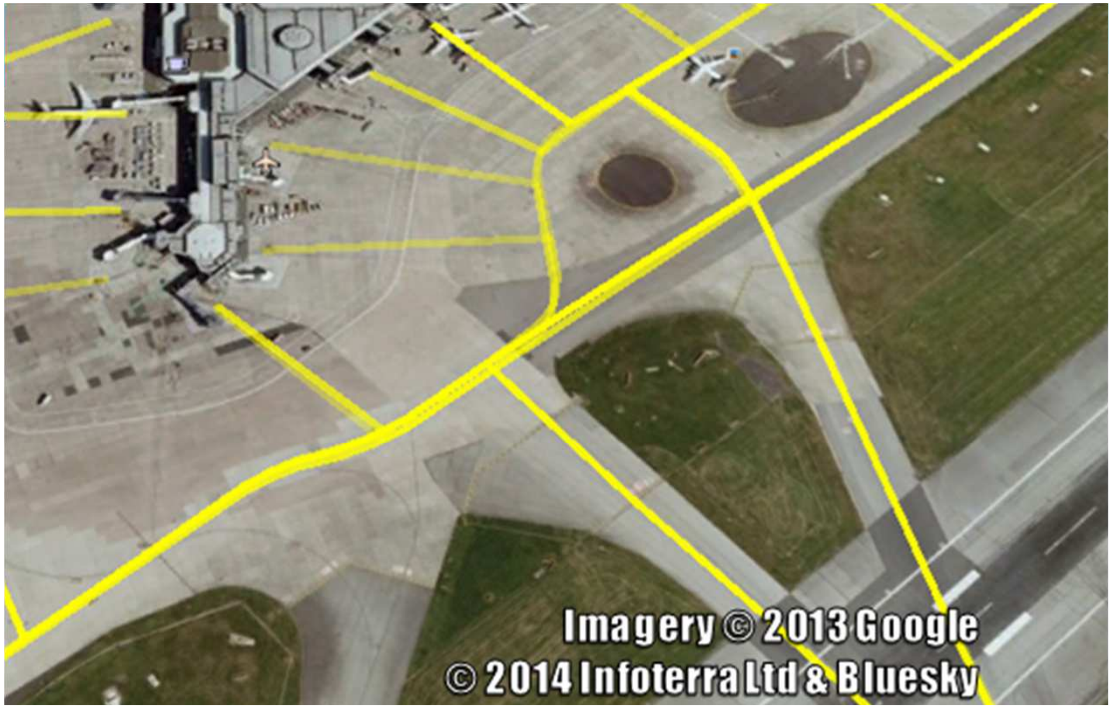

Gate 300
Manchester
Airport
ASIG
REAL TIME
ADS-B data
Want flightradar24
on your phone, tablet,
Mac OS, or Windows 8

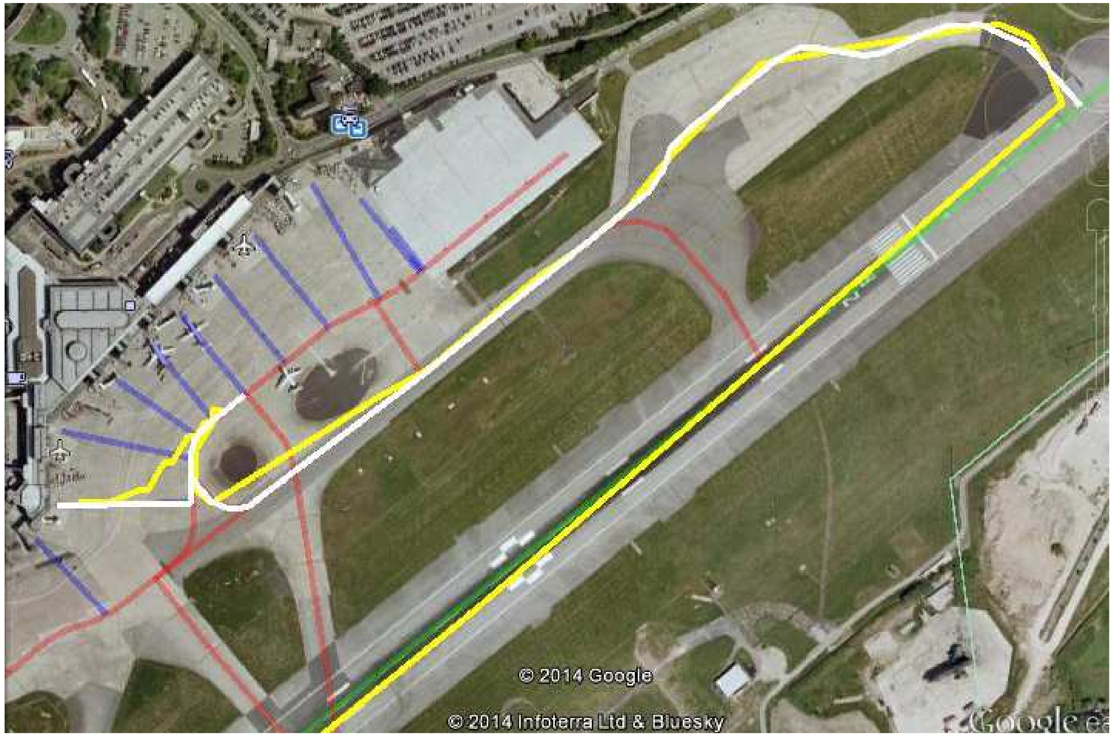
FR24 – actual movements



FR24 – snap to taxiways

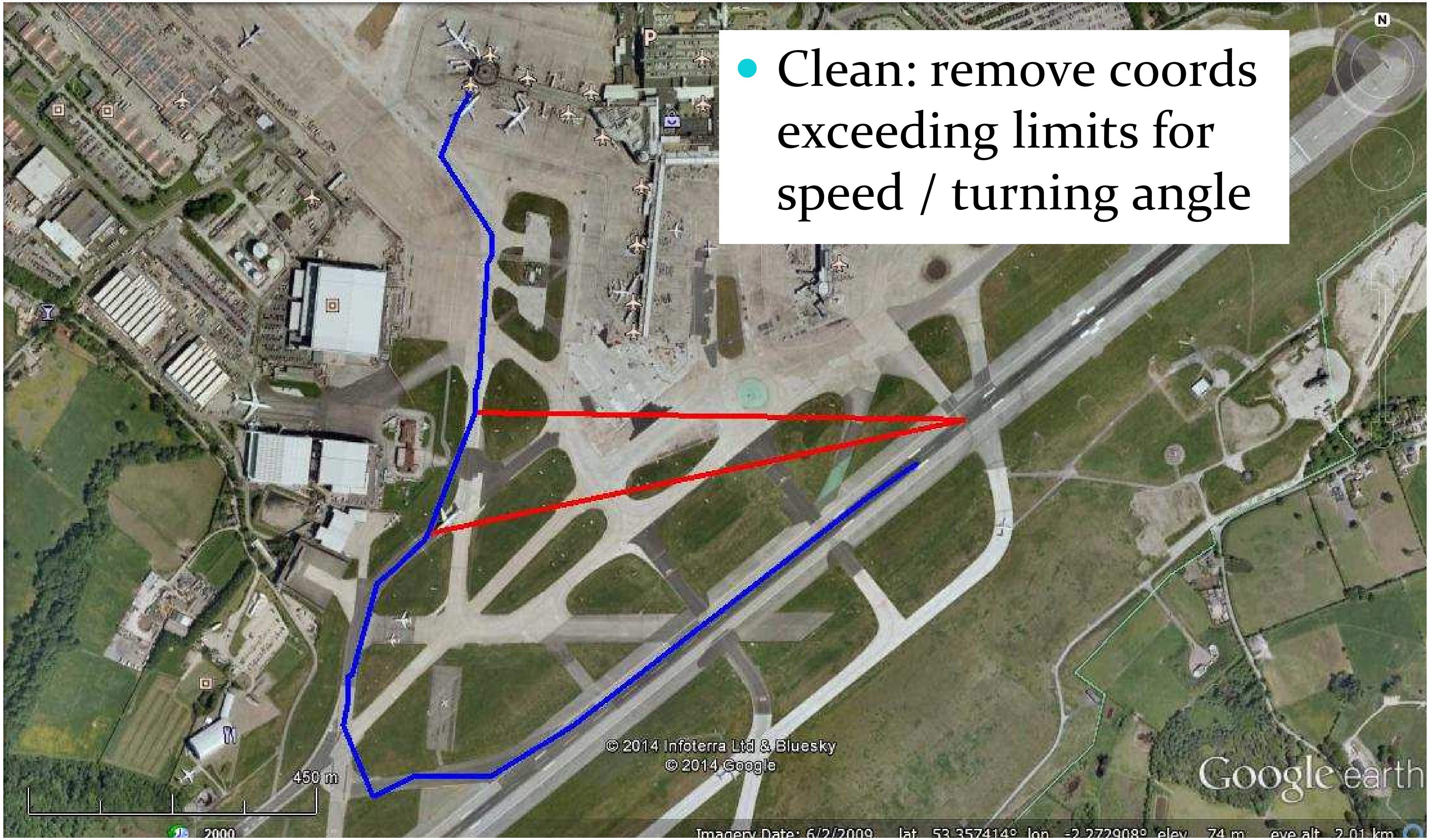
1. Clean bad coords
2. Locate edges
3. Refine selection
4. Complete route
5. Remove branches
6. Success?
    1. Calc times
    2. Split route?
7. Fail?
    1. Displace coords





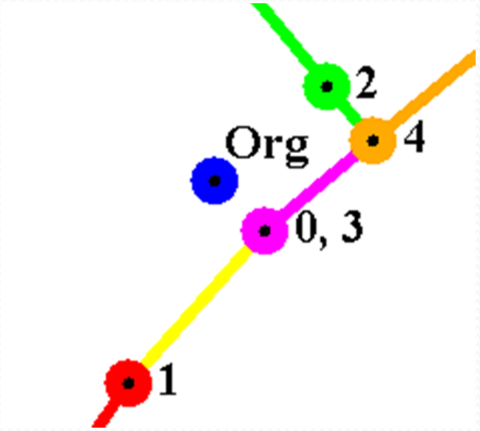
Snapping

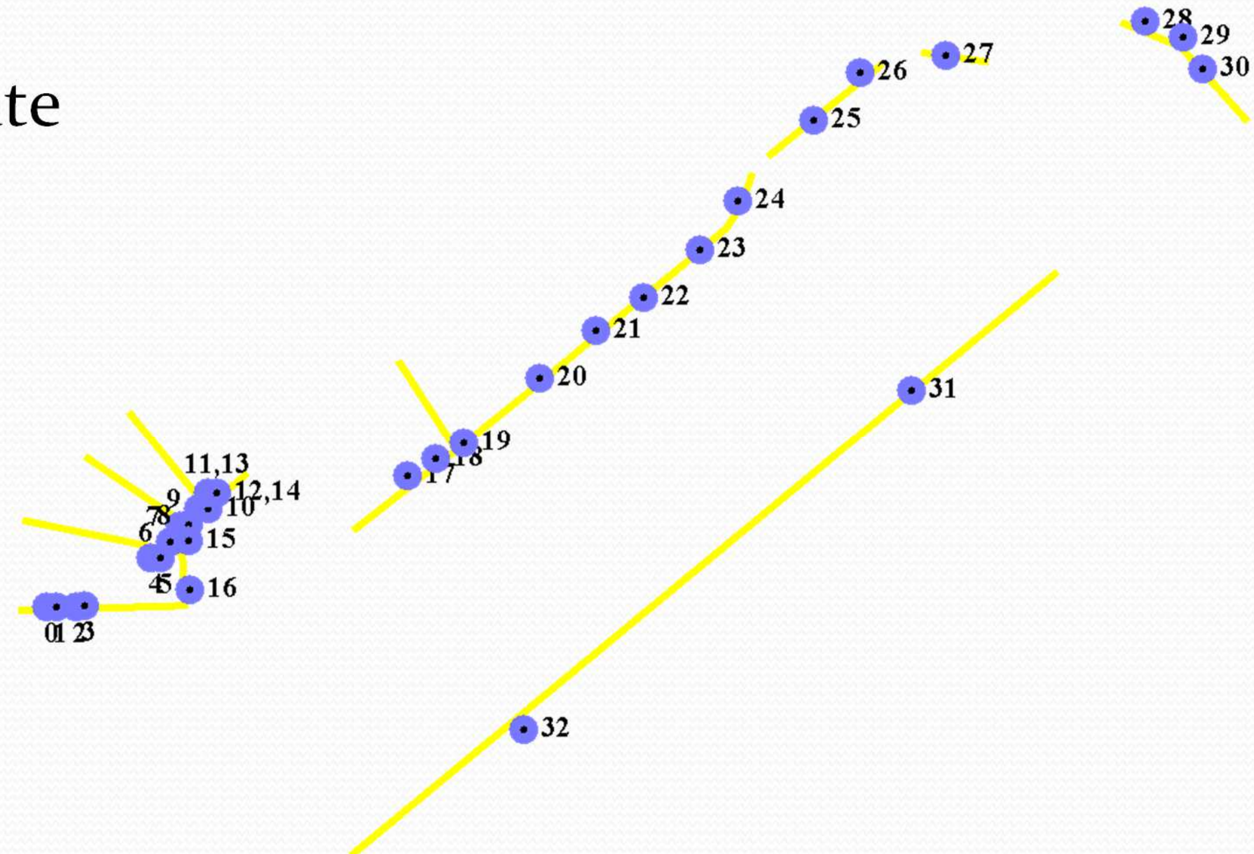
- Clean: remove coords exceeding limits for speed / turning angle



Snapping

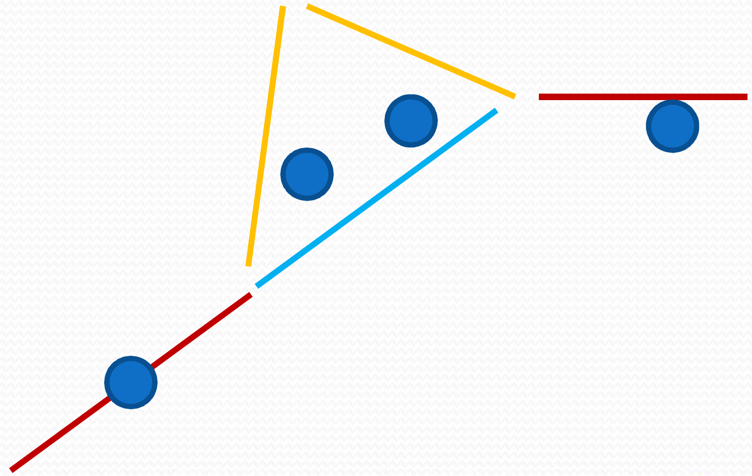
- Locate candidate edges for each coordinate

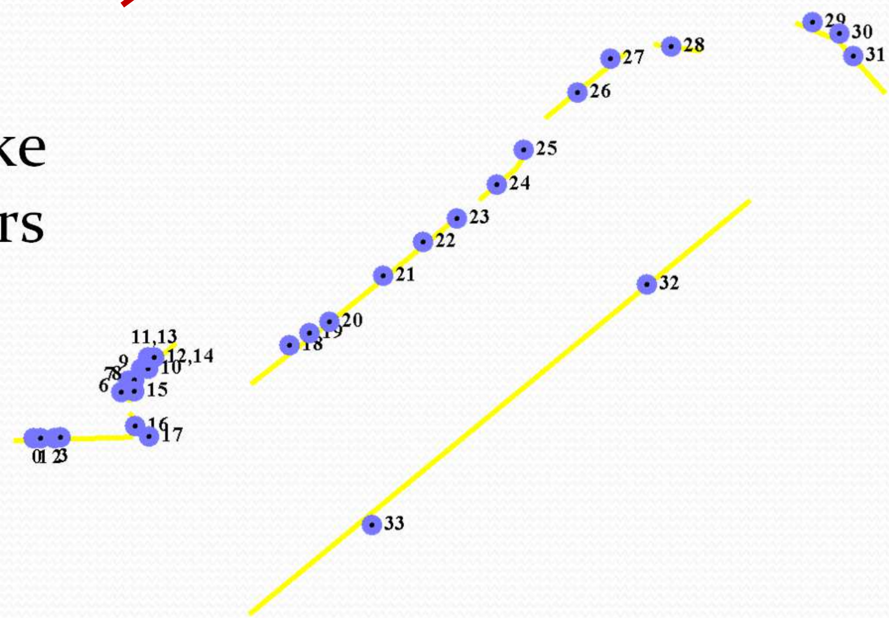




Snapping

- Refine selected edges:
  - Guided by coords matched to single edges C_s
  - Remove all stands but the “most likely” one
  - Keep edges that would make shortest paths between pairs of C_s





Rules for choosing stands

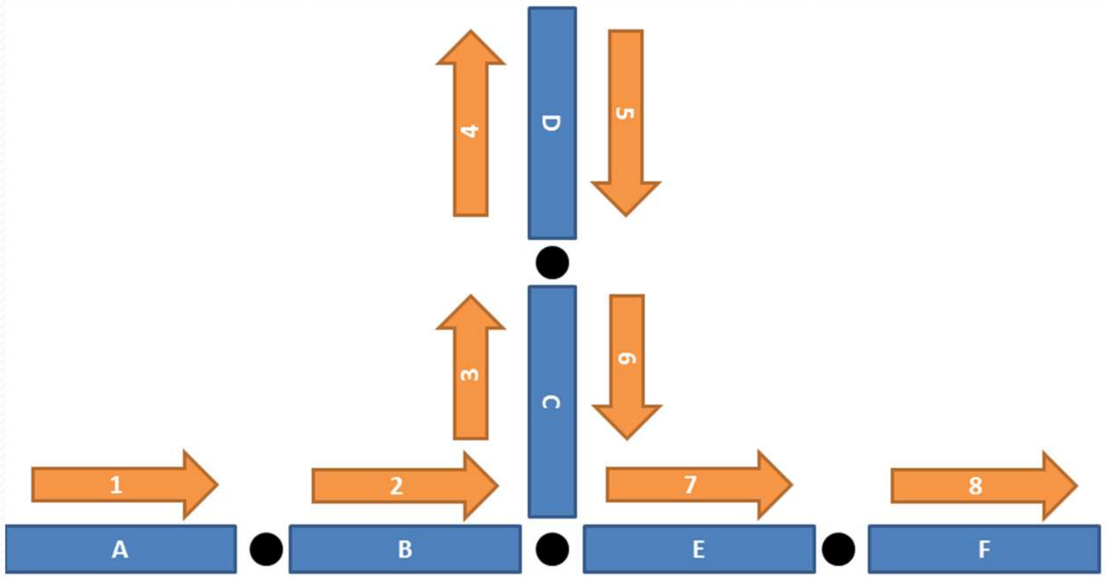
1. Of the coordinates matched to a single stand edge:
    1. If one is at the end of the route, choose that
    2. Otherwise choose the one where the coord was closest to the edge
2. If either all coords match to multiple stands, or no coords matched to stands
    1. Choose the stand closest to one of the coords

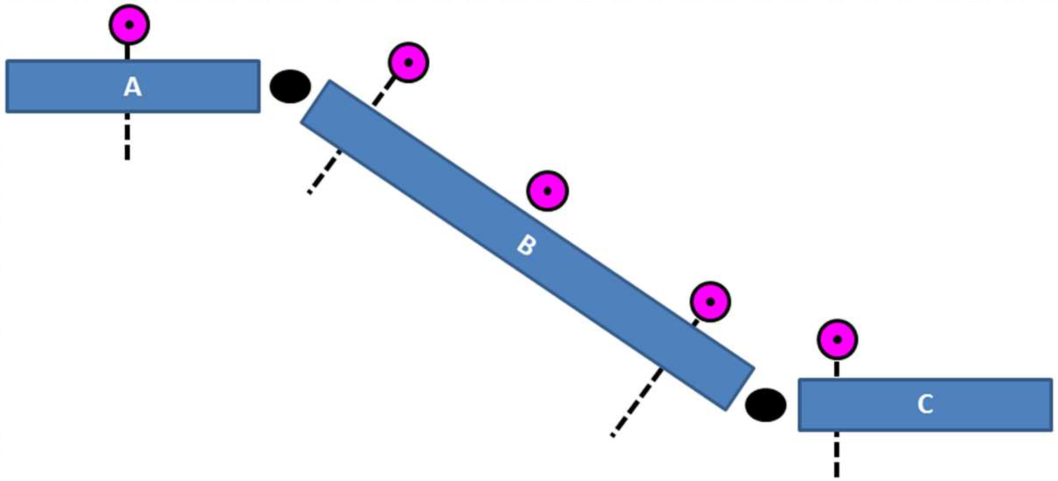
Snapping

- Complete route: shortest path to fill gaps

- Remove non-stand branches

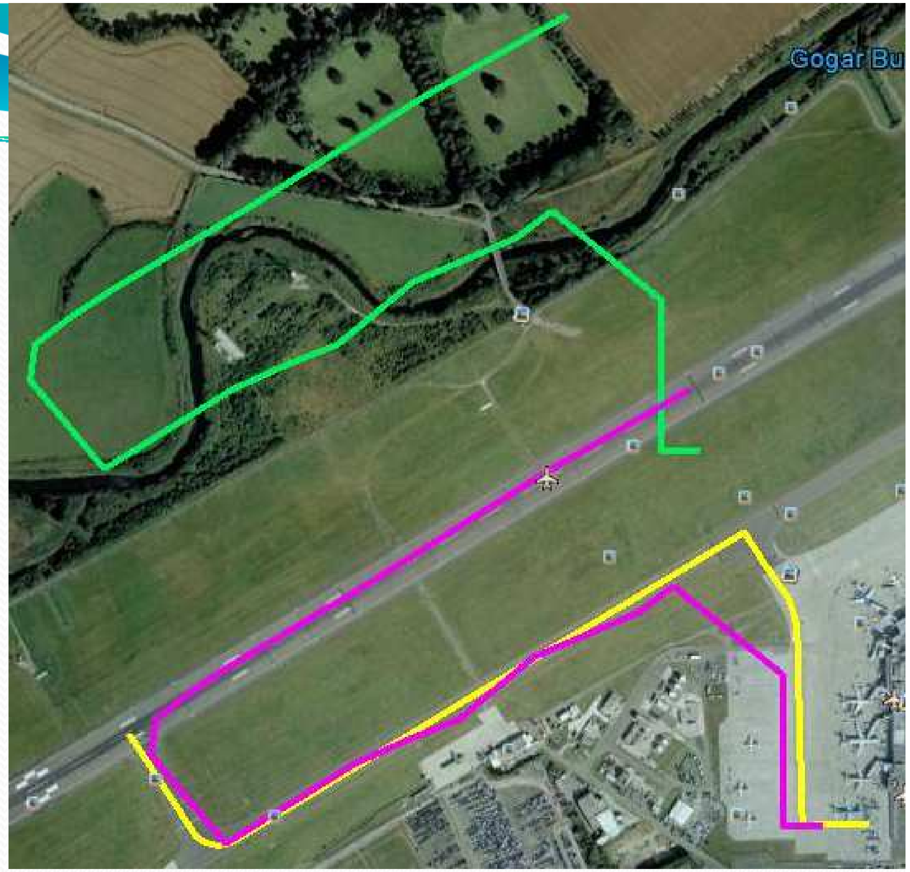
- Calc times (assume constant speed between nearest coords each side of nodes)



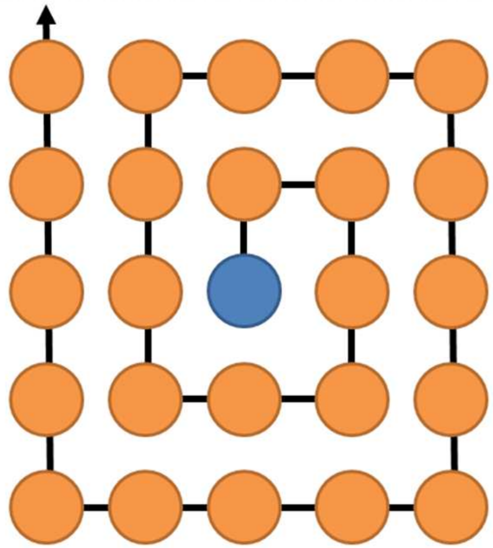


Snapping

- Split route
  - If > 1 stand / RW



- If failed, displace all coords following this pattern and try again



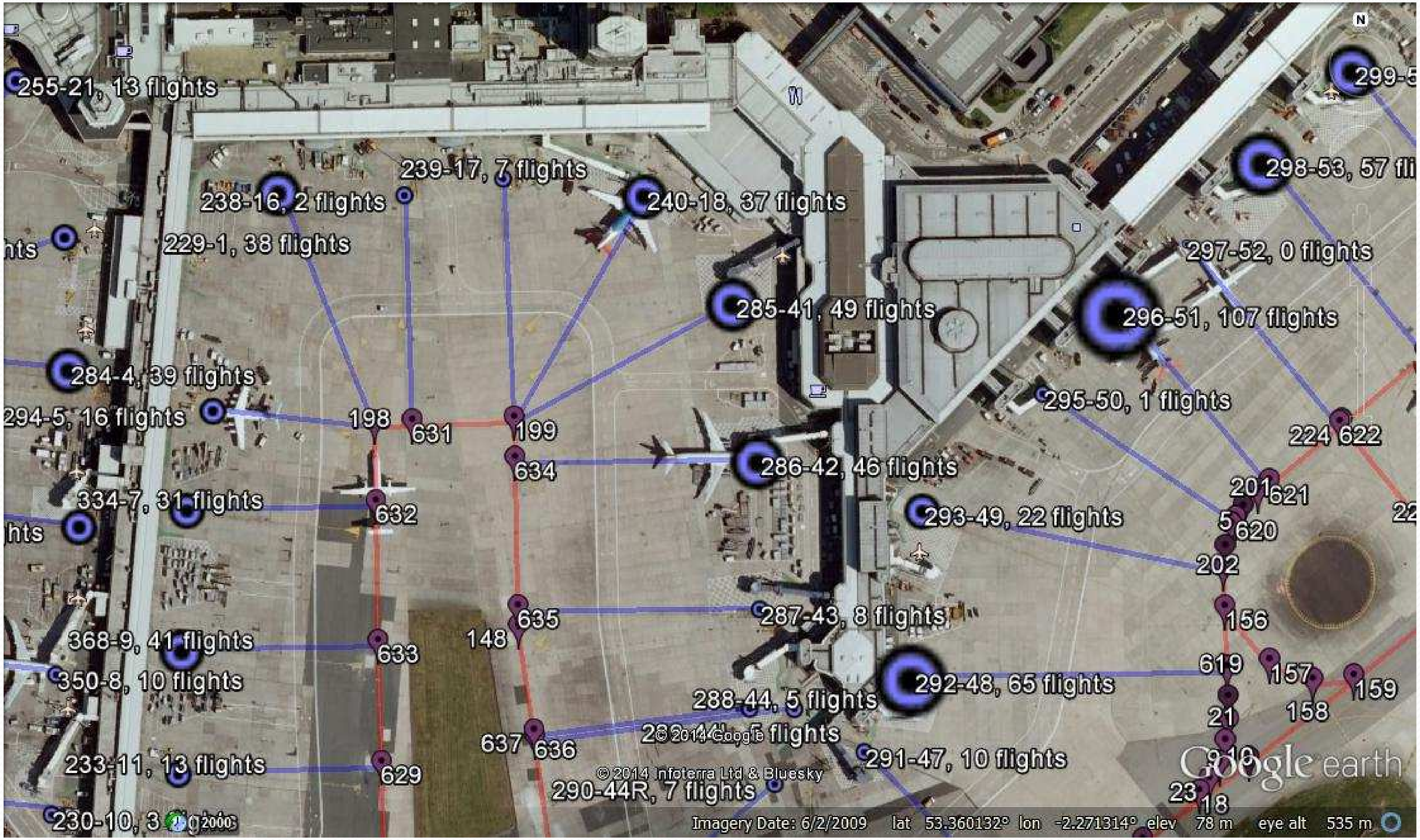
Applications

- Tested with Manchester on 5-12 November 2013
  - 1420/2172 movements captured
- Analysis of:
  - Taxi routes
  - Stand preferences
  - Operating modes
  - Taxi speeds + times (and uncertainty)
- Over a whole period, or sub-periods

Taxi routes

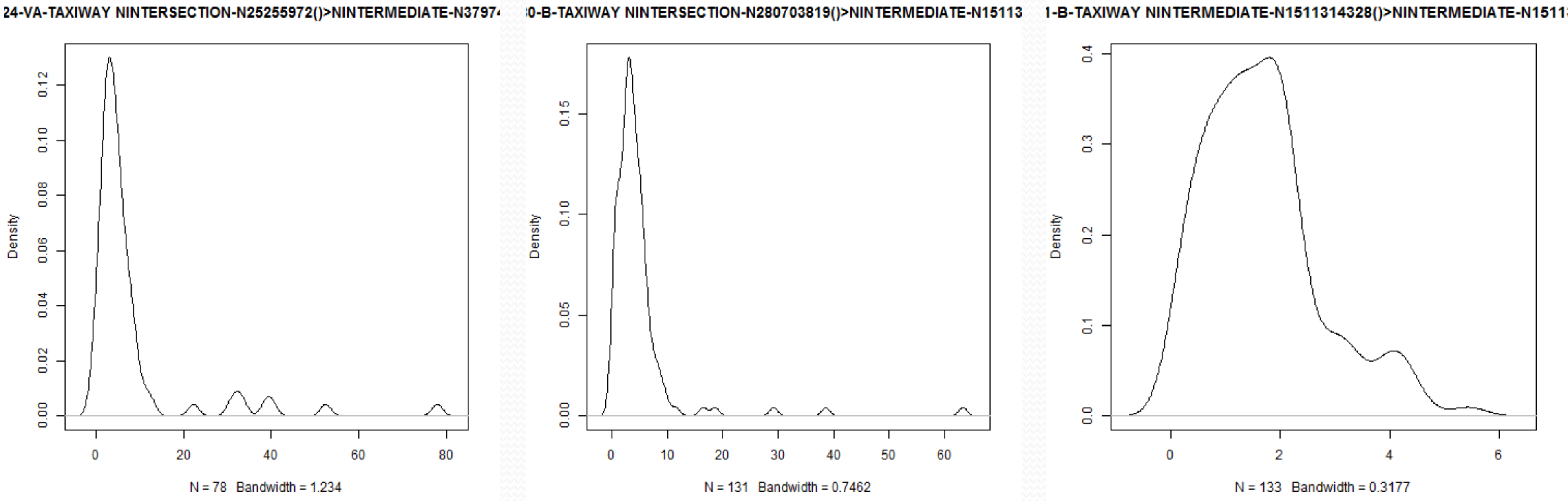
239-17, 7 flights
229-1, 38 flights
238-16, 2 flights
240-18, 39 flights
flights
285-41, 49 flights
284-4, 40 flights
294-5, 16 flights
286-42, 45 flights
334-7, 31 flights
304-6, 31 flights
60 m
© 2014 Infoterra Ltd & Bluesky
Google earth
2000
Imagery Date: 6/2/2009 lat 53.360491° lon -2.272960° elev 78 m eye alt 332 m

Stand use


255-21, 13 flights
239-17, 7 flights
238-16, 2 flights
240-18, 37 flights
229-1, 38 flights
298-53, 57 fli
297-52, 0 flights
285-41, 49 flights
296-51, 107 flights
284-4, 39 flights
294-5, 16 flights
198
631
199
634
295-50, 1 flights
224
622
286-42, 46 flights
334-7, 31 flights
632
201
621
293-49, 22 flights
5
620
202
635
287-43, 8 flights
156
148
368-9, 41 flights
633
350-8, 10 flights
619
157
159
288-44, 5 flights
292-48, 65 flights
21
158
637
636
291-47, 10 flights
233-11, 13 flights
629
290-44R, 7 flights
23
18
© 2014 Infoterra Ltd & Bluesky
© 2014 Google
Google earth
Imagery Date: 6/2/2009 lat 53.360132° lon -2.271314° elev 78 m eye alt 535 m

Taxi time uncertainty

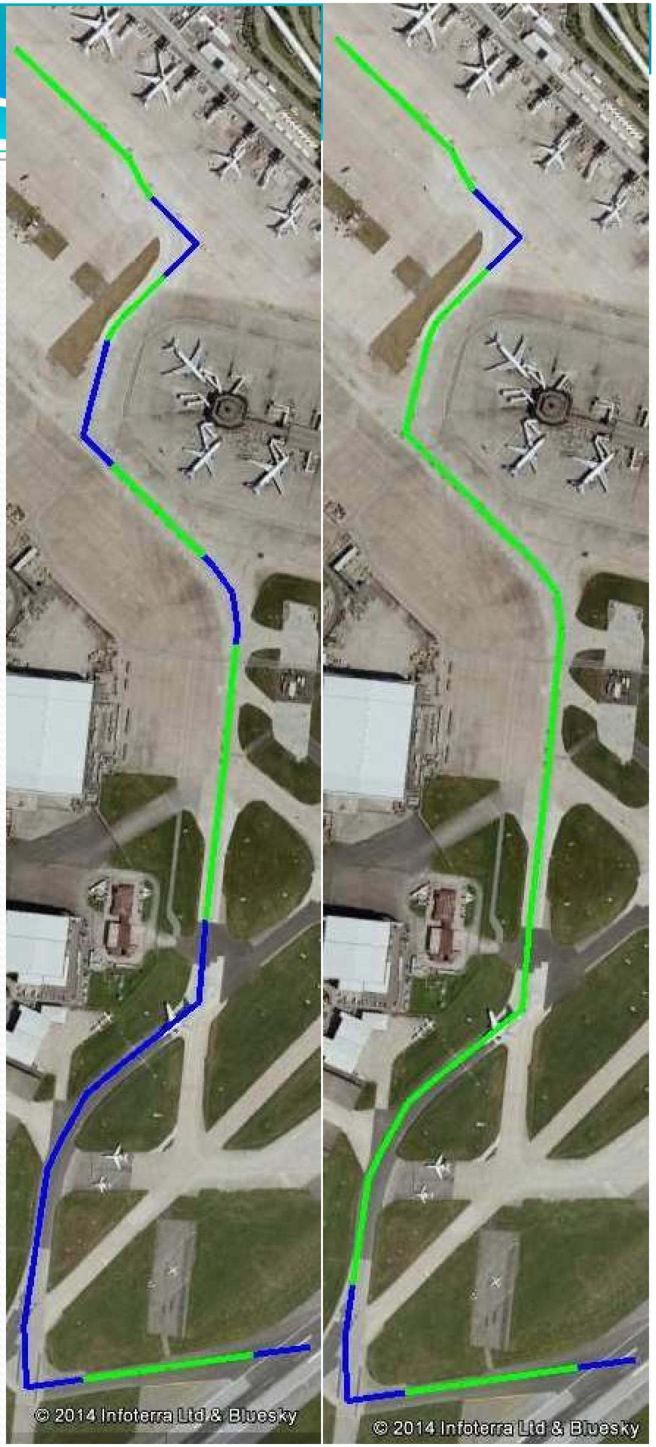
- Taxi times for individual edges are quite variable:



Taxi speeds

- Avg speed for turns / straights
- Not realistic!
- Many other factors involved

Angle for turn	Turns (m)	Straights (m)	Avg Spd Turns (SD)	Avg Spd Straights (SD)
30° in 100m	1 377 381	1 208 618	10.73 (11.83)	11.01 (10.9)
60° in 100m	579 747	2 006 453	9.81 (11.18)	11.05 (11.66)



Free Tools

- **TaxiGen** – combines OSM + stand coords to generate graph layout
- **SnapTracks** – snaps coordinates to taxiway graph
- **GM2KML** – visualise snapped data in KML (for use in Google Earth etc)
- Source and binaries available at:
- https://github.com/gm-tools/gm-tools/wiki

Summary

- Lack of data impedes airport ground movement research
  - Need better understanding of e.g. uncertainty
- Sources for freely-available data:
  - Open street map
  - NATS / EUROCONTROL EAD AIS
  - FlightRadar24
- Benchmark problem
- Approaches and tools for handling free data

Thanks

- Any questions?
- Useful addresses:
  - github.com/gm-tools/gm-tools/wiki
  - www.asap.cs.nott.ac.uk/external/atr/benchmarks/index.shtml
  - www.openstreetmap.org/
  - www.nats-uk.ead-it.com/
  - www.ead.eurocontrol.int
  - www.flightradar24.com
  - www.cs.stir.ac.uk/~sbr
  - sbr@cs.stir.ac.uk