

Evaluation of the Sequencing and Merging Procedures at Three European Airports Using Opensky Data

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Introduction

- Performance-based navigation (PBN) procedures
- Evaluation inside terminal maneuvering area (TMA)
- Investigating various aspects of the arrival performance
- Different sequencing and merging techniques
- A set of performance metrics developed by EUROCONTROL PRU and Innovation Hub, we adopt and complement them within **TMAKPI project** *(supported by Swedish Transport Administration Trafikverket and in-kind participation of LFV)*

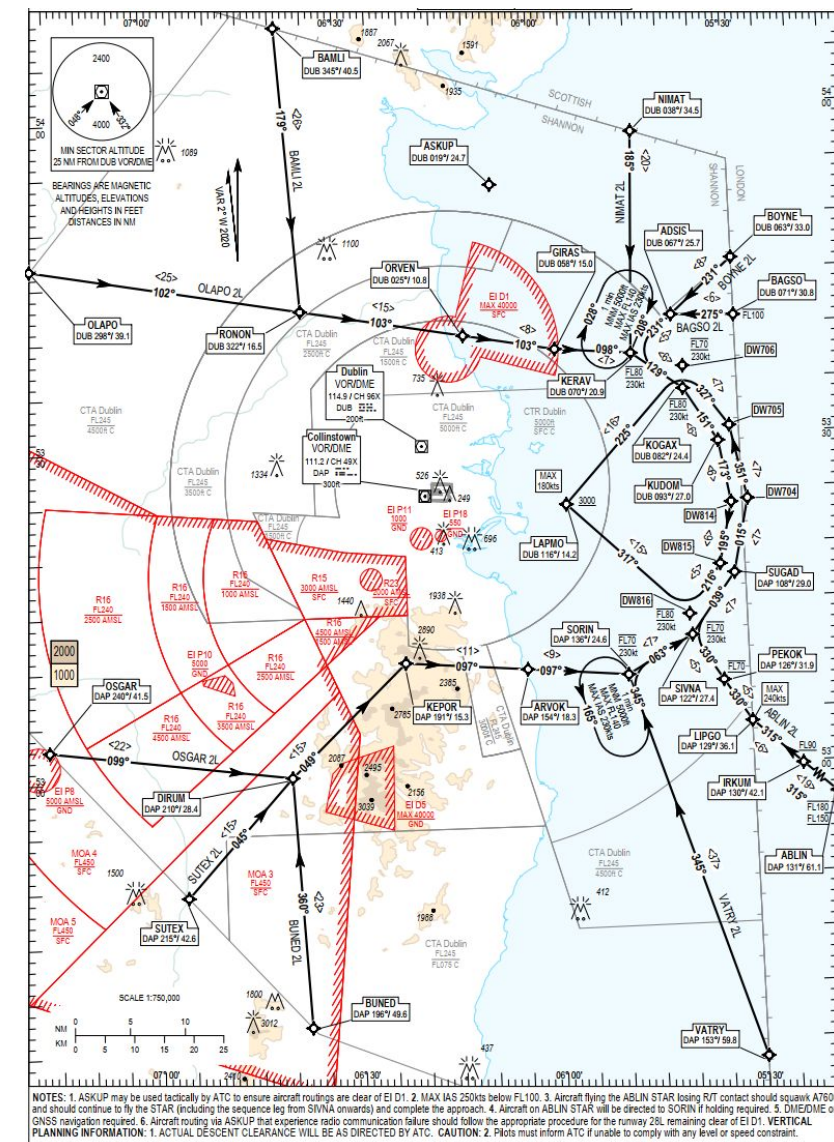
Airports

- Chosen airports:
 - Dublin airport (EIDW) – Point Merge
 - Stockholm Arlanda airport (ESSA) – Vectoring
 - Vienna airport (LOWW) – Trombone
- The most used runway in October 2019
 - Dublin - 28L
 - Stockholm Arlanda - 01R
 - Vienna - 16

Procedures inside TMAs for Arlanda and Vienna, 50 NM for Dublin (to cover eastbound trajectories)

Point Merge

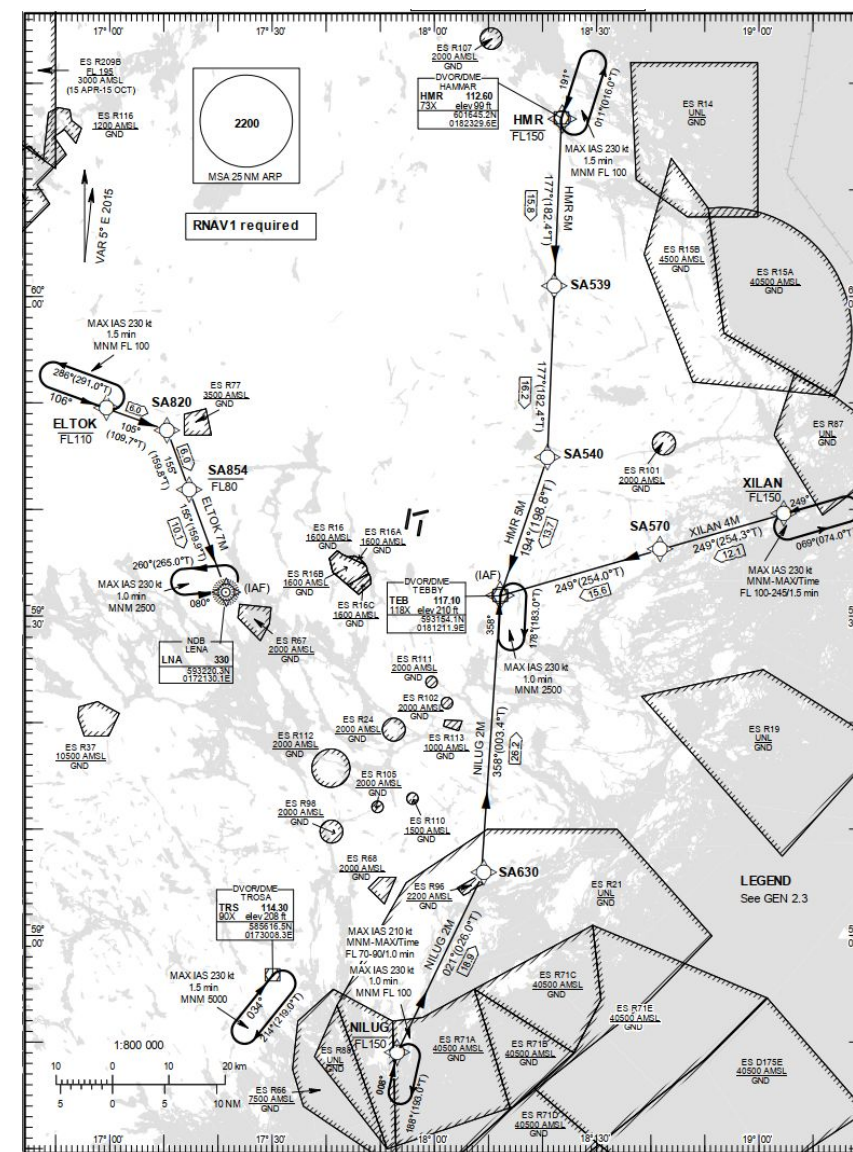
- Dublin airport
- Sequencing legs in the shape of arcs for path stretching
- Merge point
- Main runway 10R/28L (used 95 % time)
- Designed to work in high traffic loads, improve runway capacity and reduce controllers workload



Source: AIRAC Amdt 007/20 - Aeronautical information 08 OCT 2020 - EIDW AD 2.24-22.2

Vectoring

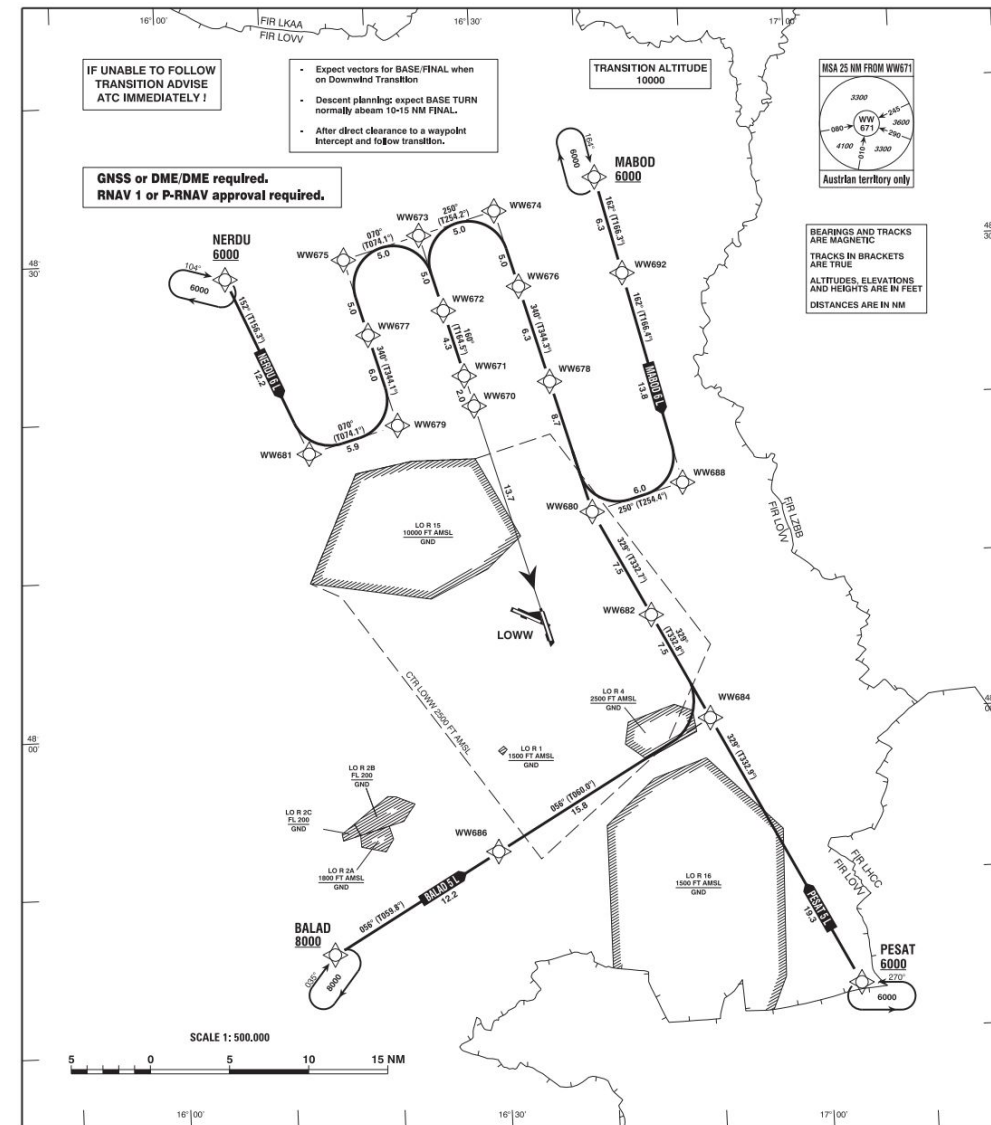
- Stockholm Arlanda airport
- Three runways
- Pair of parallel runways (used most)
- Mix of closed STARs and open STARs
- 01L/01R runway (on the figure) open loop



Source: AIP Sweden - Stockholm/Arlanda - AD
2-ESSA-4-51 - AIRAC AMDT 3/2021

Trombone

- Vienna airport
- Two intersecting runways
- Simultaneous usage
- Set of STARs and four IAFs
- Waypoints for path stretching and shortcuts
- RWY 16 (on the figure)



Source: WIEN-SCHWECHAT: AIRAC AMDT 218/25 APR 2019 - LOWW AD 2.24-5-2-3A

Datasets

- Historical database of the OpenSky Network
- 'States' data representing the parts of the arriving flight trajectories
- **Full four weeks of October 2019**
 - A year with the highest numbers worldwide
 - Month with the highest number of arrivals at our 3 airports

Data cleaning

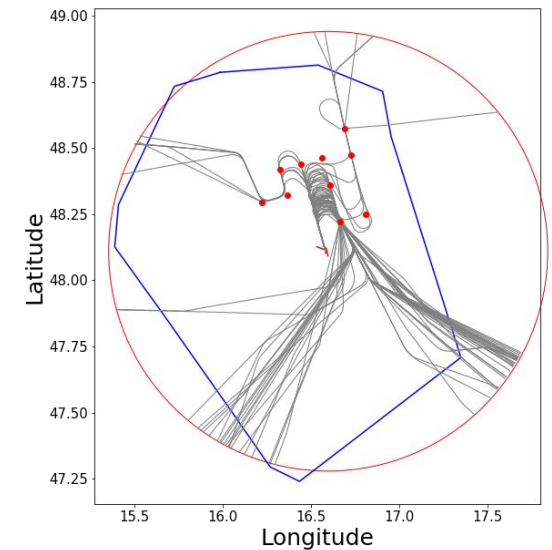
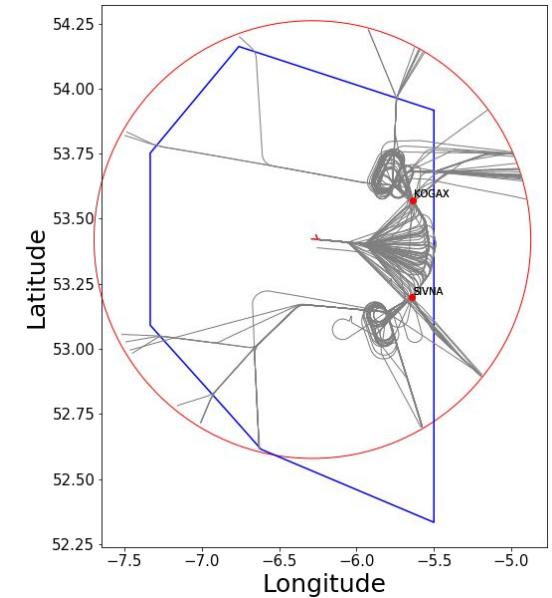
- A set of methods:
 - Fixing all incorrect positioning using linear interpolation
 - Gaussian filter to smooth the altitudes
 - Removing the trajectories:
 - that go too far from TMA border ($0,5^\circ$ threshold)
 - representing landings too far from the runway
 - that are incomplete within TMA
 - starting from the altitude lower than 600 m
 - representing go arounds within TMA

Data cleaning

- Removing of following callsigns:
 - Consisting of only letters
 - Consisting of only digits
 - Shorter than four symbols
 - Starting with DFL (Babcock Scandinavian Air Ambulance)
 - Starting with SVF (Swedish Armed Forces)
 - Starting with HMF (Swedish Maritime Administration)

Datasets

- PM Dataset
 - Adherence to Point Merge procedure
 - Trajectories, which pass SIVNA or KOGAX waypoints
 - 0.5 degrees is the threshold for the catchment area
 - Total of 3466 flights (45%)
- TB Dataset
 - Adherence to Trombone procedure
 - Trajectories, which pass selected waypoints or pairs of points
 - Total of 1681 flights (40%)



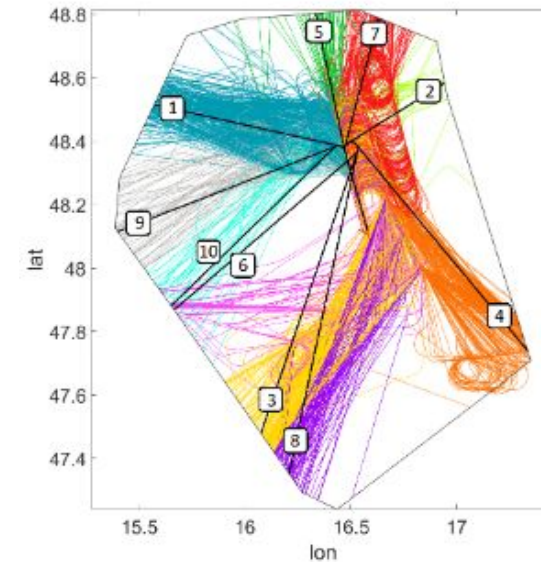
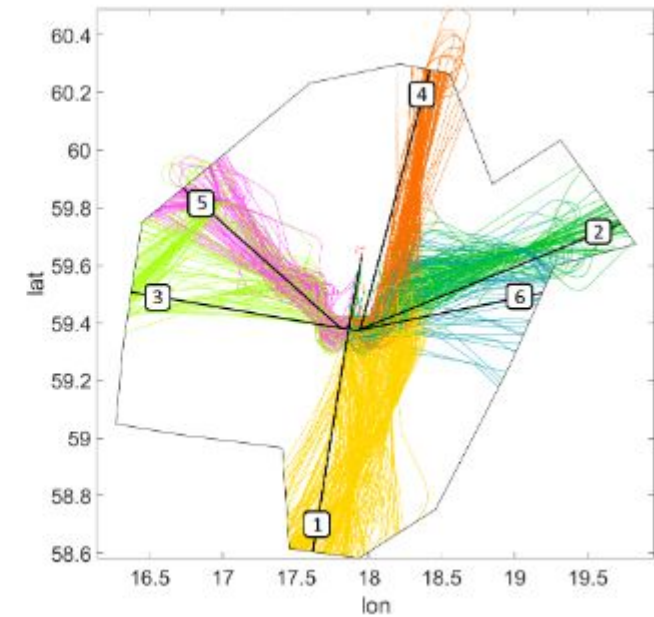
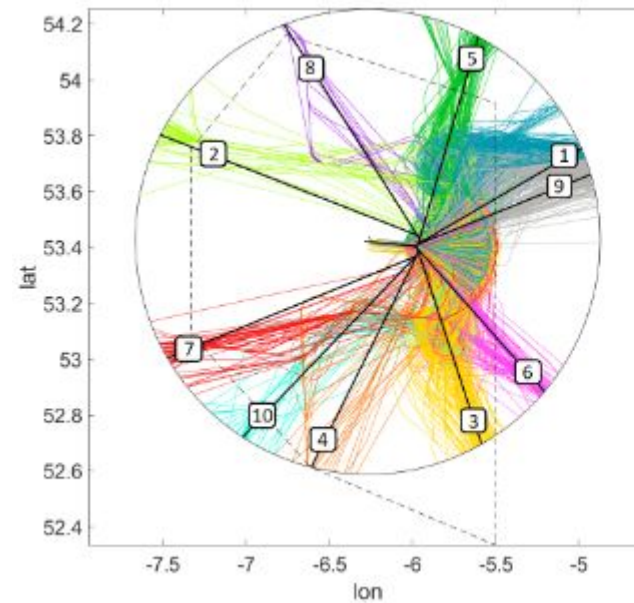
Datasets

- TT Dataset
 - Peak-time periods
 - All arrivals which spent significant average time in TMA (0.3 percentile left)
 - 2587 flights for Dublin, 1045 for Arlanda and 1641 for Vienna
- Small Datasets
 - For fine-grained evaluation
 - 1-hour subsets from the TT dataset
 - Two types:
 - **Busy** hours
 - EIDW - 4th of October, 16:00 - 17:00 (32 flights)
 - ESSA - 3rd October, 18:00 - 19:00 (33 flights)
 - LOWW - 17th of October, 17:00 - 18:00 (33 flights)
 - The **most delayed** hours
 - EIDW - 1st of October, 12:00 - 13:00 (32.15 min)
 - ESSA - 15th of October, 14:00 - 15:00 (23 min)
 - LOWW - 13th of October, 7:00 - 8:00 (29.58 min)

Methodology

Additional Distance

- To evaluate horizontal flight efficiency
- Clustered trajectories in each TMA
- Ideal reference trajectory
- Calculated as the difference between the actual path length and the length of the reference trajectory inside TMA



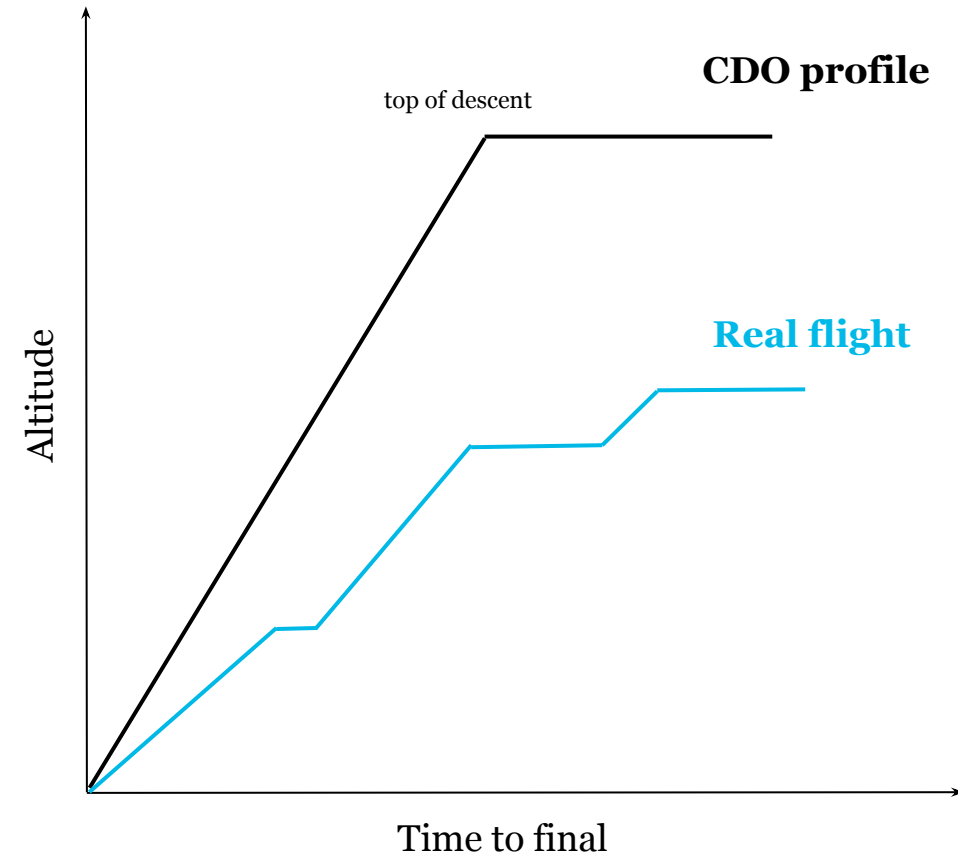
Methodology

Time on Flight Levels

- To evaluate the vertical flight efficiency
- Starting point where the aircraft enters TMA

VFE by EUROCONTROL

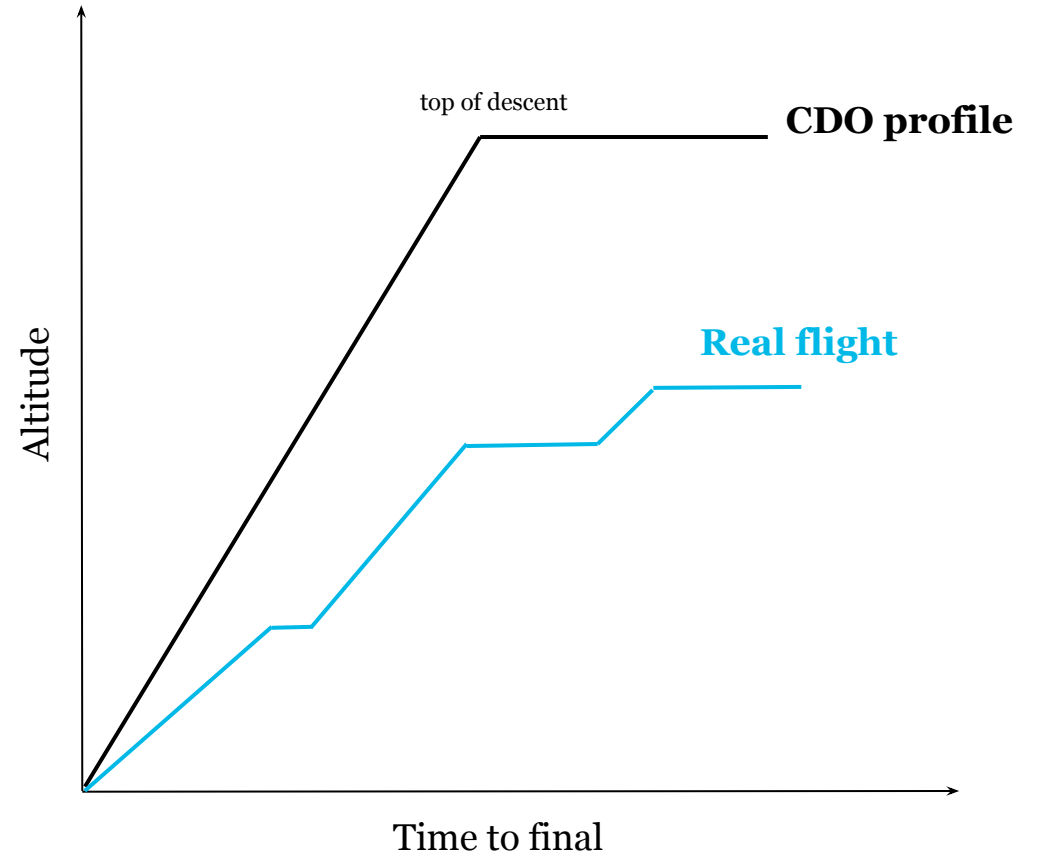
- Level segment= vertical speed below 300 feet per minute
- time flown level is minimum 30 seconds



Methodology

Additional Fuel Burn

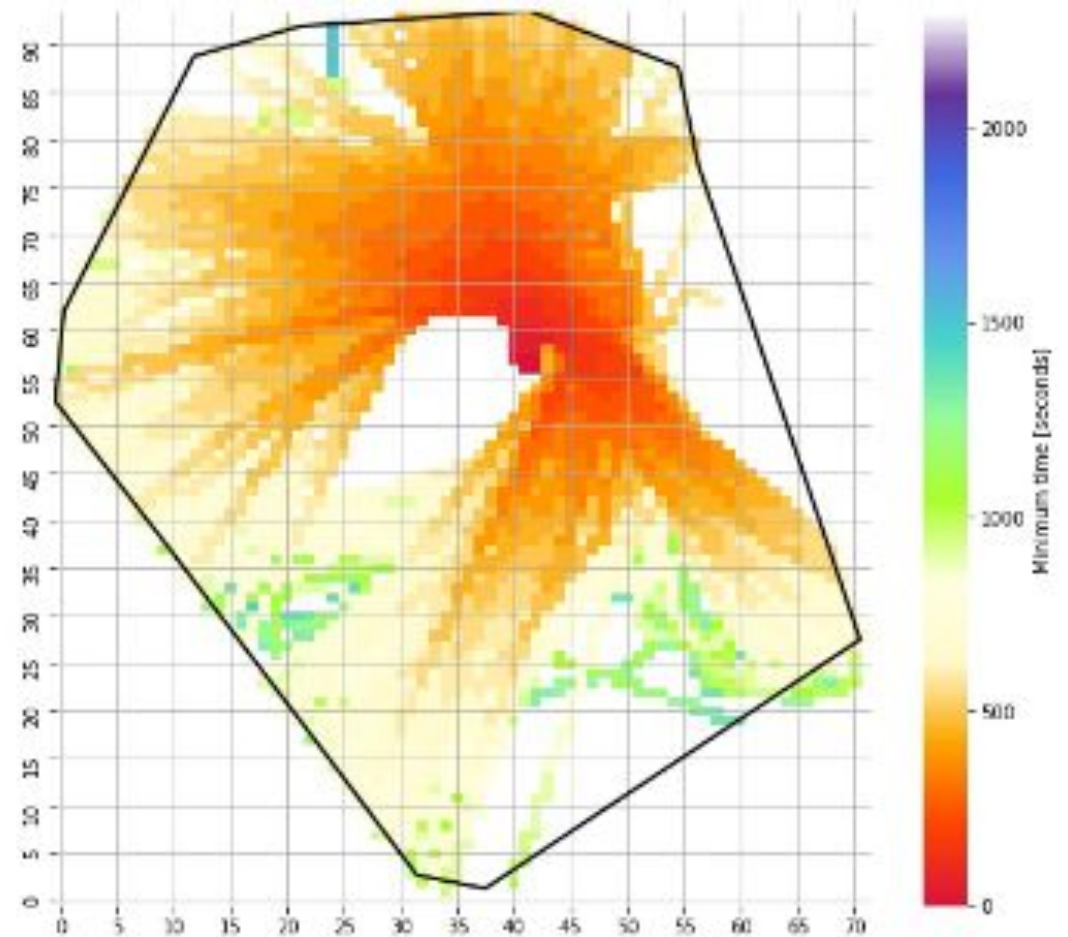
- To evaluate environmental efficiency
- Difference in fuel consumption between the real trajectory and a reference flight performing a CDO at *idle thrust*, flying a direct route from TMA entry to the final approach
- CDO profiles and fuel consumption calculated with Eurocontrol BADA v4.2, considering actual wind and temperature conditions from ERA5



Methodology

Minimum Time to Final

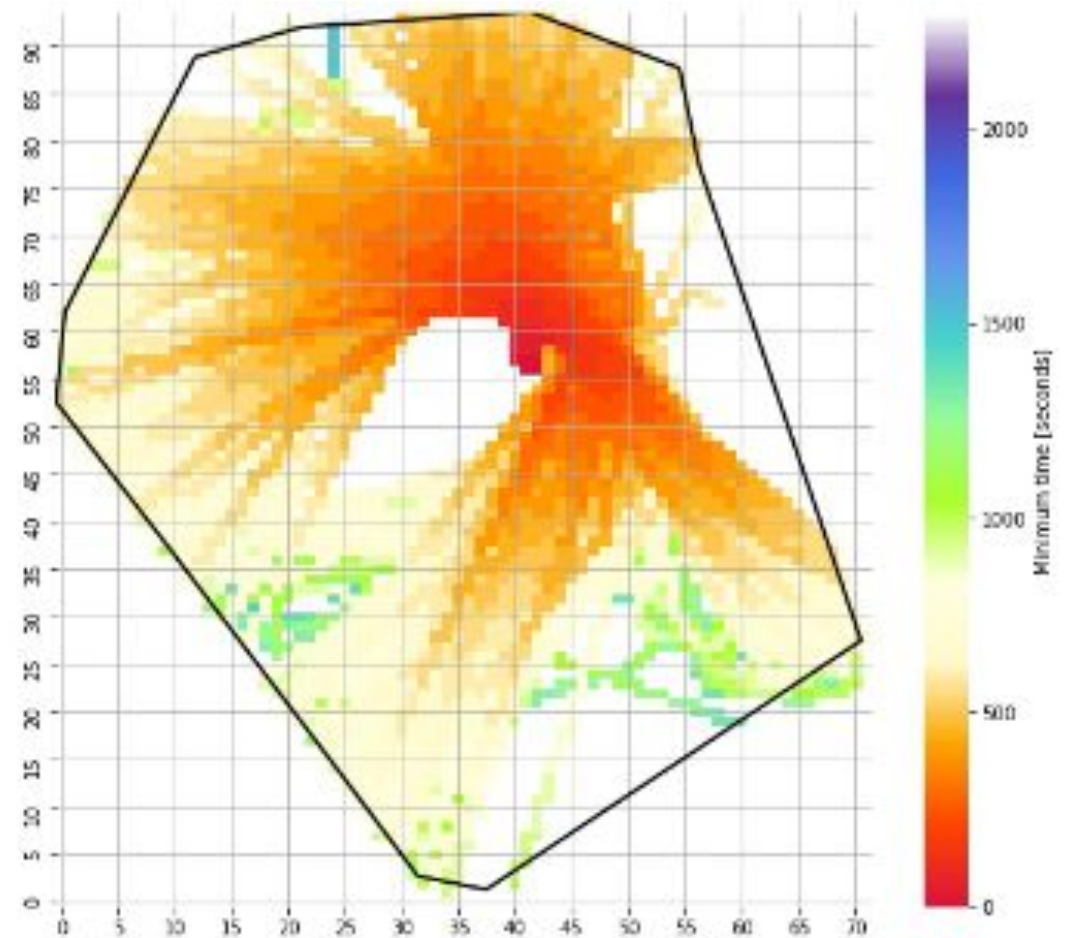
- A rectangular grid with the cell side of ≈ 1 NM laid over the TMA
- The minimum time needed from any point *within the cell* of the grid to the final approach
- Infinite in the cells through which no trajectories pass
- Heatmap visualization



Methodology

Horizontal Spread

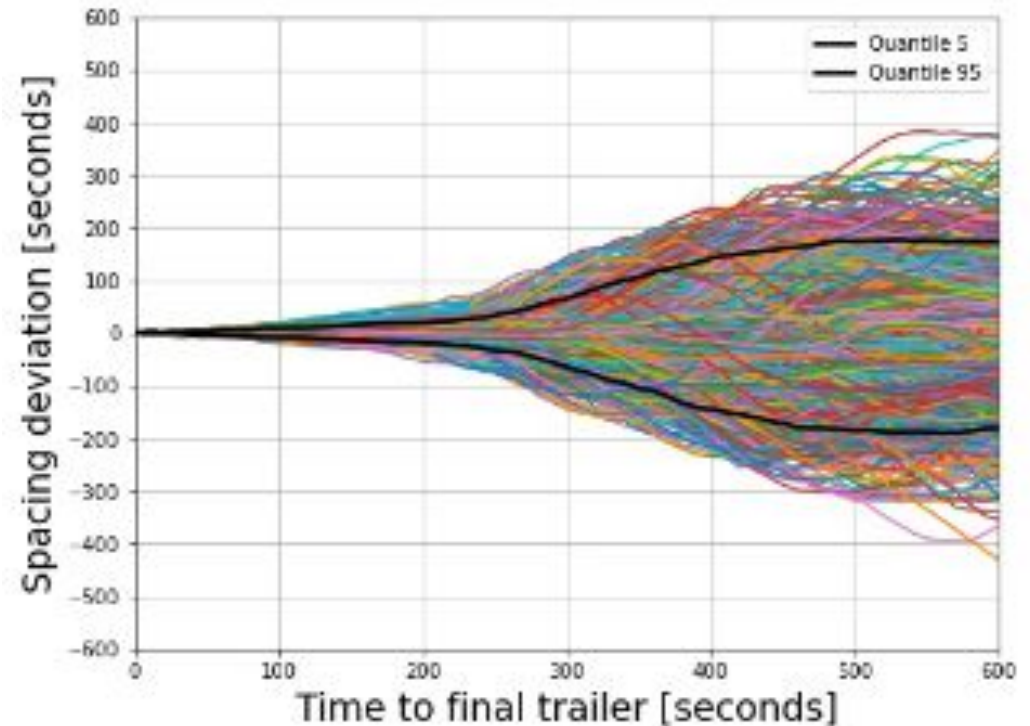
- NEW KPI for estimation of the percentage of the TMA area occupied by the flights
- To quantify the dispersion of the arrival flows
- Calculated as a ratio of the number of cells through which at least one trajectory passes to the total number of grid cell in TMA



Methodology

Spacing Deviation

- Difference between the respective minimum times to final of an aircraft pair
- Reflects information about the control error

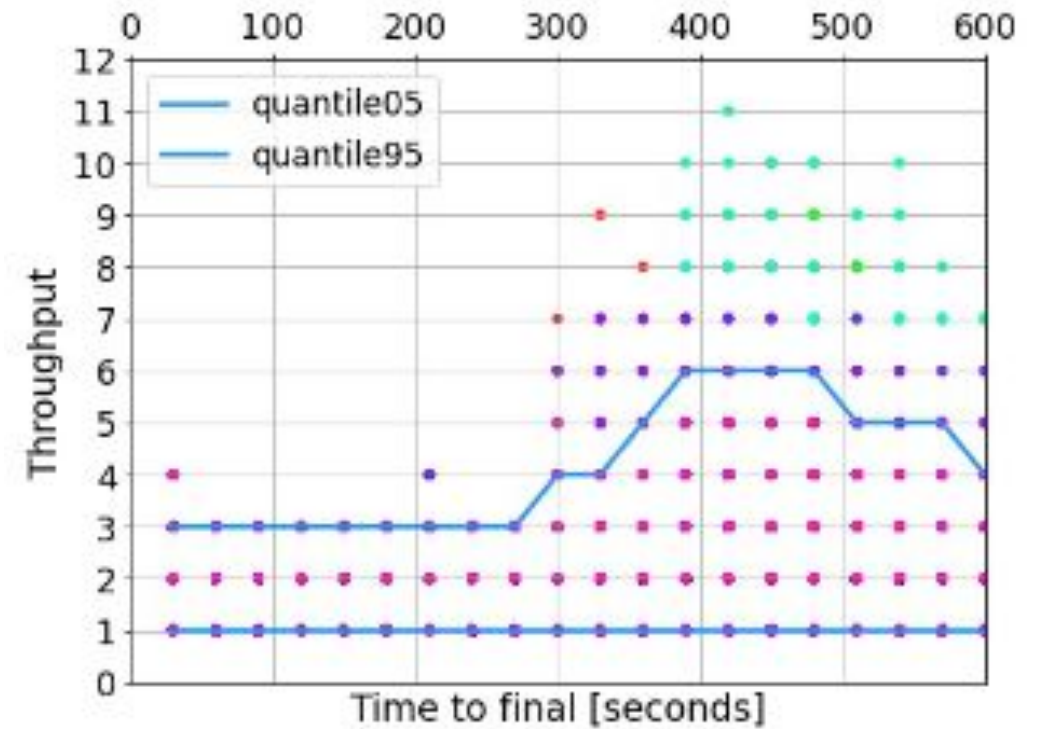


$$sd(t) = \min_time(\text{trailer}(t)) - \min_time(\text{leader}(t - s_{rwy})).$$

Methodology

Throughput

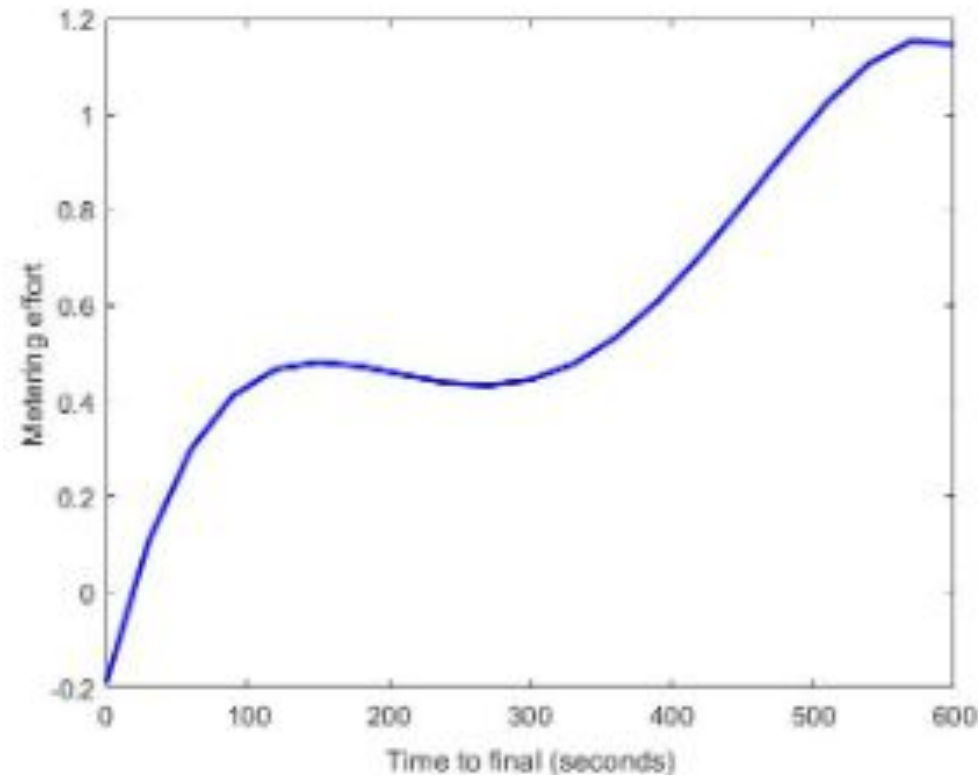
- The number of aircraft with the same minimum time to final within a given time window
- Iso-minimum time lines from 600 to 30s to final
- 30 seconds sampling rate over 5-minute periods



Methodology

Metering Effort

- Difference between the throughput at the given time horizon and the one close to the final
- Quantifies the controller's effort for metering
- Proxy to controller's workload

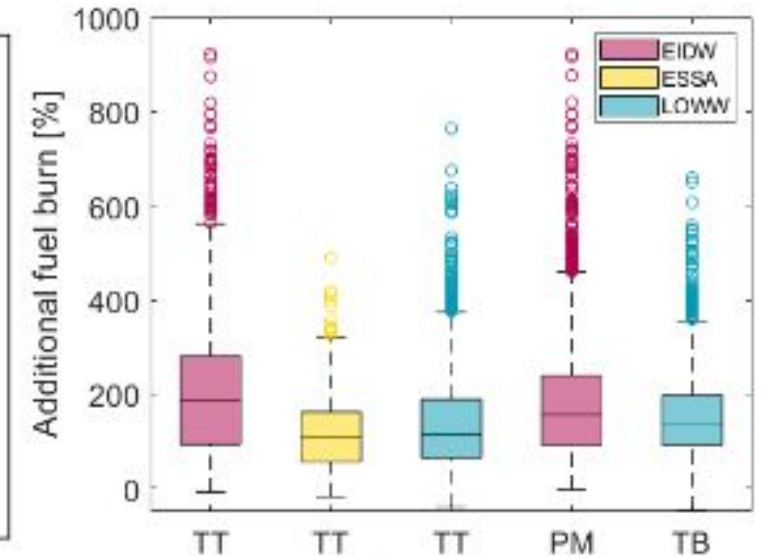
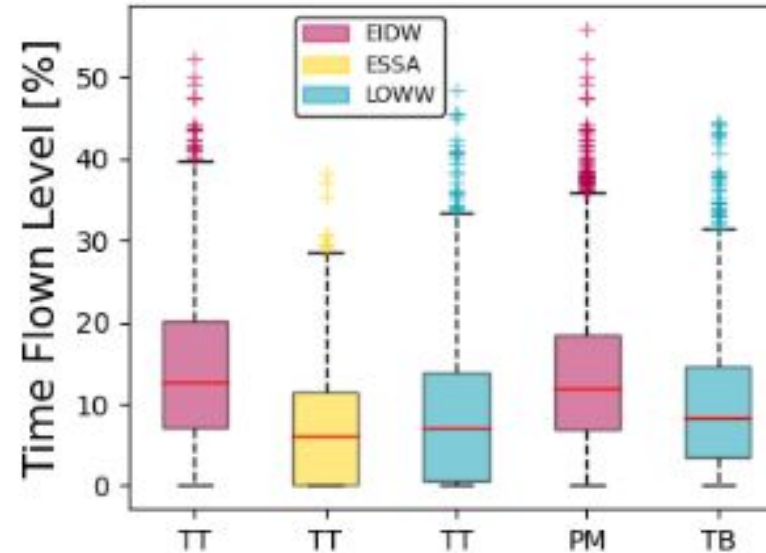
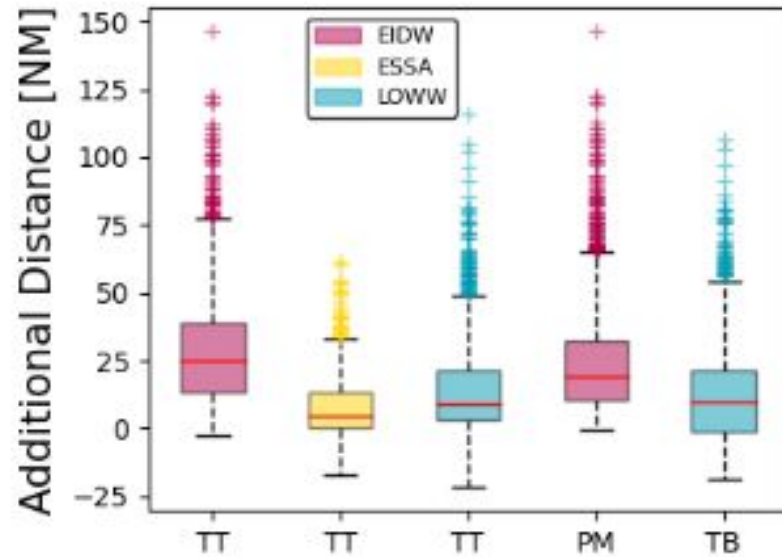


Large-scale Analysis

Additional Distance

Average Time on Levels

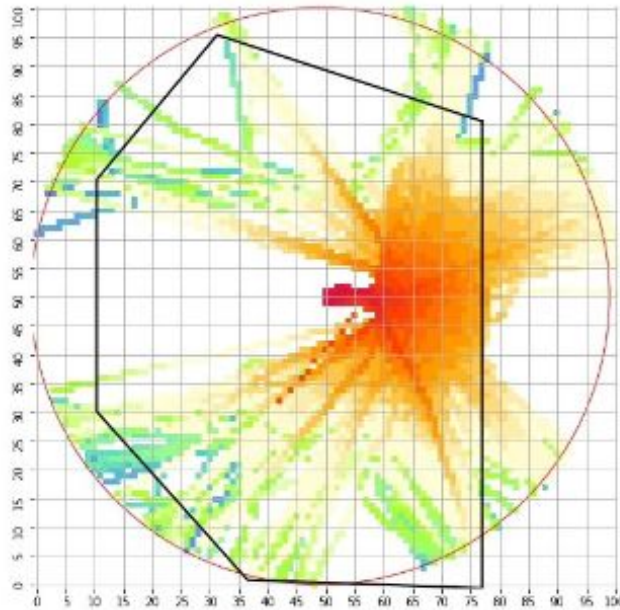
Additional Fuel Burn



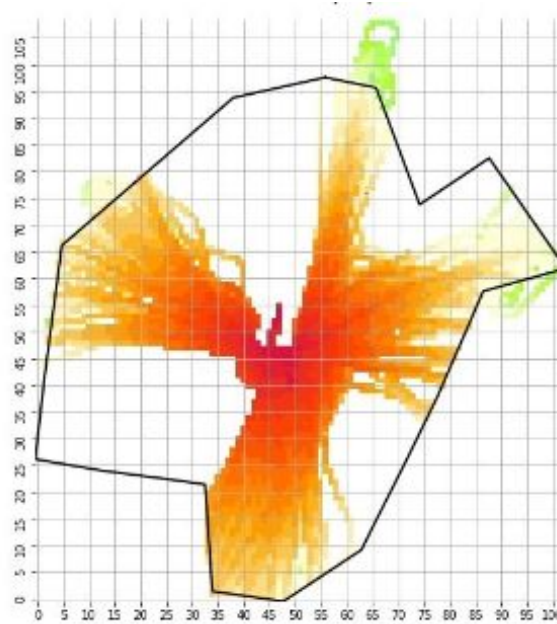
- Dublin shows higher median values for additional distance than Arlanda and Vienna (24.8 NM, 4.9NM, 8.8NM)
- With similar median values, Vienna has higher dispersion of values in comparison to Arlanda
- Similar disposition according to all three indicators
- Adherence to Point Merge procedures improves the performance
- The adherence to Trombone procedures raised the median values, but lowered the variance

Large-scale Analysis

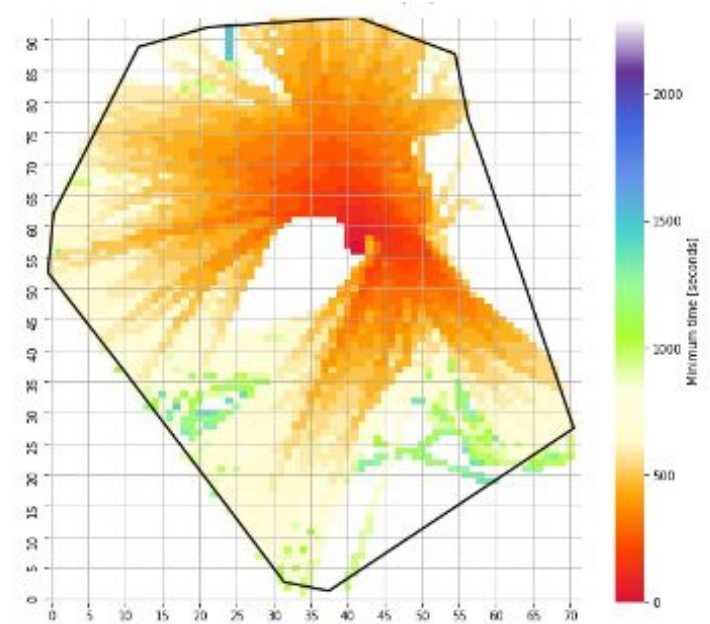
Dublin



Stockholm Arlanda



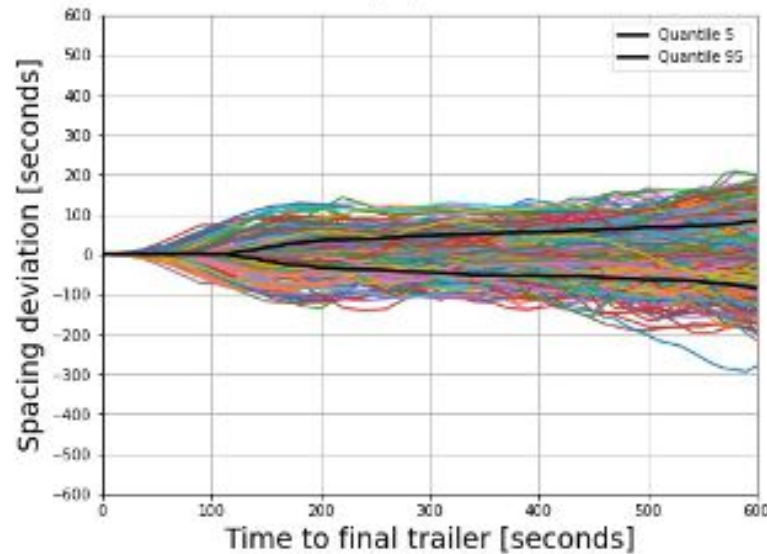
Vienna



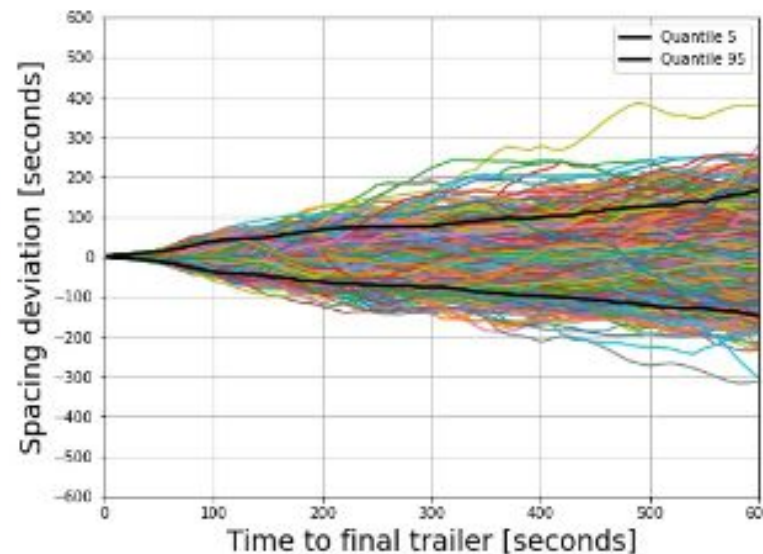
- Horizontal spread is 64% for Dublin, 59% for Arlanda, and 84% for Vienna
- Significantly higher values for EIDW
- Consistent with the results obtained for the Additional Distance

Large-scale Analysis

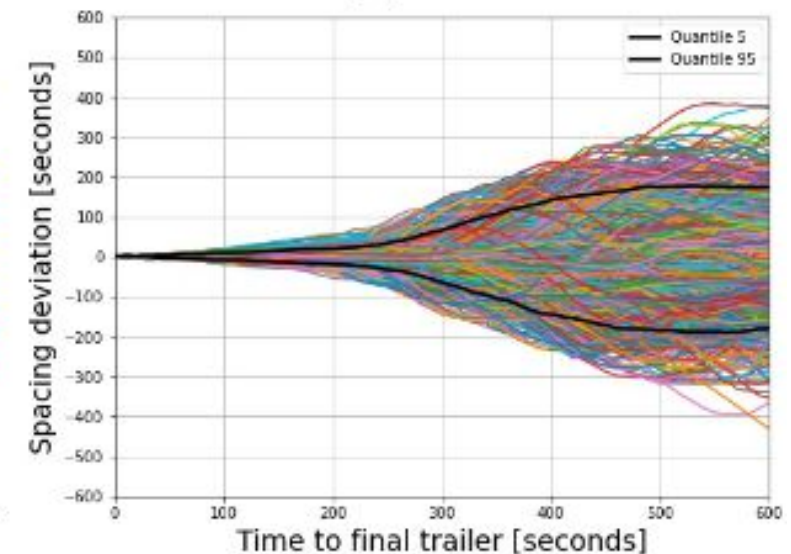
Dublin



Stockholm Arlanda



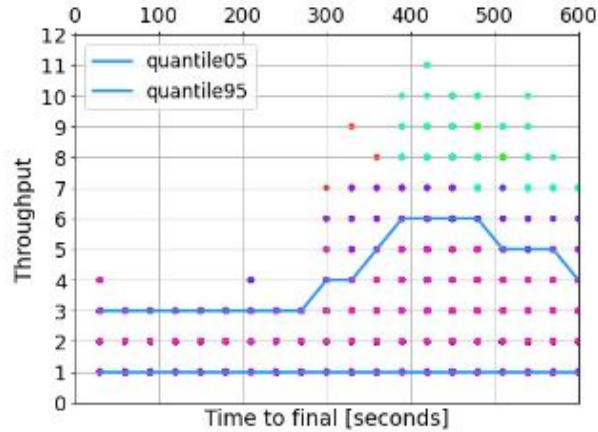
Vienna



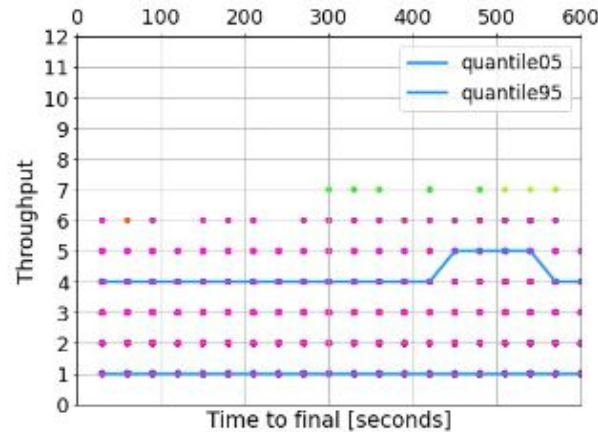
- Clear difference in the 90th quantile for these airports:
 - 169s for Dublin, 314s for Arlanda, and 365s for Vienna
- Different time to final horizons when the flows start to converge to final

Large-scale Analysis

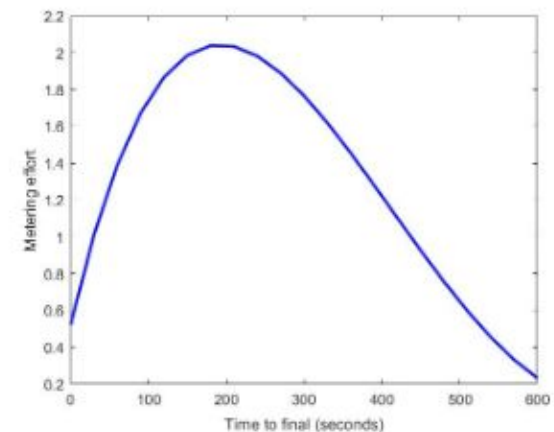
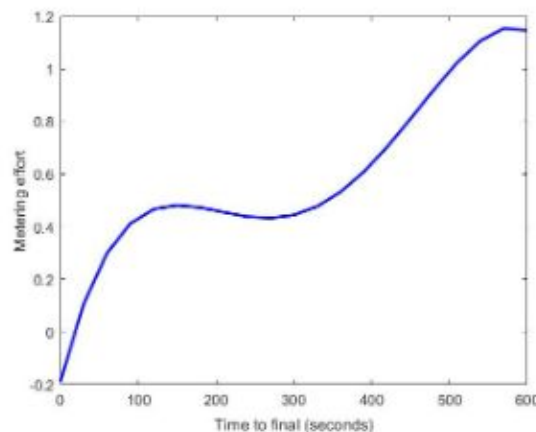
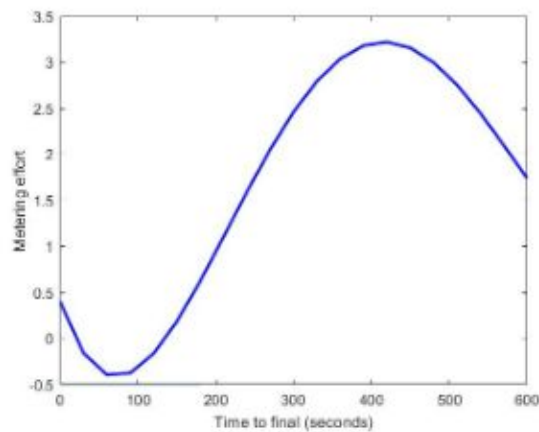
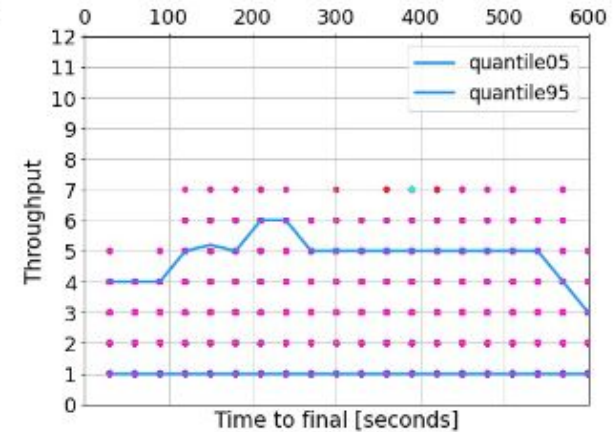
Dublin



Stockholm Arlanda

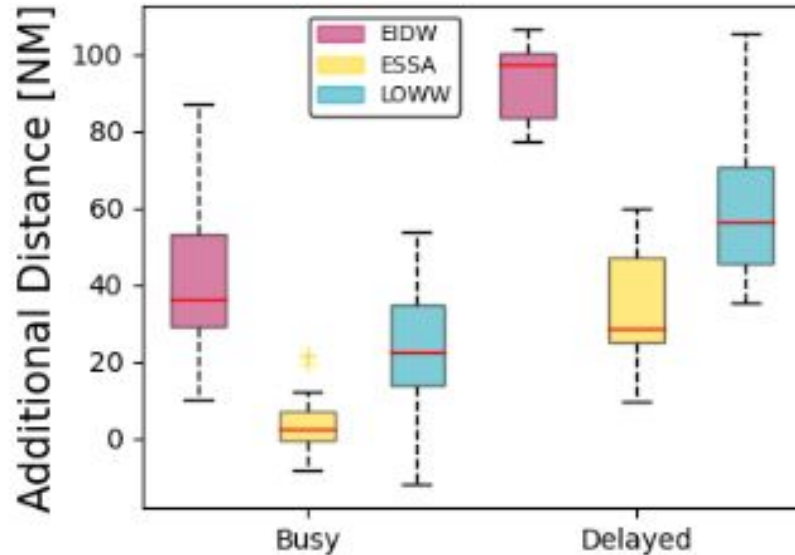


Vienna

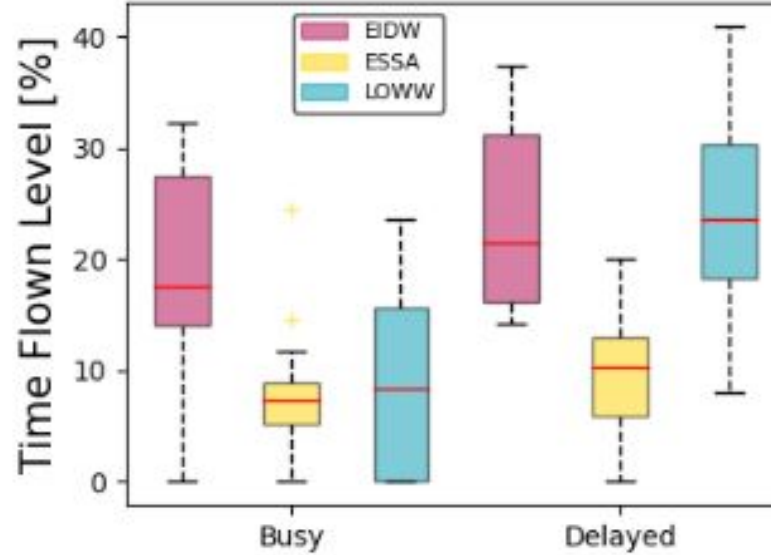


Fine-grained Analysis

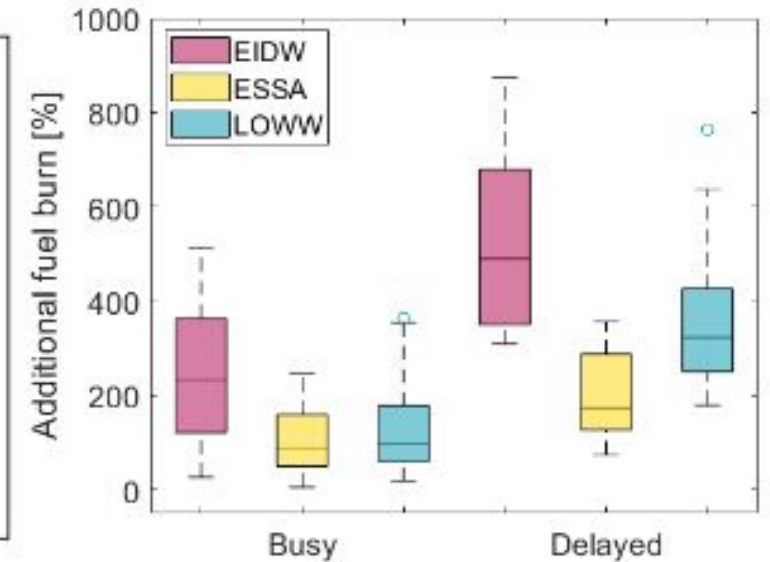
Additional Distance



Average Time on Levels



Additional Fuel Burn



- Improvement in the Additional Distance at Arlanda in comparison to TT dataset (2.7NM)
- Degraded performance during the most delayed hours, which result from longer paths in TMA
- Traffic intensities are handled better than delays (especially vertical efficiency in Vienna and the additional distance in Dublin)

Fine-grained Analysis

- Higher minimum time to final during the most delayed hours
- Higher horizontal spread for the busy hours (lowest at Dublin)
- Larger 90th quantile for spacing deviation for Dublin and Vienna, but smaller for Arlanda during the delayed periods
- Higher values for metering effort during the most delayed hours for Arlanda and Vienna, but lower for Dublin

Statistics	Busy Hour			Delayed Hour		
	Airport	EIDW	ESSA	LOWW	EIDW	ESSA
Minimum Time to Final (seconds)						
Minimum	0	0	0	0	0	0
Maximum	1616	1128	1376	2054	1572	1798
Average	735	573	662	848	729	799
Standard deviation	351	235	271	479	345	378
Horizontal Spread (percent)						
	11	18	21	7	10	17
Spacing deviation (seconds)						
Minimum	-420	-195	-274	-373	-191	-333
Maximum	302	334	383	307	227	322
Average	0.52	2.57	2.56	3.08	-4.9	4.08
Standard deviation	73.13	63.09	87.96	85.04	57.63	84.25
90 th Quantile Width	487.5	364.5	451.6	559.2	315.25	494.8
Throughput						
Minimum	1	1	1	1	1	1
Maximum	7	6	7	5	8	8
Average	2.69	2.58	3.06	1.51	3.18	2.37
Standard deviation	1.15	1.04	1.13	0.77	1.36	1.18
Metering Effort						
Minimum	0.25	-0.75	0	-1	0	0
Maximum	4.25	1	3	2	6	5
Average	1.92	0.14	1.25	0.24	2.09	1.64
Standard deviation	1.14	0.5	0.88	0.69	1.25	1.05

Conclusions

- Evaluation of the arrival efficiency at three European airports with different airspace complexity and different sequencing and merging techniques
- Adherence to the designated route procedures significantly improved the efficiency at Dublin airport, but the results for Vienna are ambiguous
- All the airports perform relatively better in the high-traffic scenarios than during the periods with high delays.
- Improved horizontal performance in congested scenarios was observed at Arlanda
- Arlanda operations seem to cope better with the delays than the point merge and trombone procedures
- No fair comparison is possible without considering the entry conditions to the terminal area
- Further studies would be required to analyze flight efficiency under comparable entry conditions

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THANK YOU!

Thank you
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