Aircraft trajectory usage

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Autumn School 2025

ADS-B for Ground movement

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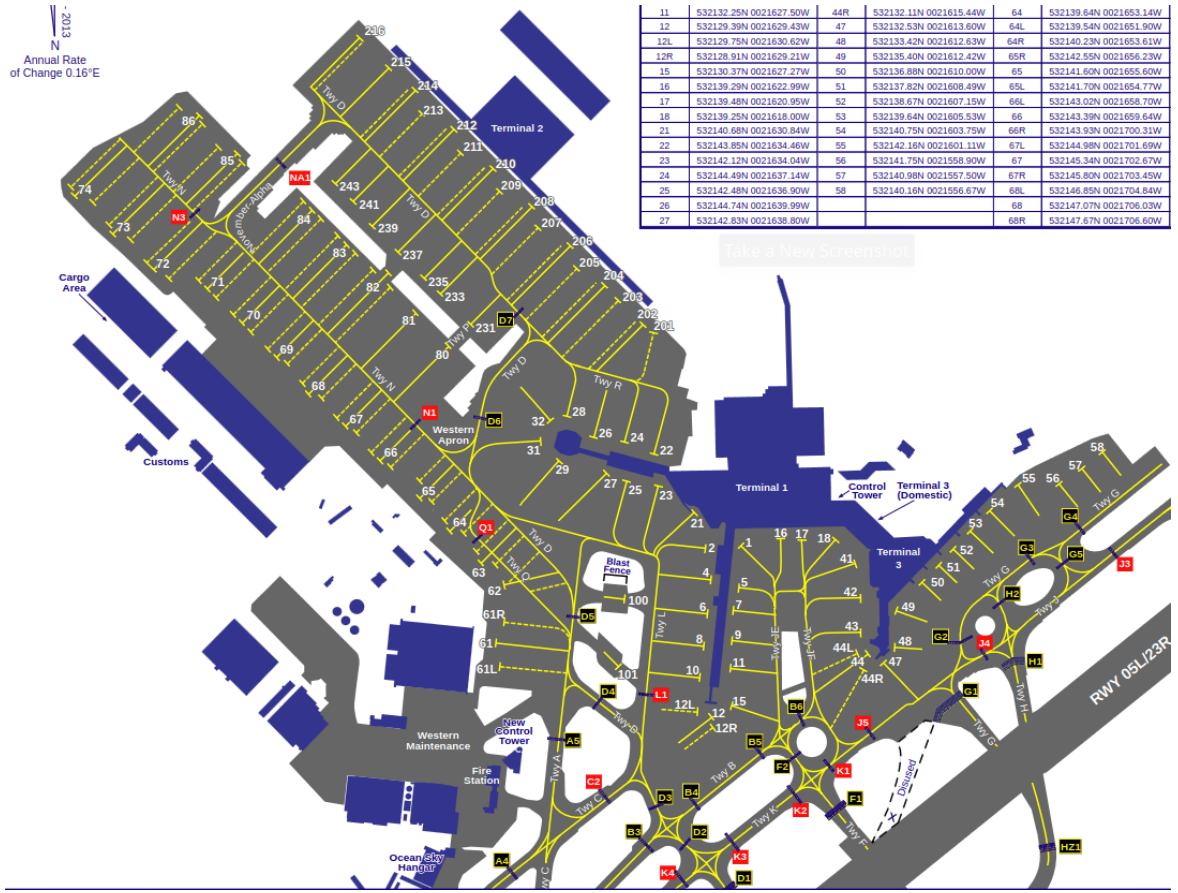
Aircraft Ground Movement

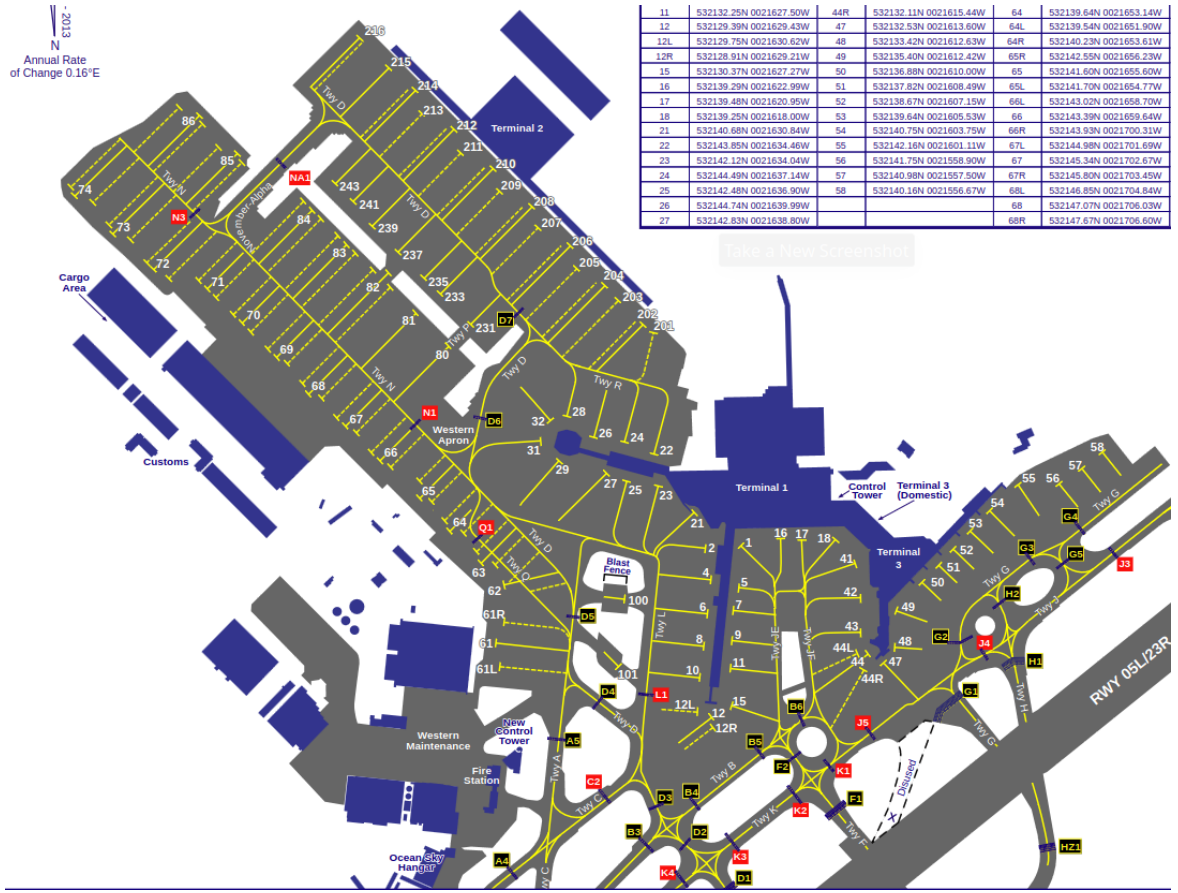
- Aircraft Ground movement is one of the key operations at the airport:
- Links other operations (RWY scheduling, gate assignment)
- Taxiing alone represents up to 6% of fuel consumption for short-haul flights, (5m tonnes per year).
- Taxiing is the largest source of emissions in a standard LTO cycle.



11	532132.25N 0021627.50W	44R	532132.11N 0021615.44W	64	532139.64N 0021653.14W
12	532129.39N 0021629.43W	47	532132.53N 0021613.60W	64L	532139.54N 0021651.90W
12L	532129.75N 0021630.62W	48	532133.42N 0021612.63W	64R	532140.23N 0021653.61W
12R	532128.91N 0021629.21W	49	532135.40N 0021612.42W	65R	532142.55N 0021656.23W
15	532130.37N 0021627.27W	50	532136.88N 0021610.00W	65	532141.60N 0021655.60W
16	532139.29N 0021622.99W	51	532137.82N 0021608.49W	65L	532141.70N 0021654.77W
17	532139.48N 0021620.95W	52	532138.67N 0021607.15W	66L	532143.02N 0021658.70W
18	532139.25N 0021618.00W	53	532139.64N 0021605.53W	66	532143.39N 0021659.64W
21	532140.68N 0021630.84W	54	532140.75N 0021603.75W	66R	532143.93N 0021700.31W
22	532143.85N 0021634.46W	55	532142.16N 0021601.11W	67L	532144.98N 0021701.69W
23	532142.12N 0021634.04W	56	532141.75N 0021558.90W	67	532145.34N 0021702.67W
24	532144.49N 0021637.14W	57	532140.98N 0021557.50W	67R	532145.80N 0021703.45W
25	532142.48N 0021636.90W	58	532140.16N 0021556.67W	68L	532146.85N 0021704.84W
26	532144.74N 0021639.99W			68	532147.07N 0021706.03W
27	532142.83N 0021638.80W			68R	532147.67N 0021706.60W

Data sources

- Best source is airports (radar, ADS-B, EFPS, layout)
- Next best thing is Free sources
- For layout (Edge + Nodes):
  - Google Earth /Open street map
  - NATS / EUROCONTROL EAD AIS
- Movements (ADS-B):
  - FlightRadar 24
  - OpenSky



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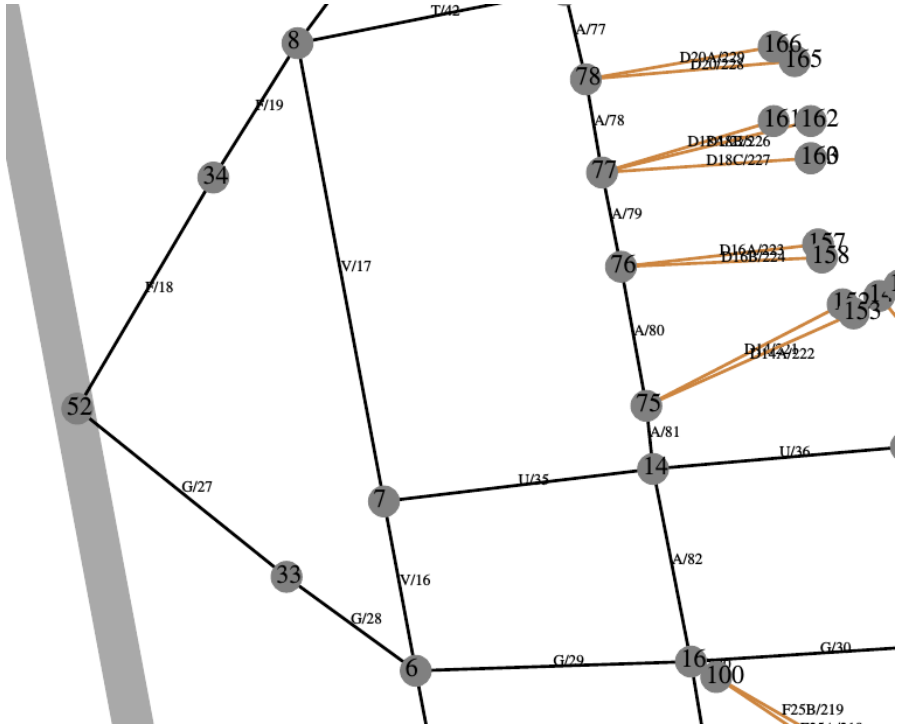
27	532142.83N 0021638.80W			68R	532147.67N 0021706.60W

Airport Layout

- Created from Google Earth (manually),
- Automatically transformed to a list of nodes.



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Airport Layout

- Other good source is Open Street Map
- Some airports have taxiways in OSM which can be extracted.
- Gate and stand coordinates are also published in NATS / Eurocontrol AIS

STAND	COORDINATE	STAND	COORDINATE
	Terminal 1	28	532145.90N 0021642.40W
1	To be surveyed	29	532143.47N 0021643.17W
2	532138.77N 0021629.89W	31	532144.58N 0021644.84W
4	532137.10N 0021629.72W	32	532145.73N 0021643.95W
5	532136.63N 0021626.85W		Terminal 3
6	532135.22N 0021629.54W	41	532137.93N 0021616.22W
7	532135.40N 0021627.33W	42	532136.08N 0021615.75W
8	532133.47N 0021630.04W	43	532134.20N 0021615.73W
9	532133.77N 0021627.44W	44L	532133.04N 0021615.99W
10	532131.73N 0021630.18W	44	532133.03N 0021615.00W
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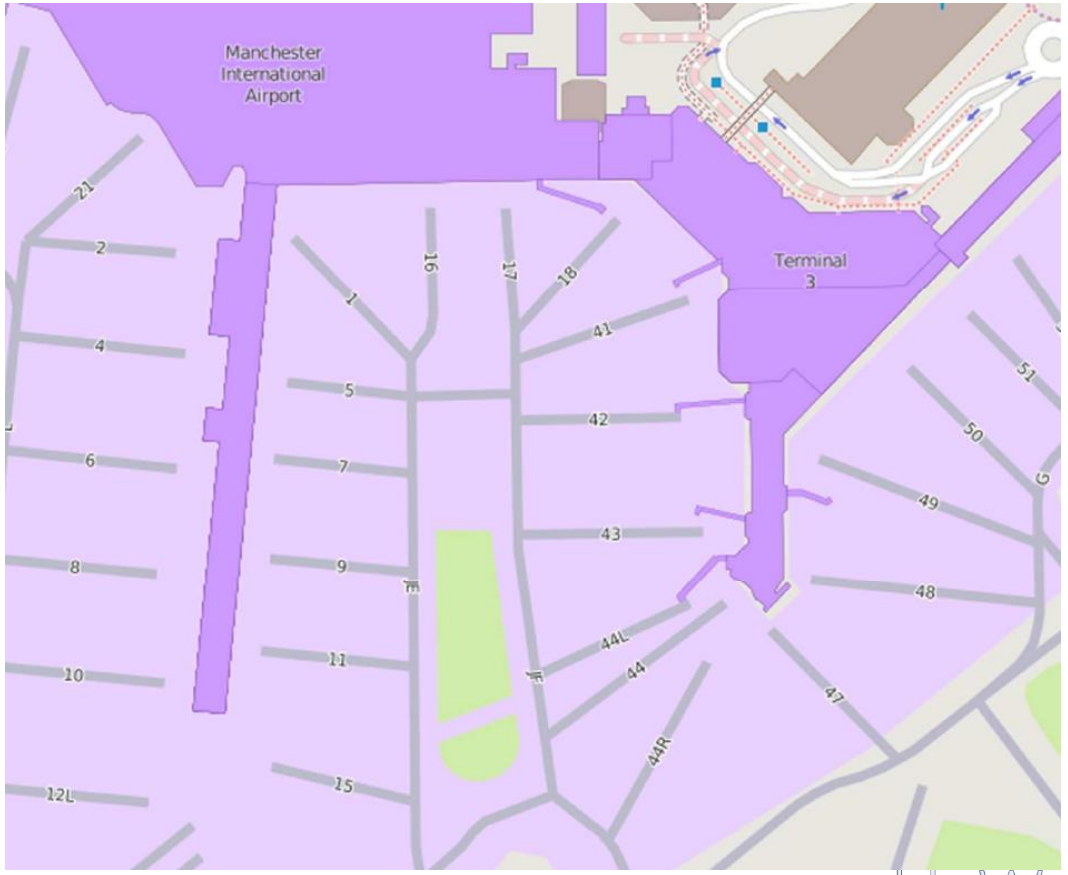

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ADS-B

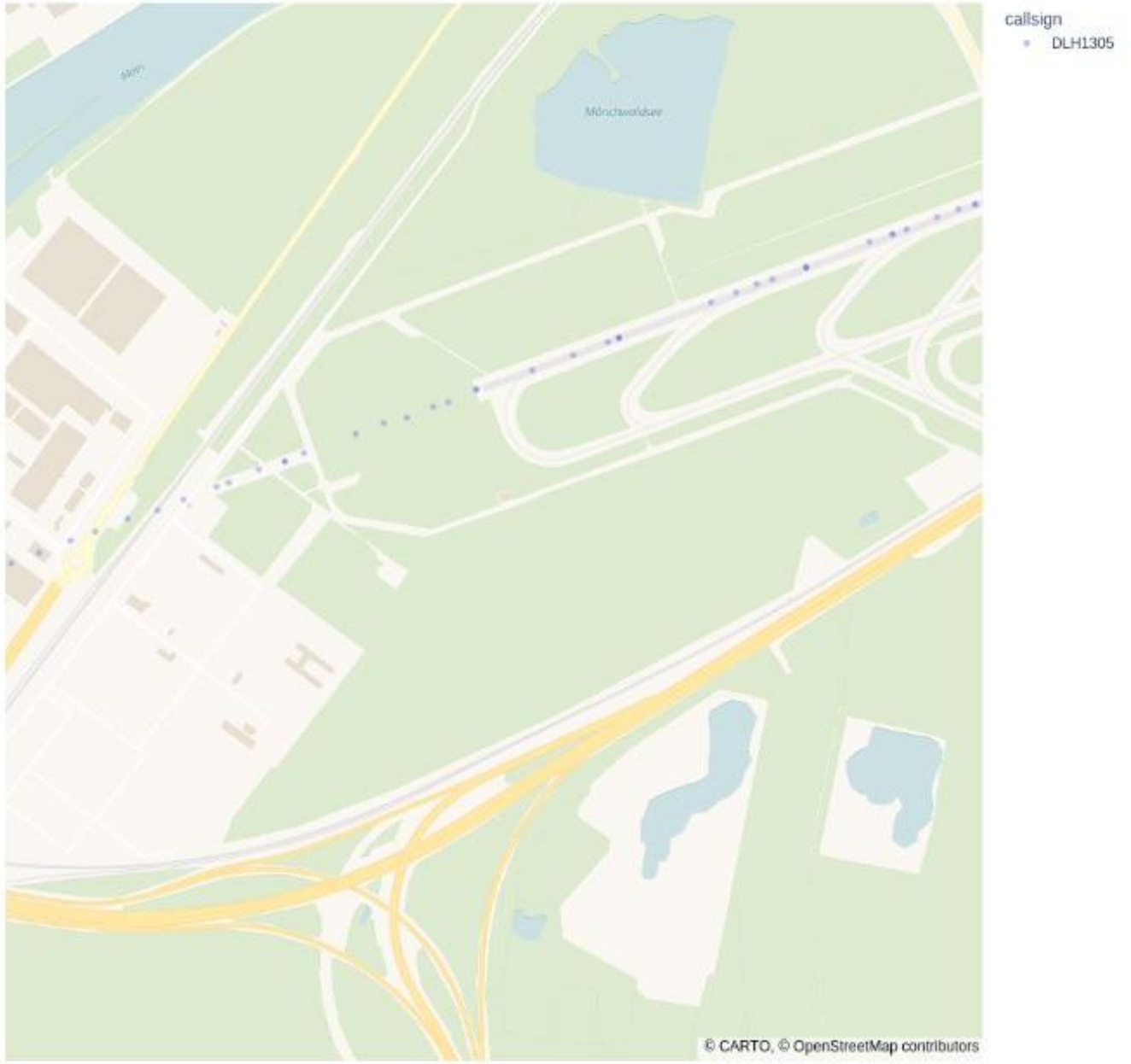
Automatic Dependent Surveillance–Broadcast (ADS-B) is an aviation surveillance technology in which an aircraft periodically broadcasts its position and other related data.

- Can be captured by ground (space) based receivers

Name	Example
time_recorded	14-Dec-2021 19:50:28
lat	53.368549
lon	-2.28959
flight_level	13.75
alt	1175
call_sign	RYR81EQ
mode_s	0x4CA7B5

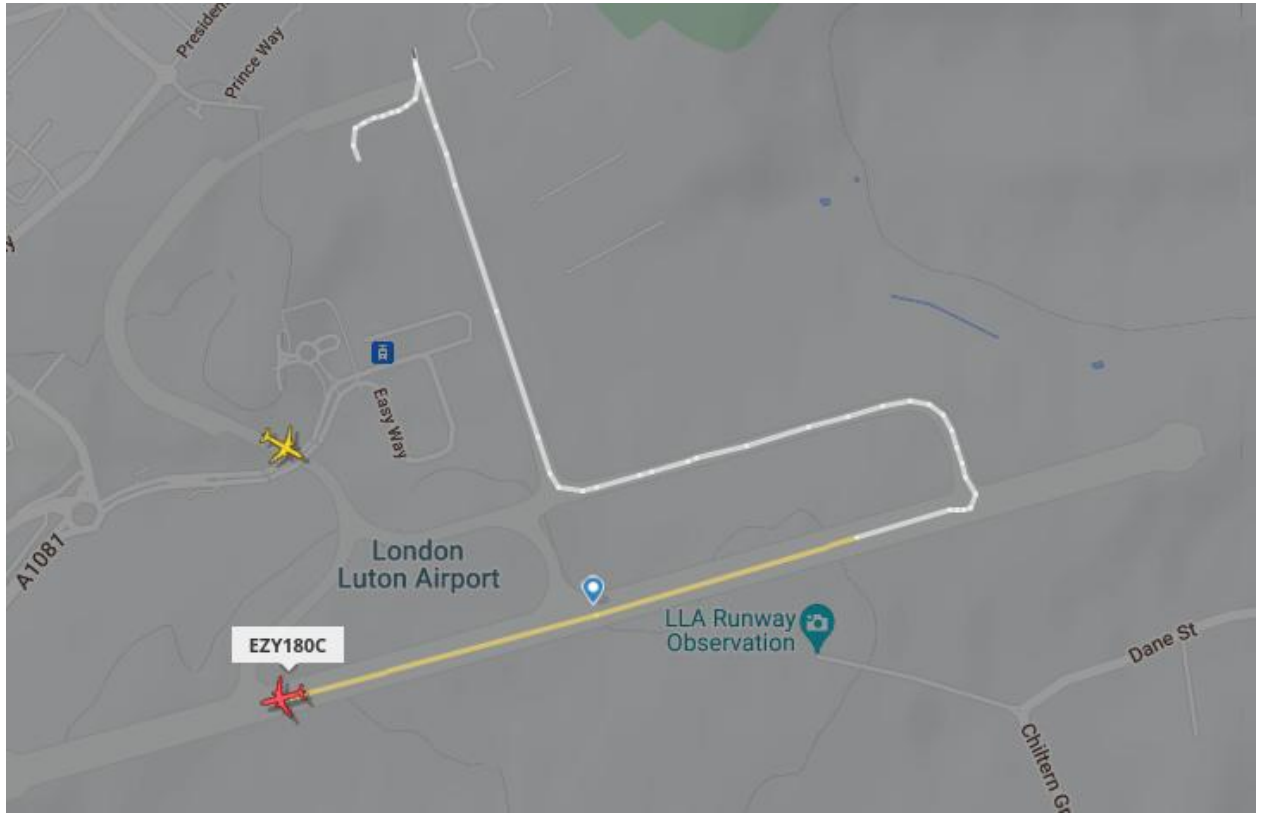
ADS-B example

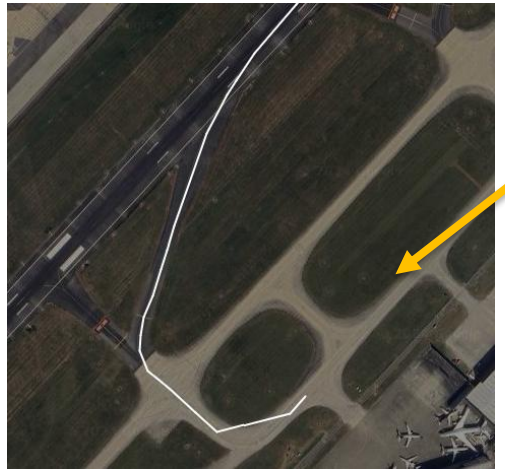
Trajectory is a discrete set of points



ADS-B challenges

- FR24/Opensky provides real-time tracking of ADS-B transponder data
- Covers most airports in worldwide
- Includes many but not **all** flights
- Noisy, needs cleaned
- Also, the data is not structured: no information about ground movement
- We need to transform unstructured data to structured
- Associate points to the airport layout graph

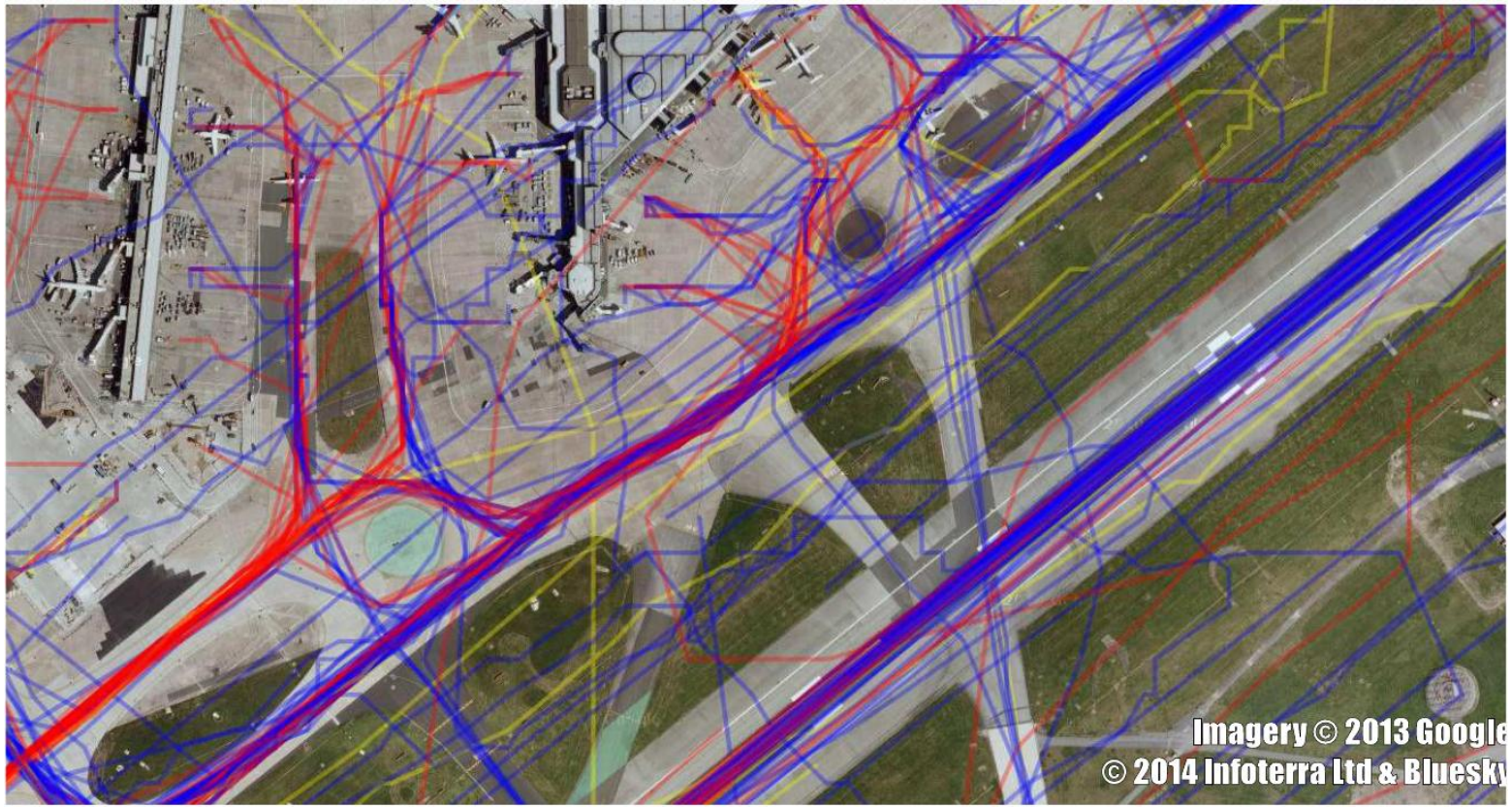




Rest of the movement is missing

ADS-B challenges

- Data points can be very noisy



Source: Brownlee, A.E.I., Atkin, J.A.D., Woodward, J.R., Benlic, U. and Burke, E.K. (2014). Airport Ground Movement: Real World Data Sets and Approaches to Handling Uncertainty, Proc. of the Practice and Theory of Automated Timetabling (PATAT) Conference, York, UK, pp. 462-464. Extended abstract for presentation.

Data processing flow

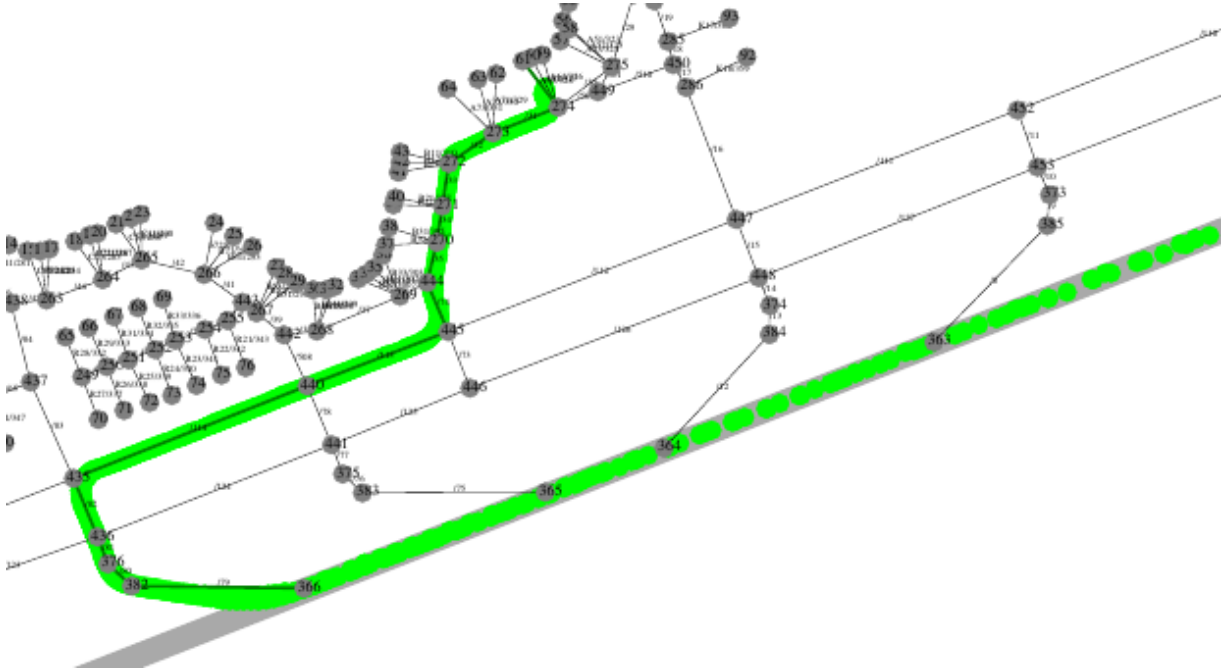
1. reducing:
    - Basic data cleaning and processing,
2. joining flights crossing midnight:
    - Detecting flight crossing midnight and divide_flights: splitting movements with same ID performing separate flights.
3. snapping to graph (also called map matching):
    - Snapping raw ADS-B tracks to the airport graph,

Reducing

- We need a unique ID for movements (call sign or aircraft registration repeats on different days)
- For each data point, a unique id named *my_id* is determined as *date+call_sign* or *date+mode_s* if call sign is missing.
- Data points with blank mode_s or call signs for maintenance vehicles (RANGER,MAINT) are removed.
- Any data point with altitude larger than 100 (ft) is removed.

Snapping

1. Build a connected airport graph.
2. For each flight identified by my_id iterate over the tracks.
    1. Skip if speed>30 m/s or 0.1 m/s (stationary). Skipping tracks too fast for taxiing and stationary tracks mostly at gate) to speed up the snapping.
    2. Identify neighboring nodes and edges to the last identified edge. This step limits the snapping to the neighboring edges/nodes to speed up the snapping.
    3. Calculate distance to neighboring edges centre.
    4. Identify and add edge with the minimum distance to edge sequence, exclude rwy crossing.

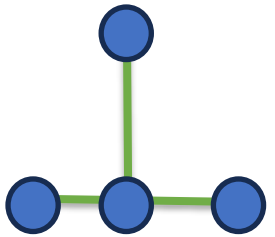


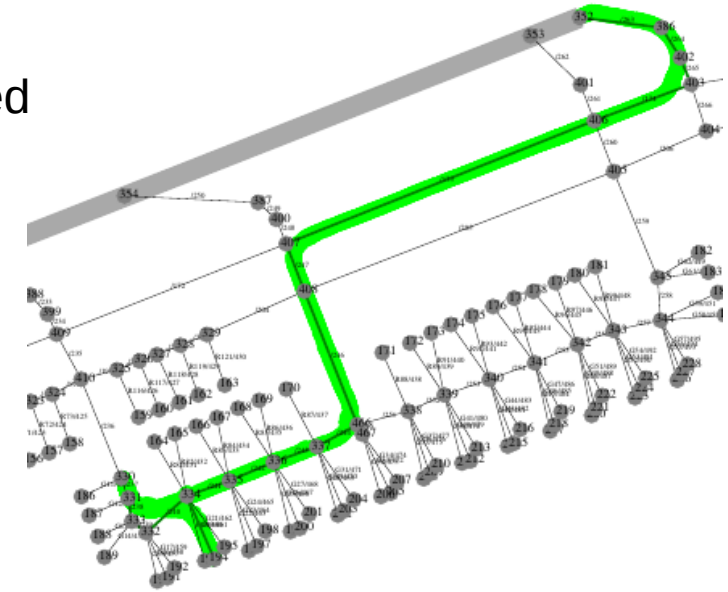
Edge sequence: 53, 38, 124, ...

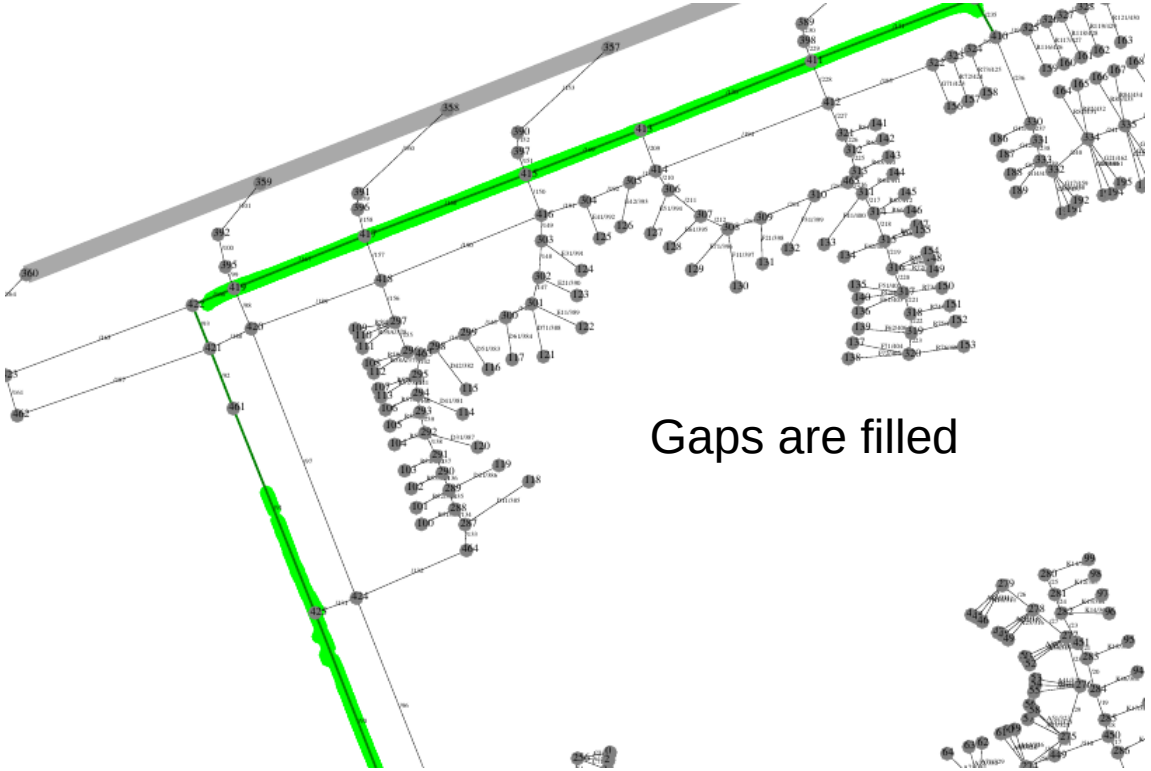
Snapping

5. Check the found edge sequence:
    - if there is a discontinuity (each edge must have two neighbours), fill the discontinuity with the shortest path.
    - Skip if the shortest path is too long (>=7 edges). In that case the data is probably noisy and the shortest path would be guessing.
6. Check the found edge sequence and remove edges not connected to the rest of the sequence (each edge must have two neighbours).
7. Count complete routes: if start/end is rwy/gate, then the found route is marked as complete.
8. Iterate over tracks and the found edge sequence:
9. If speed <1 m/s, add wait time to the identified nearest node.
10. Identify tracks closest to start/end node of edge, to find timings when the aircraft traverses the edge.

Branches are removed







Gaps are filled

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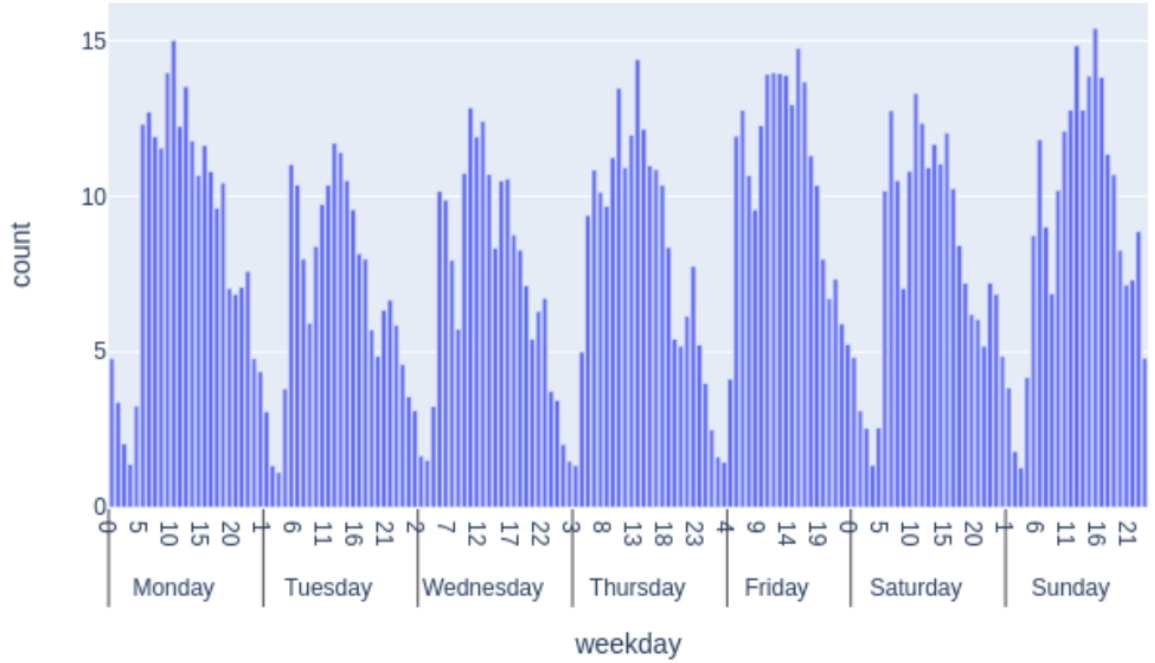
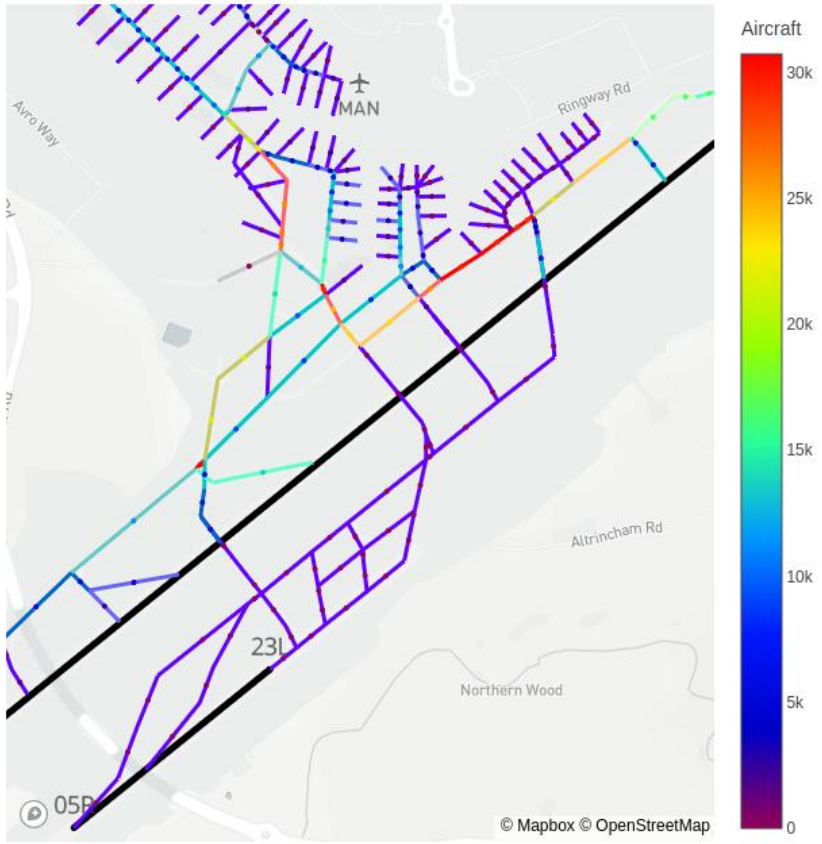
Application

- A range of KPIs can be calculated:
- Taxiway and Intersections use
- Runway exits use
- Runway occupancy times
- Taxi time and speeds
- Turnaround time
- …

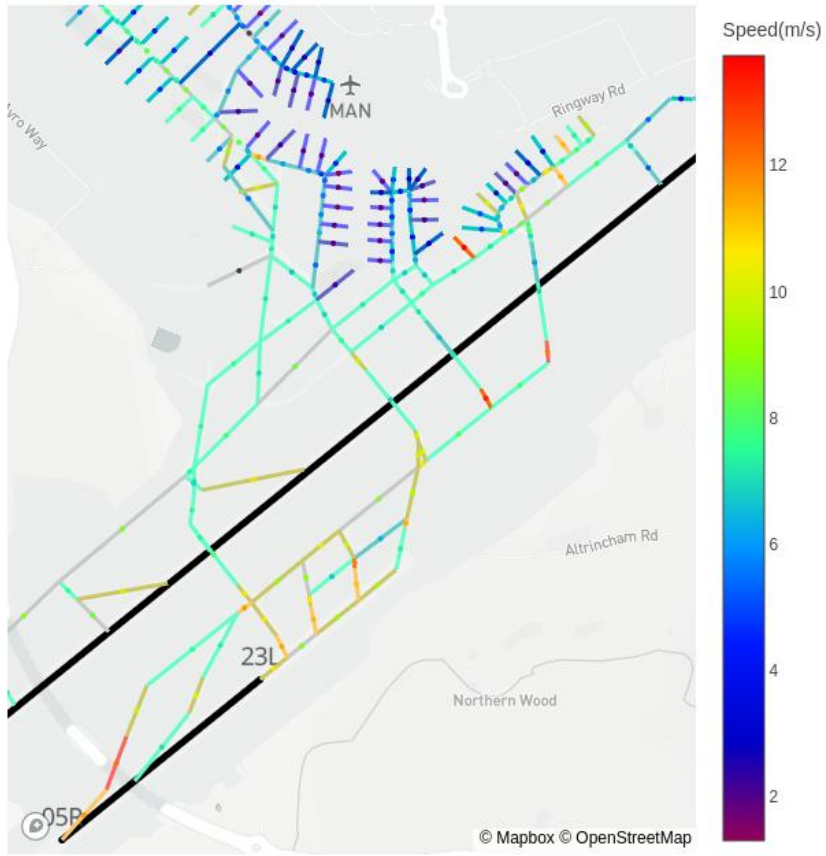


Taxiway use and speeds

Aircraft count



Avg speed count



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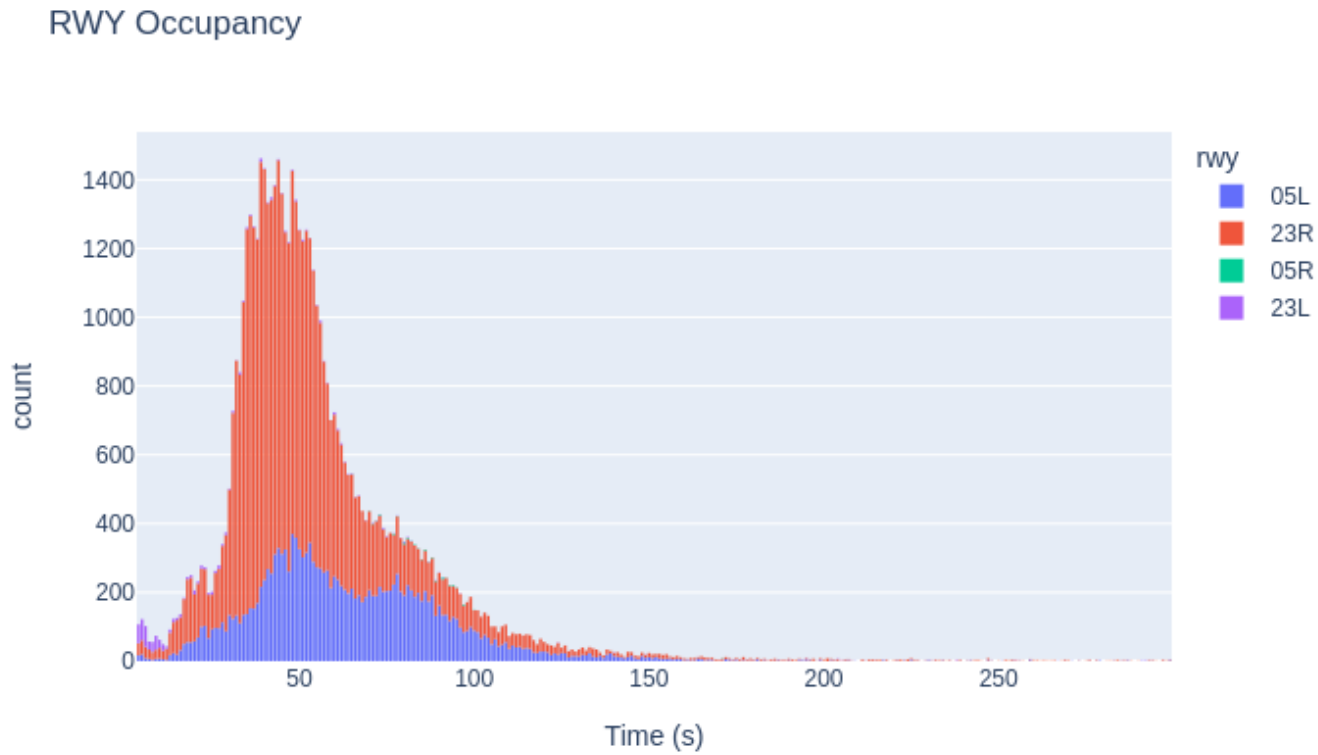
Source: AVISIM - Intelligent Airport Simulation and Analytics. 2024. Available at: https://www.avisu.co.uk/services/avisim-analytics/

Runway use

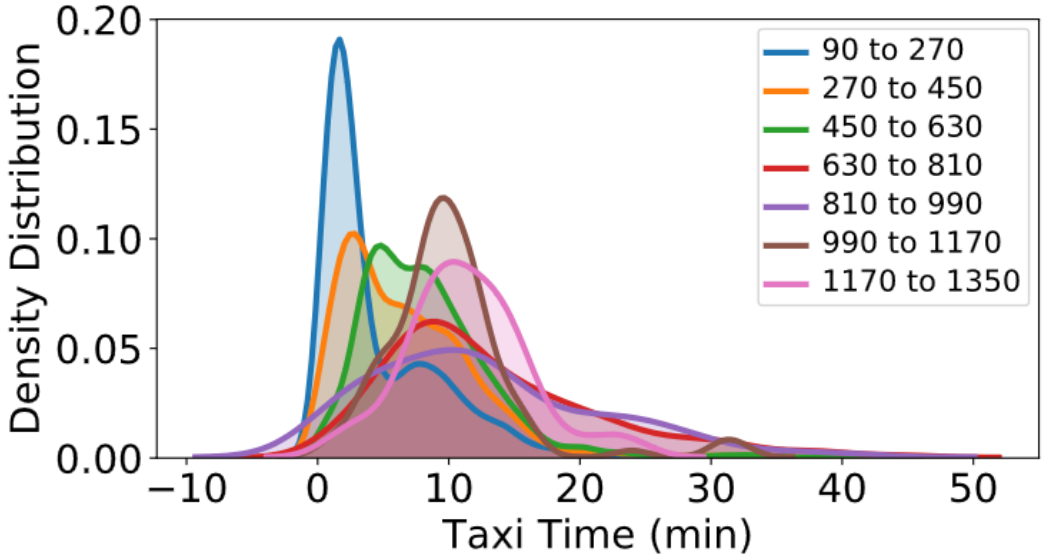

Runway exits
M1
H1
F1
D1
BD
B1
AE
AF
U1
Altrincham Rd
Aircraft
16k
14k
12k
10k
8k
6k
4k
2k
0
© Mapbox © OpenStreetMap


RWY Occupancy
count
1400
1200
1000
800
600
400
200
0
50
100
150
200
250
Time (s)
rwy
05L
23R
05R
23L

Further application

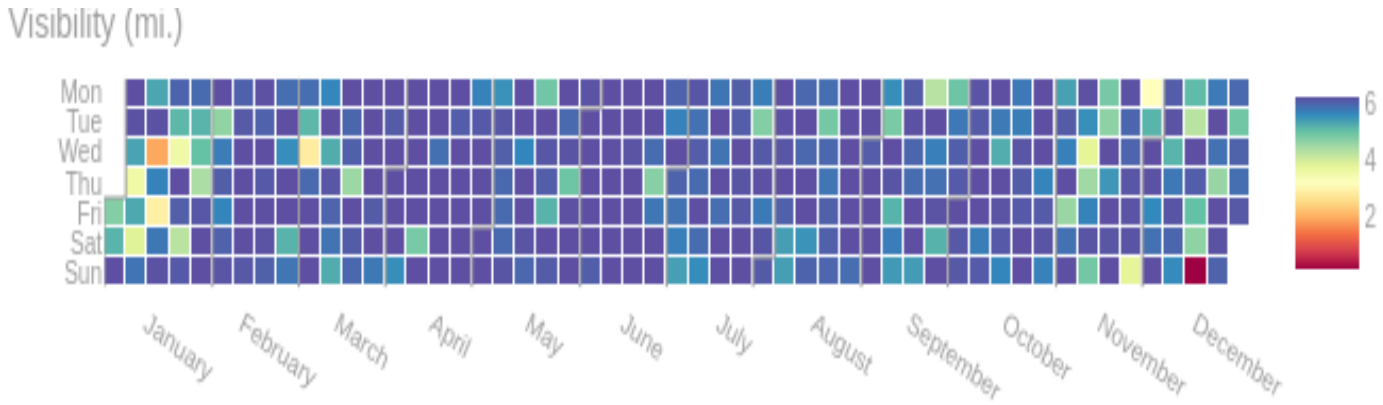
Processed data can be used for:

- Taxi time prediction
- Combination with weather data (METAR)
- Airport simulation



(f) *angle_sum* (degree)

Source: [1]



[1] Wang, Xinwei, et al. "Aircraft taxi time prediction: Feature importance and their implications." *Transportation Research Part C: Emerging Technologies* 124 (2021): 102892.

Conclusions

- ADS-B is a vast and very detailed data source
- (mostly) freely available
- High resolution enables versatile and detailed analysis of different flight phases, operation, etc
- Worldwide coverage

- Requires time-intensive processing and data reduction
- Can be noisy and have missing datapoints
- Problems related to Big data

Trajectory clustering for air traffic categorisation

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October 2025

Goal

Data availability:

Trajectory – different historical datasets
Economic airline related data – very little

Data – mining techniques available

Goal is to learn about usual (or nominal) choices airlines make

Routing,
Aircraft types
Operational flight costs

Apply trajectory clustering and statistical analysis

Data

ADS-B data from OPenSky Network

Summer season 2019 - 31 March 2019--27 October 2019
2 396 394 trajectories

State vector

4D positions sent sometimes even twice per second
Callsign for the flight, origin, destination (if available) and mode-S transponder ID

Filtering

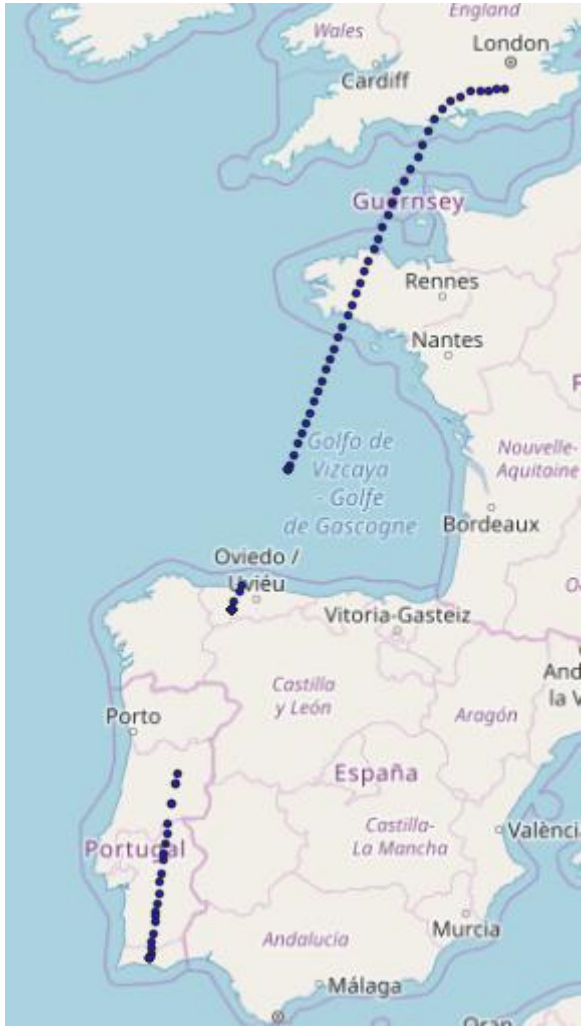
Every 30 seconds

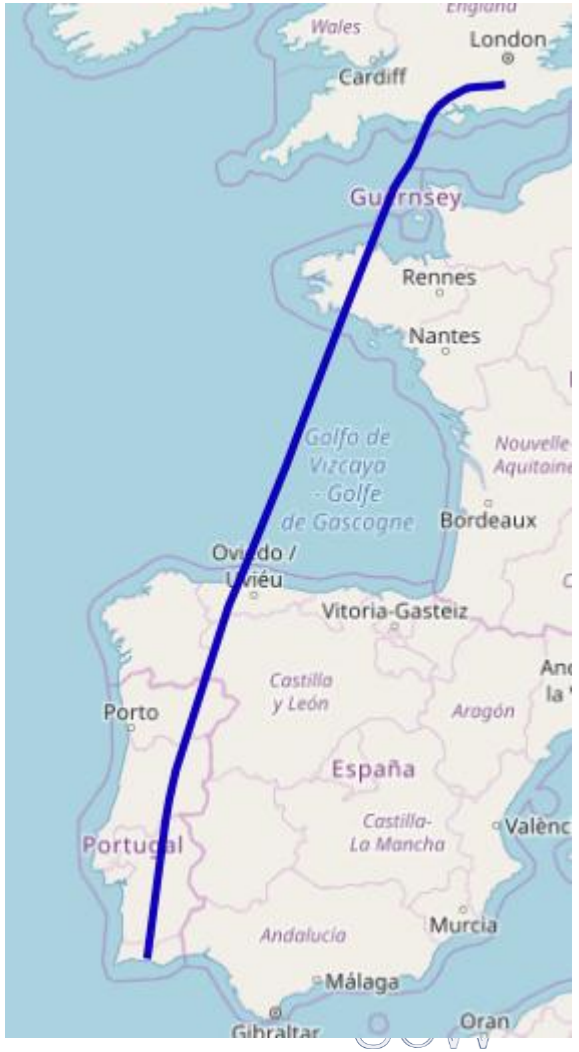
Data cleaning

About half of trajectories did not have origin or destination or both

Needed to create an algorithm to add origin and destination
Similar algorithm became available in OpenSky Network resources

Clean the trajectories
Missing points
Outliers





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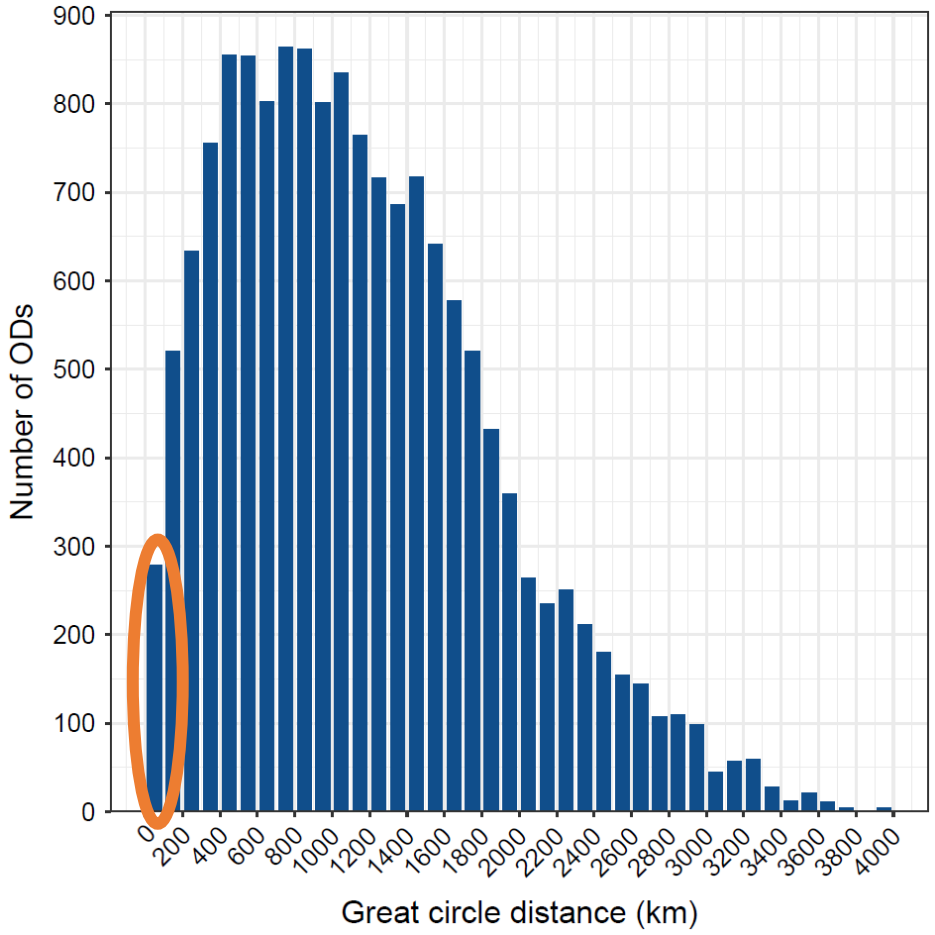
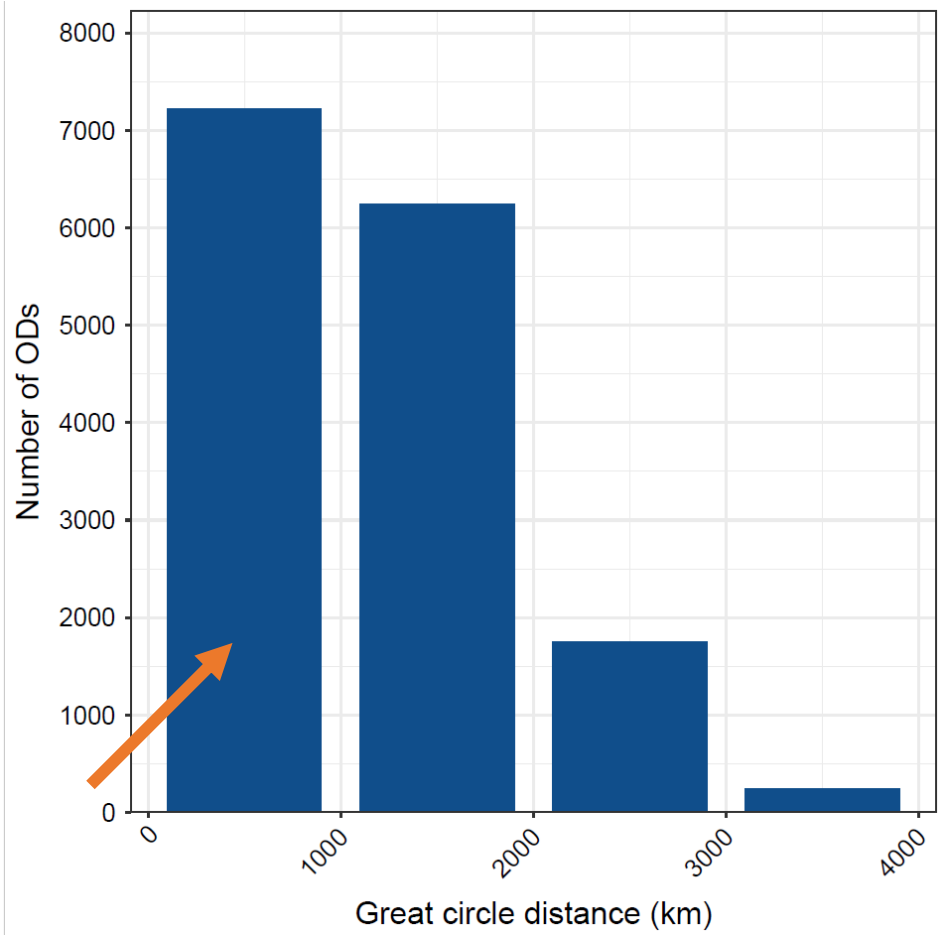
Data inspection



Positioning or ferry flights



45% less than <1000 km
68% one airline
250 ODs six flights a day - feeders

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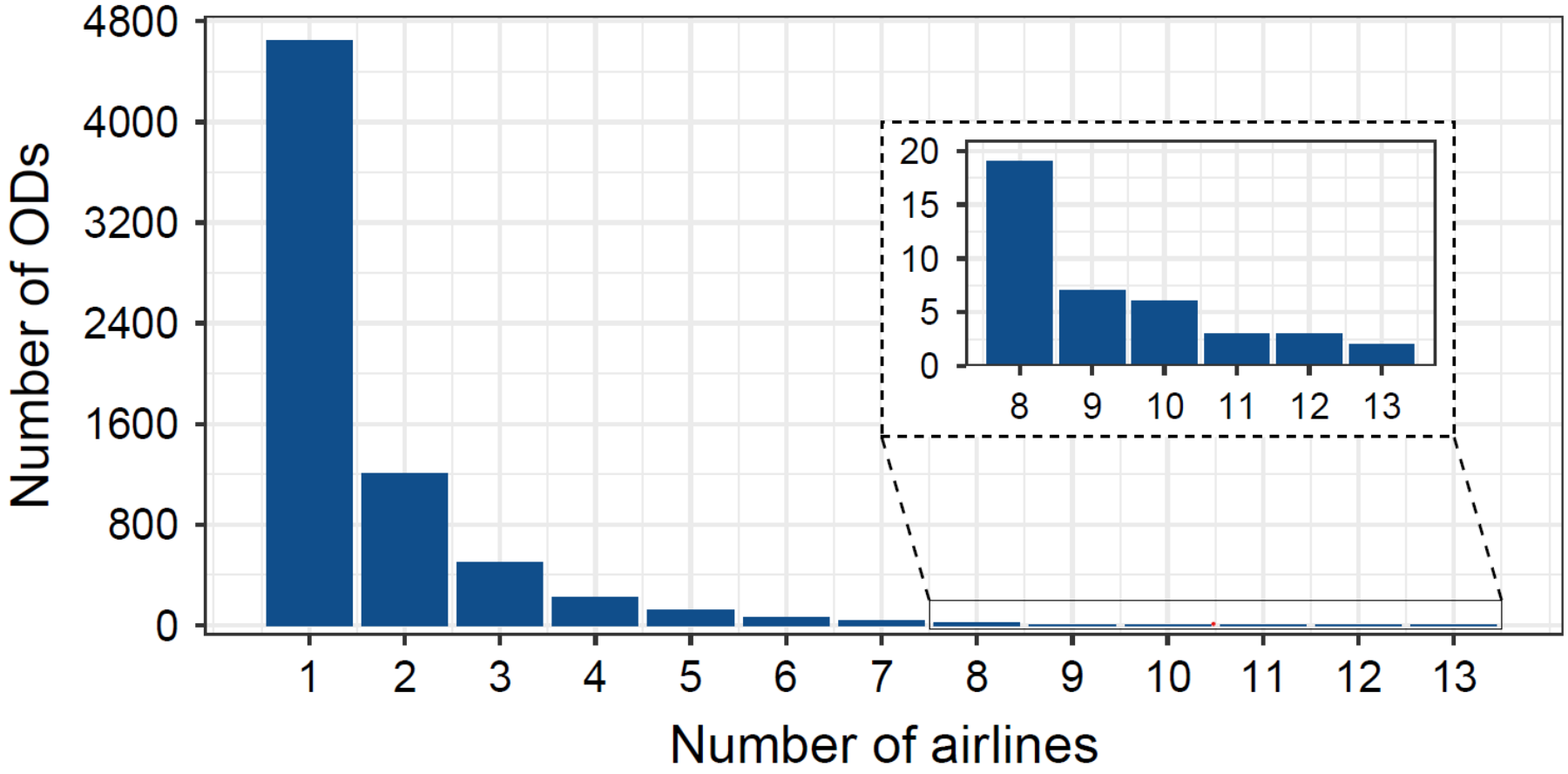
Data inspection



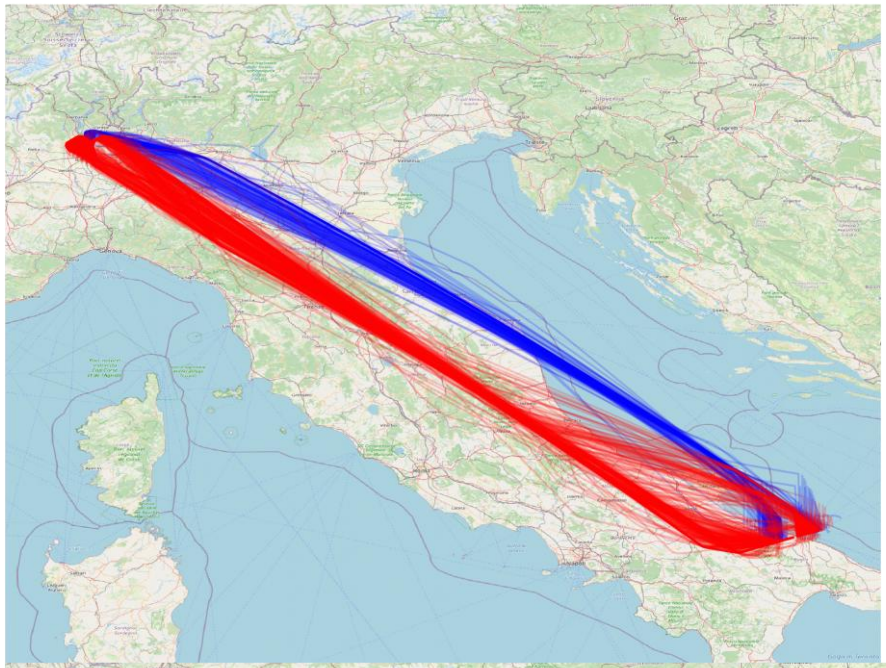
Indicates charter flights

Clustering

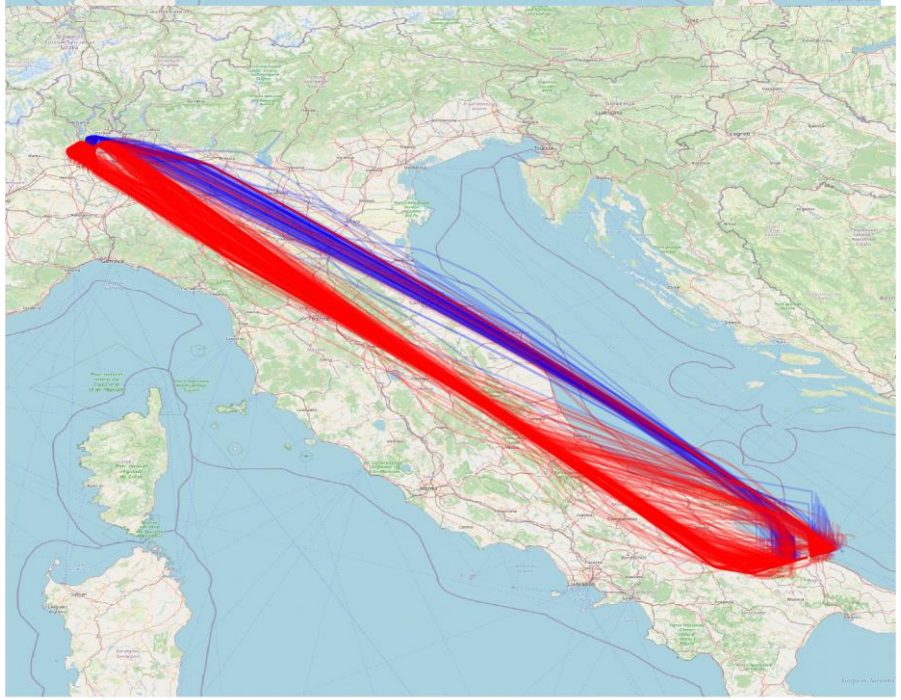
Used DBSCAN

Maximum radius of the neighbourhood ϵ = 0.3 - corresponds to 30 km
An airway has a width of 10 NM, which equals 18.52 km plus a buffer
Minimum number of elements m = 2
An element is a flight trajectory - a geometric representation of a set of connected position messages
The distance between two elements is represented by the undirected Hausdorff distance.

clusters



airlines



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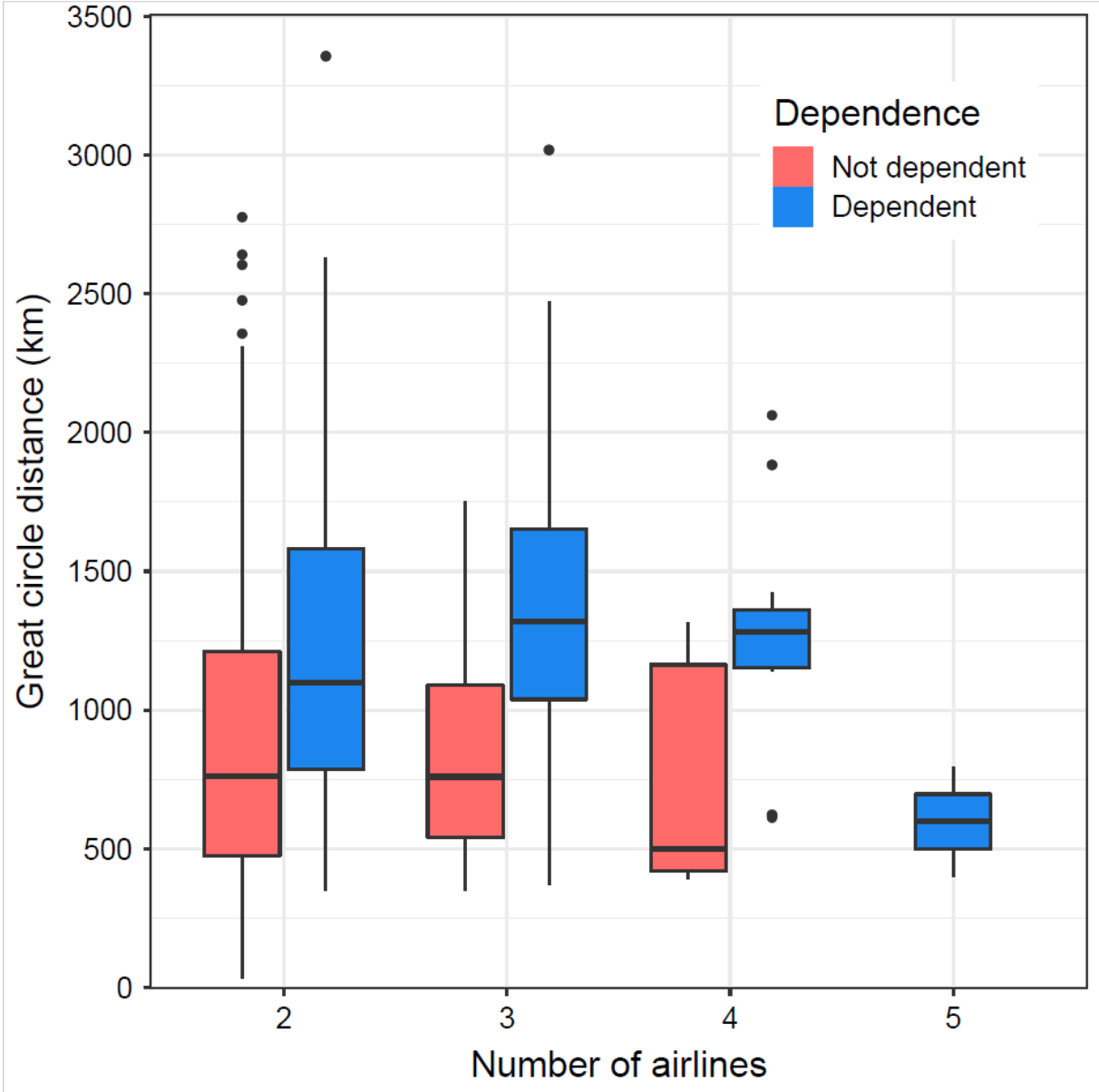
Other characteristics

Airline
Aircraft type
Airline cost type

Used Pearson's $\chi 2$ test of independence

Higher GCD between ODs where there is dependence between the airline and the trajectory cluster



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- **THANK YOU**