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

Sandy Brownlee¹, Jason Atkin², John Woodward¹, Una Benlic¹ & Edmund Burke¹

¹ CHORDS Group, University of Stirling
² ASAP Group, University of Nottingham
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

<table>
<thead>
<tr>
<th>STAND</th>
<th>COORDINATE</th>
<th>STAND</th>
<th>COORDINATE</th>
<th>STAND</th>
<th>COORDINATE</th>
<th>STAND</th>
<th>COORDINATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal 1</td>
<td>28</td>
<td>532145.000 N 0021642.400 W</td>
<td>61L</td>
<td>532132.350 N 0021648.480 W</td>
<td>69</td>
<td>532149.070 N 0021648.020 W</td>
<td></td>
</tr>
<tr>
<td>To be surveyed</td>
<td>29</td>
<td>532143.470 N 0021643.170 W</td>
<td>61</td>
<td>To be surveyed</td>
<td>22R</td>
<td>532144.540 N 0021644.840 W</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>532136.770 N 0021629.800 W</td>
<td>31</td>
<td>532144.580 N 0021644.840 W</td>
<td>61</td>
<td>532132.350 N 0021648.480 W</td>
<td>69</td>
<td>532149.070 N 0021648.020 W</td>
</tr>
<tr>
<td>4</td>
<td>532132.700 N 0021629.720 W</td>
<td>32</td>
<td>532145.730 N 0021643.950 W</td>
<td>61R</td>
<td>532134.750 N 0021648.150 W</td>
<td>70L</td>
<td>532150.470 N 0021648.020 W</td>
</tr>
<tr>
<td>5</td>
<td>532136.830 N 0021626.850 W</td>
<td>Terminal 3</td>
<td>62</td>
<td>532136.770 N 0021648.200 W</td>
<td>70</td>
<td>532150.940 N 0021648.020 W</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>532135.220 N 0021629.540 W</td>
<td>41</td>
<td>532137.830 N 0021616.220 W</td>
<td>62L</td>
<td>532136.260 N 0021646.830 W</td>
<td>70R</td>
<td>532151.400 N 0021648.020 W</td>
</tr>
<tr>
<td>8</td>
<td>532133.470 N 0021630.040 W</td>
<td>43</td>
<td>532134.200 N 0021615.730 W</td>
<td>63</td>
<td>532137.510 N 0021650.290 W</td>
<td>71</td>
<td>532152.810 N 0021648.020 W</td>
</tr>
<tr>
<td>9</td>
<td>532133.770 N 0021627.440 W</td>
<td>44L</td>
<td>532133.040 N 0021615.990 W</td>
<td>63L</td>
<td>532137.550 N 0021648.490 W</td>
<td>71R</td>
<td>532153.270 N 0021648.020 W</td>
</tr>
<tr>
<td>10</td>
<td>532131.730 N 0021630.160 W</td>
<td>44</td>
<td>532133.030 N 0021615.000 W</td>
<td>63R</td>
<td>532138.620 N 0021650.730 W</td>
<td>72L</td>
<td>532154.620 N 0021648.020 W</td>
</tr>
<tr>
<td>11</td>
<td>532132.750 N 0021627.500 W</td>
<td>44R</td>
<td>532132.310 N 0021615.440 W</td>
<td>64</td>
<td>532139.640 N 0021653.140 W</td>
<td>72</td>
<td>532154.570 N 0021648.020 W</td>
</tr>
<tr>
<td>12</td>
<td>532129.390 N 0021629.430 W</td>
<td>47</td>
<td>532132.530 N 0021613.600 W</td>
<td>64L</td>
<td>532139.540 N 0021651.900 W</td>
<td>72R</td>
<td>532154.980 N 0021648.020 W</td>
</tr>
<tr>
<td>12L</td>
<td>532129.730 N 0021630.620 W</td>
<td>48</td>
<td>532133.420 N 0021612.630 W</td>
<td>64R</td>
<td>532140.230 N 0021653.610 W</td>
<td>73L</td>
<td>532155.940 N 0021648.020 W</td>
</tr>
<tr>
<td>15</td>
<td>532130.370 N 0021627.270 W</td>
<td>50</td>
<td>532136.880 N 0021610.000 W</td>
<td>65</td>
<td>532141.600 N 0021656.600 W</td>
<td>73R</td>
<td>532156.190 N 0021648.020 W</td>
</tr>
<tr>
<td>16</td>
<td>532136.290 N 0021622.940 W</td>
<td>51</td>
<td>532137.020 N 0021638.490 W</td>
<td>65L</td>
<td>532141.700 N 0021654.770 W</td>
<td>74L</td>
<td>532157.870 N 0021648.020 W</td>
</tr>
<tr>
<td>17</td>
<td>532134.440 N 0021637.050 W</td>
<td>52</td>
<td>532138.670 N 0021637.150 W</td>
<td>65L</td>
<td>532143.020 N 0021658.700 W</td>
<td>74L</td>
<td>532158.580 N 0021648.020 W</td>
</tr>
</tbody>
</table>
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:
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 – 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
Stand use
Taxi time uncertainty

- Taxi times for individual edges are quite variable:
### Taxi speeds

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

<table>
<thead>
<tr>
<th>Angle for turn</th>
<th>Turns (m)</th>
<th>Straights (m)</th>
<th>Avg Spd Turns (SD)</th>
<th>Avg Spd Straights (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30° in 100m</td>
<td>1 377 381</td>
<td>1 208 618</td>
<td>10.73 (11.83)</td>
<td>11.01 (10.9)</td>
</tr>
<tr>
<td>60° in 100m</td>
<td>579 747</td>
<td>2 006 453</td>
<td>9.81 (11.18)</td>
<td>11.05 (11.66)</td>
</tr>
</tbody>
</table>
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:
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](https://github.com/gm-tools/gm-tools/wiki)
  - [www.openstreetmap.org/](http://www.openstreetmap.org/)
  - [www.nats-uk.ead-it.com/](http://www.nats-uk.ead-it.com/)
  - [www.ead.eurocontrol.int](http://www.ead.eurocontrol.int)
  - [www.flightradar24.com](http://www.flightradar24.com)
  - [www.cs.stir.ac.uk/~sbr](http://www.cs.stir.ac.uk/~sbr)
  - sbr@cs.stir.ac.uk