ATM Seminar
2023-06-06

Performance Characterization of Arrival Operations With Point Merge at Oslo Gardermoen Airport

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Presentation Outline

- Background and Introduction
- Methodology
- Performance Evaluation: Results
- Conclusions
- Future Work

Background and Introduction

Introduction

- Comprehensive investigation of the point merge (PM) arrival flight performance
- Oslo Gardermoen airport (PM implemented in 2011)
- KPIs – both existing and new
- Contribute to better understanding of the effect of the PM implementation on the arrival performance

The Point Merge Concept

- Sequencing legs used to delay the aircraft (create sufficient inter-aircraft separation)
- Merge point, equidistant from each sequencing leg
- ”Direct to” merge point when the desired separation is achieved
- 38 airports in 19 countries operate with PM (May 2023)

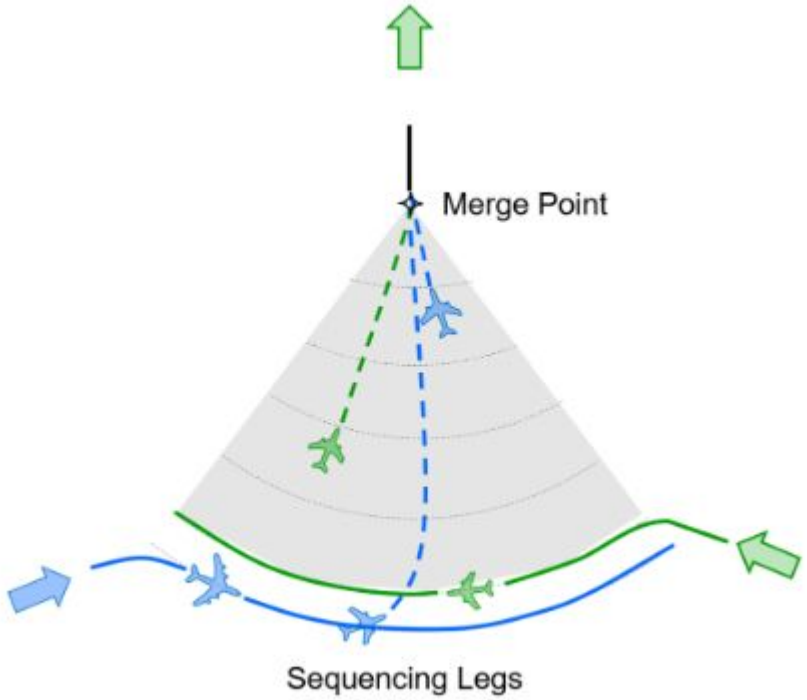


Figure: EUROCONTROL

The Point Merge Concept

- **Different design alternatives**
  Trade-off between capacity and environmental efficiency

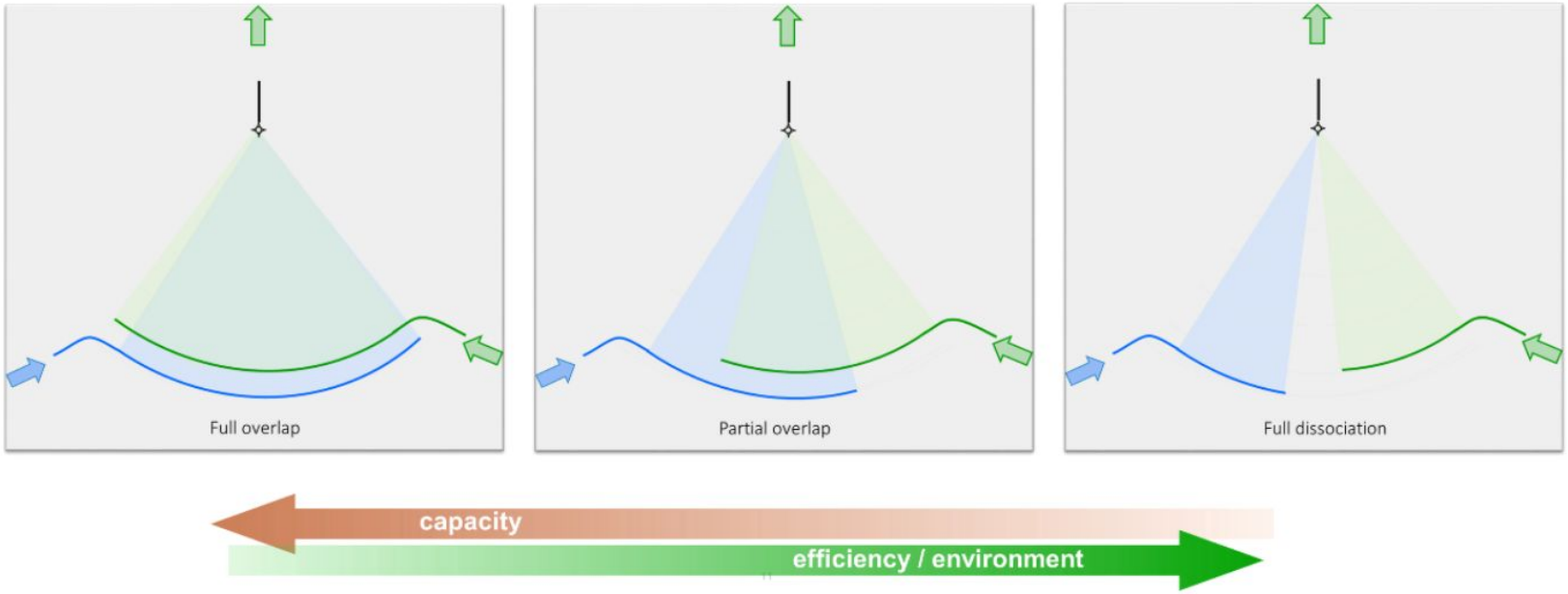
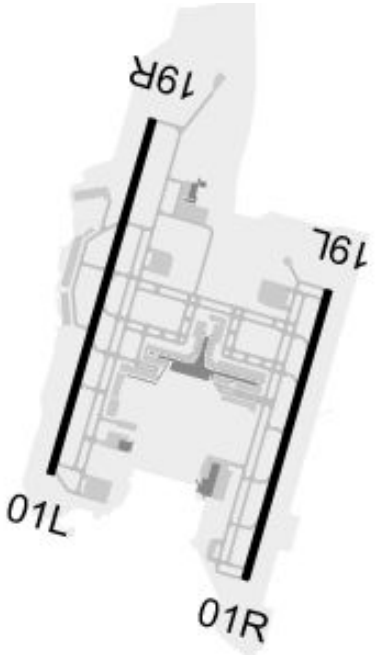


Figure: EUROCONTROL

Point Merge in Oslo Gardermoen

- Six entry points to TMA
- RWY 01L/R, 19L/R
- Four PM systems
- Sequencing legs at FL90, 100 and 110
- Fully overlapping legs (level-flight required)



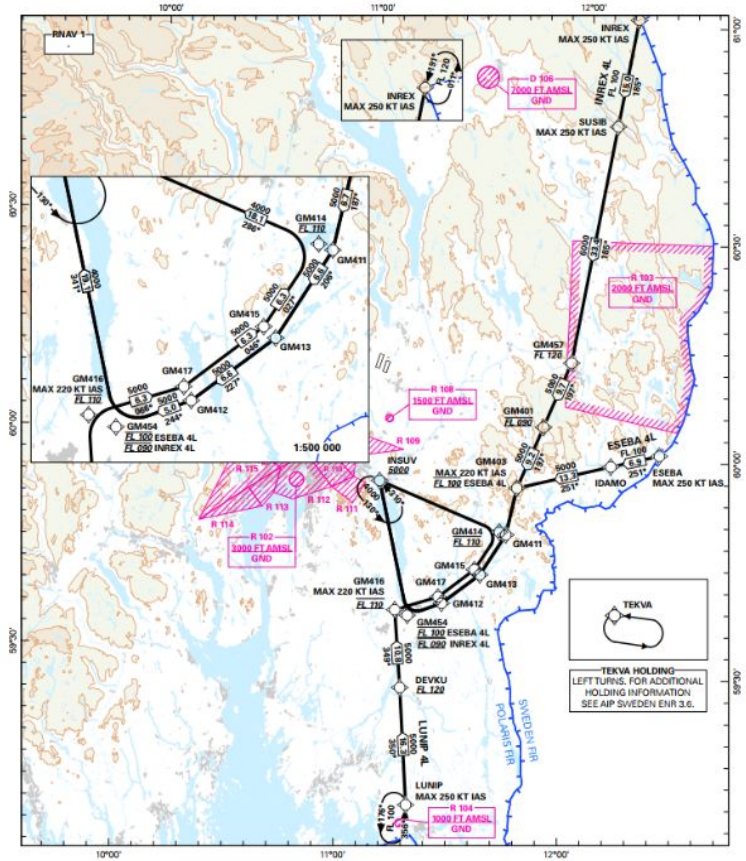
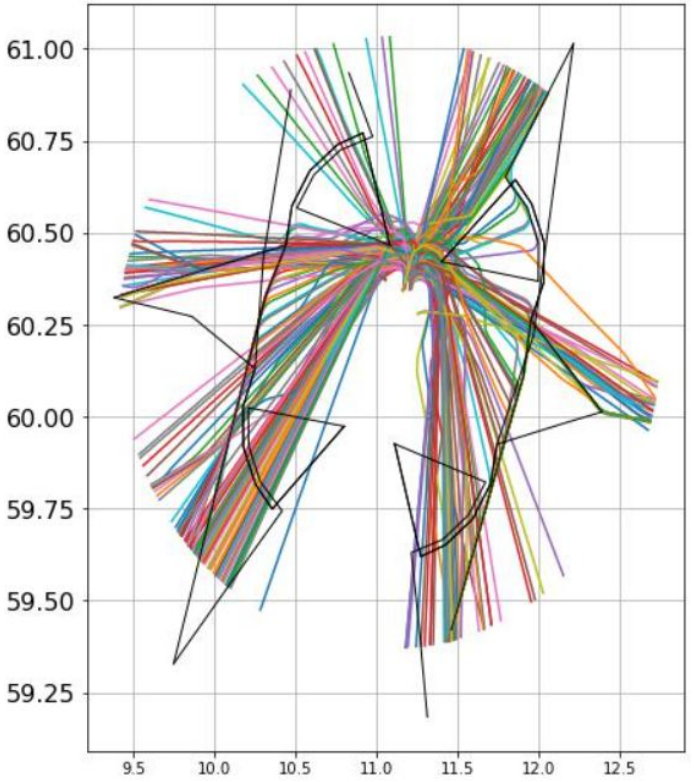


Chart: Norwegian AIP (Avinor)

Methodology

Data

- OpenSky Network ADS-B data (open-source)
- Within 50 NM circle
- 4 full weeks of October 2019 – 7829 arrivals
- Cleaning and pre-processing



Datasets

- ***TT* – Time in TMA**
  Peak time periods – 0.7 percentile of average time in TMA removed
  The rest correspond to hours when a/c spend significantly long time in TMA

- ***PM* – Point Merge**
  a/c following PM (methodology to follow)

- ***Non-PM* – Non-Point Merge**
  a/c not following PM (PM subset subtracted from the full dataset)

- *North* (19 L/R) and *South* (01 L/R) subsets

Datasets

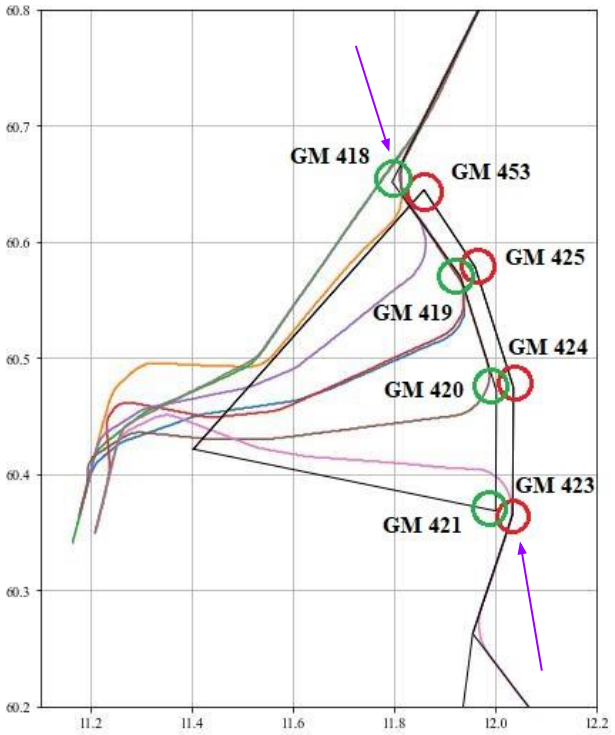
- *PM* + *non-PM* = full dataset
- *TT* is a subset of full dataset (40% of the flights in full dataset)

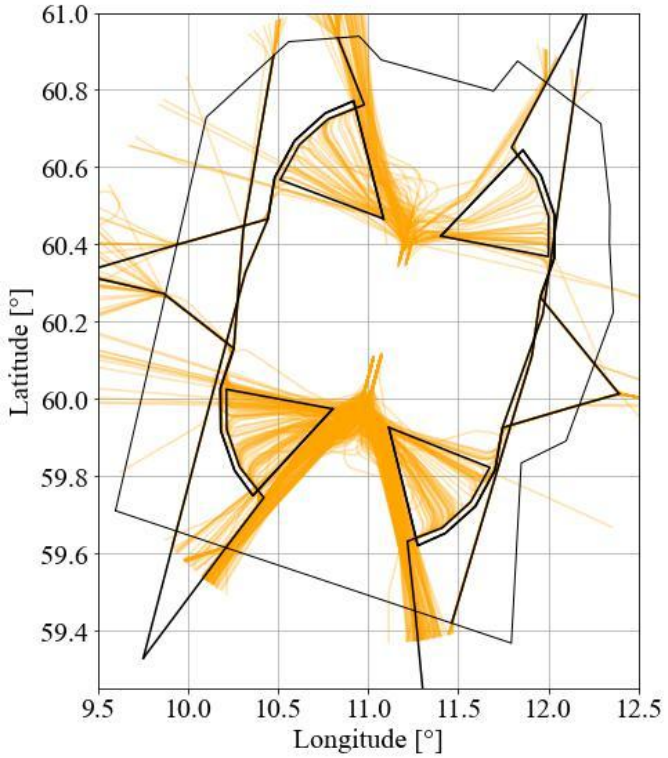
Dataset	# flights
TT	3141
TT_{North}	1047
TT_{South}	2094
PM	2262
PM_{North}	681
PM_{South}	1581
non-PM	5567
$non\text{-}PM_{North}$	2683
$non\text{-}PM_{South}$	2884

Datasets

PM vs non-PM detection

- 3 NM circle catch area around the starting points of the PM sequencing legs (GM418 and GM423 for 19 East)
- Captured flights belonging to *PM* dataset, the rest to *non-PM*
- Method applied to all four PM systems





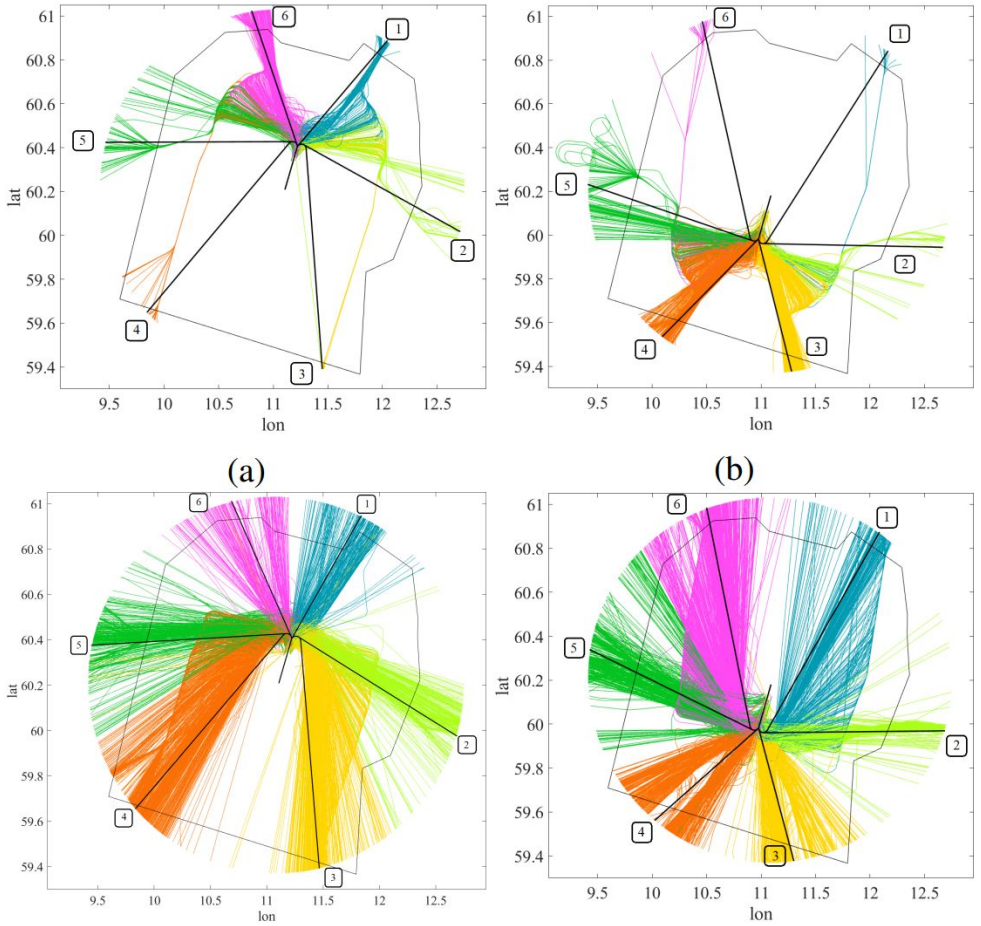
Performance Evaluation Metrics

- Horizontal efficiency
- Vertical efficiency
- Environmental efficiency
- Sequencing and spacing (*TT* datasets only)
- Time efficiency
- PM utilization

Horizontal Flight Efficiency

Additional Distance

- Actual trajectories clustered into six clusters
- Reference trajectory from cluster centroid (along 50 NM circle) to the final approach
- Calculated separately for *PM* and *non-PM*, and *North* and *South* datasets
- Difference between actual distance and length of corresponding reference trajectory



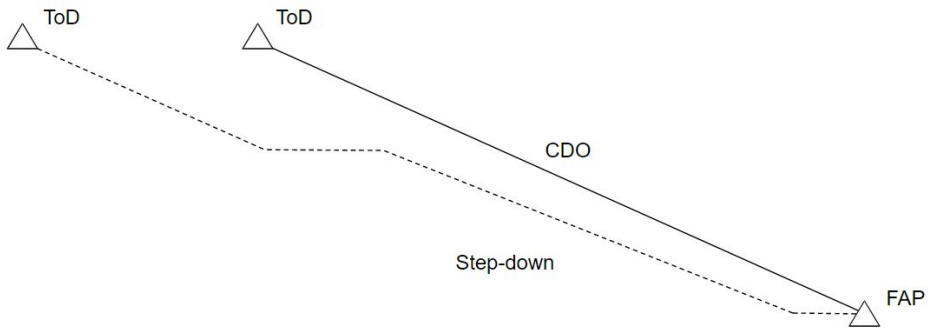
Vertical Flight Efficiency

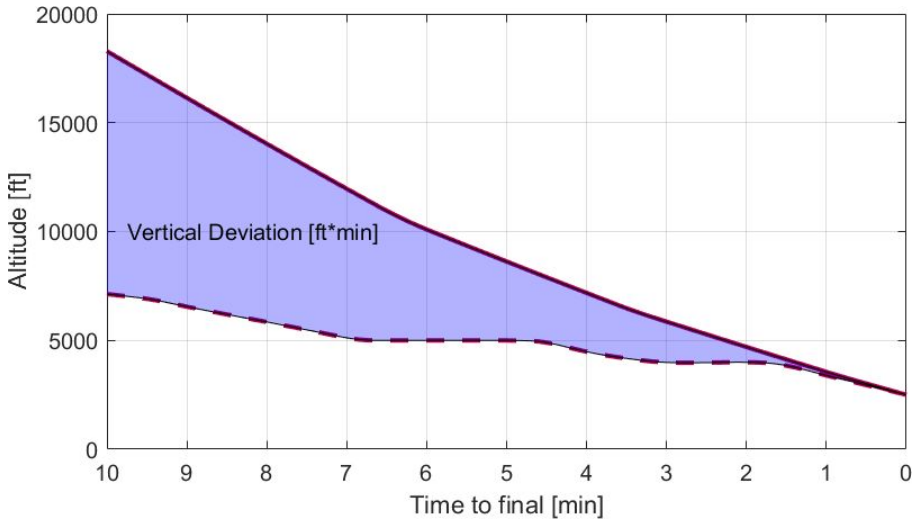
Time Flown Level

- Detecting level-flight segments for trajectories
- <300 ft/min. for ≥30 sec.
- First 30 sec. removed

Vertical Deviation

- Altitude deviation from a unique reference CDO profile
- CDO profiles (idle-thrust) created with BADA v4.2
- Last 10 min. of flight

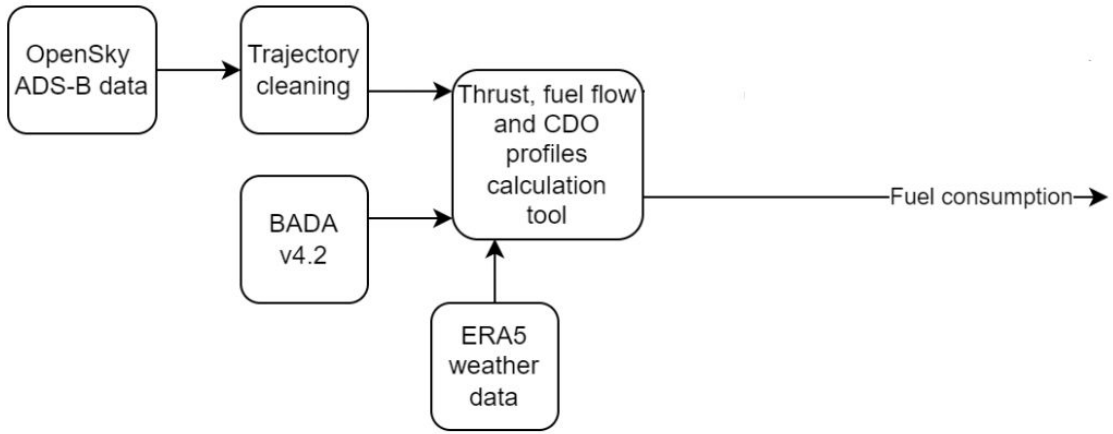




Environmental Efficiency

Additional Fuel Burn

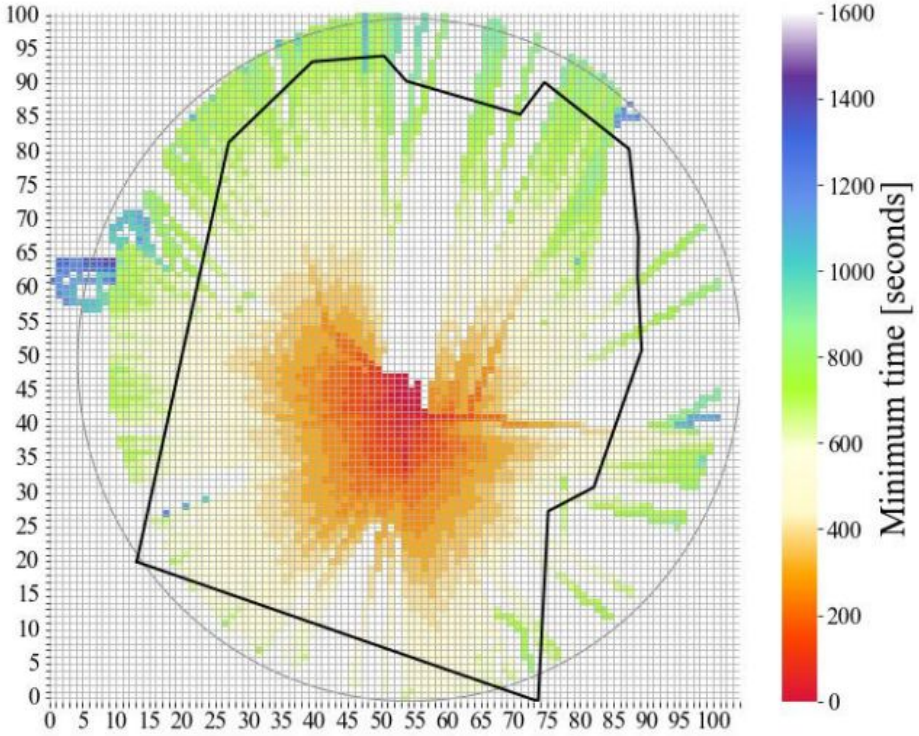
- Difference in fuel burn between actual trajectories and reference CDO at idle thrust
- Fuel consumption modelled with BADA v4.2
- Wind and temperature considered (from ERA5)



Sequencing and Spacing

Minimum time to final

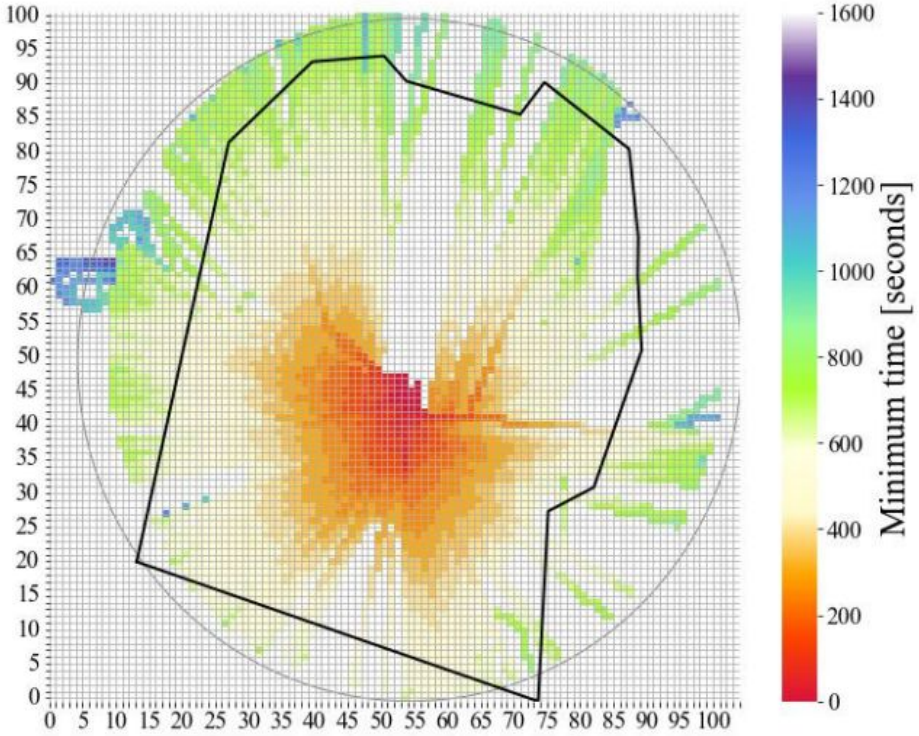
- 1 NM cell size grid overlayed
- Time-wise best-performer's time needed from the cell location to the final approach calculated
- Resulting times assigned to each cell
- Cell empty if no flight passes through it - Infinite minimum time to final assigned



Sequencing and Spacing

Horizontal Spread

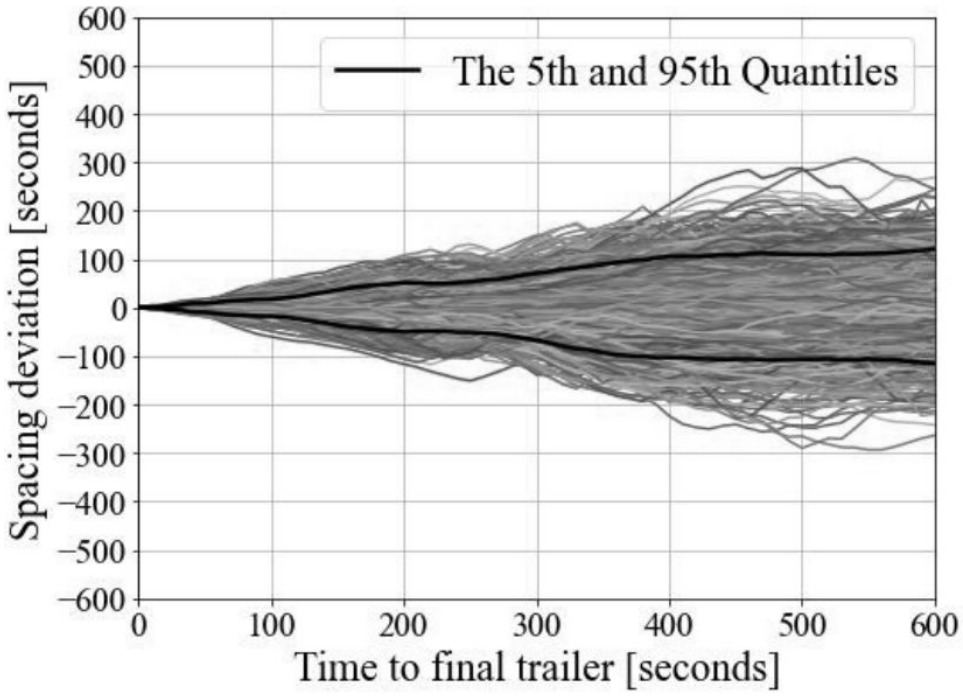
- Percentage of TMA area occupied
- Quantifier of arrival flows dispersion
- Ratio of the number of cells containing at least one trajectory to the number of cells covering the TMA



Sequencing and Spacing

Spacing Deviation

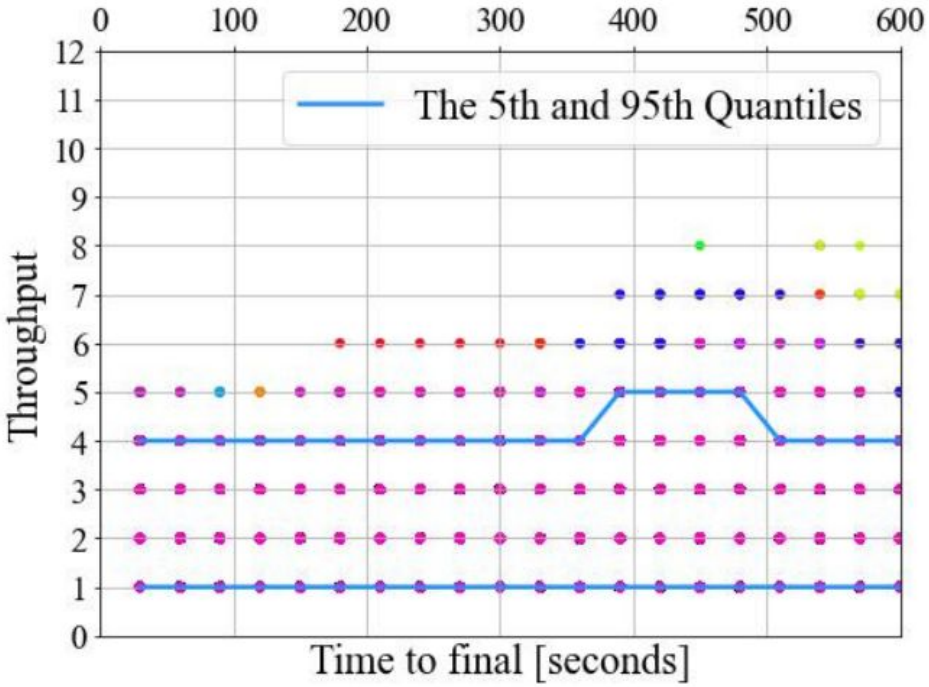
- Defined for an arriving aircraft pair
- Difference between their (leader and trailer) respective minimum times to final
- Reflects information about the control error (accuracy of spacing around the airport)



Sequencing and Spacing

Throughput

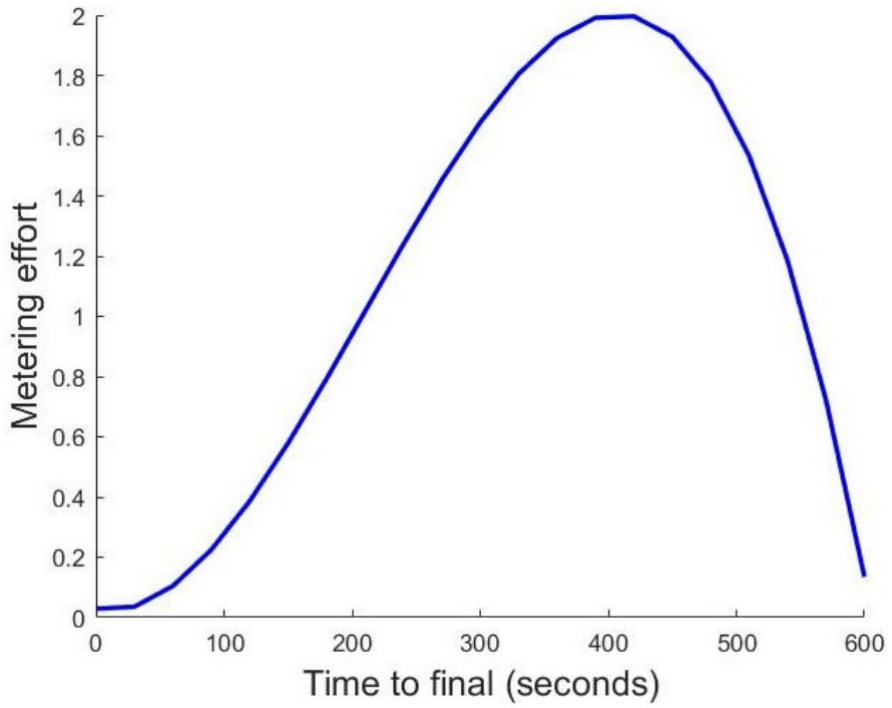
- The number of aircraft with the same minimum time to final at a given time horizon
- Sampled at a 30 sec. rate over 5 min. periods
- Not to be confused with *runway throughput*



Sequencing and Spacing

Metering Effort

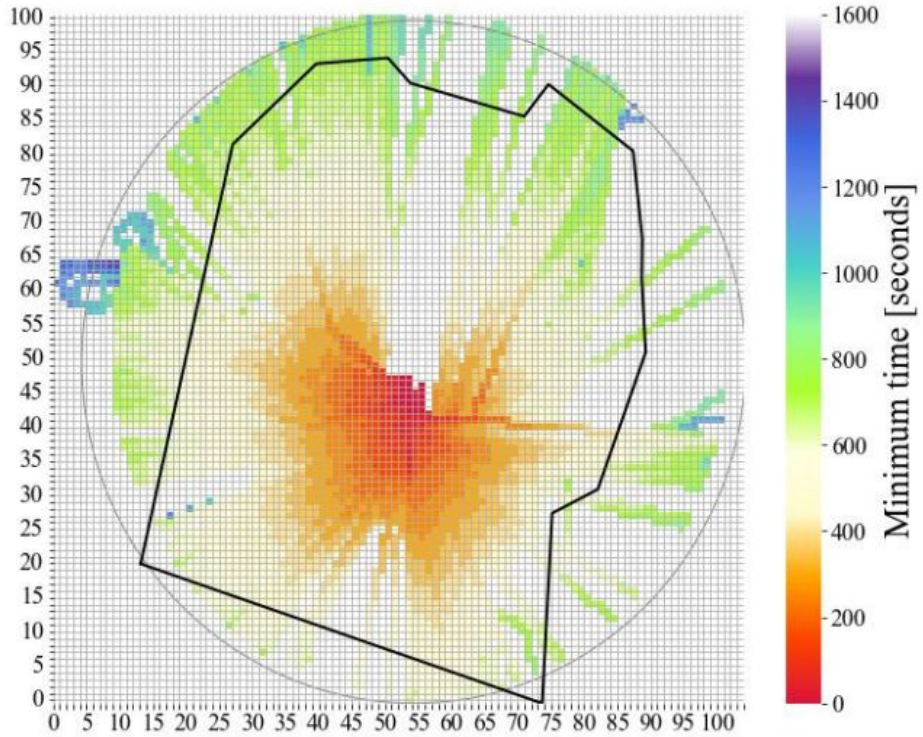
- The difference between the throughput value at the given time horizon and the one close to the final
- Quantifier of the controllers effort for metering
- May be used as a proxy for controller workload



Time Efficiency

Additional Time

- Difference between the Time in TMA and the Minimum Time to Final value assigned to the first cell in the grid, which the aircraft trajectory passes through after TMA entry



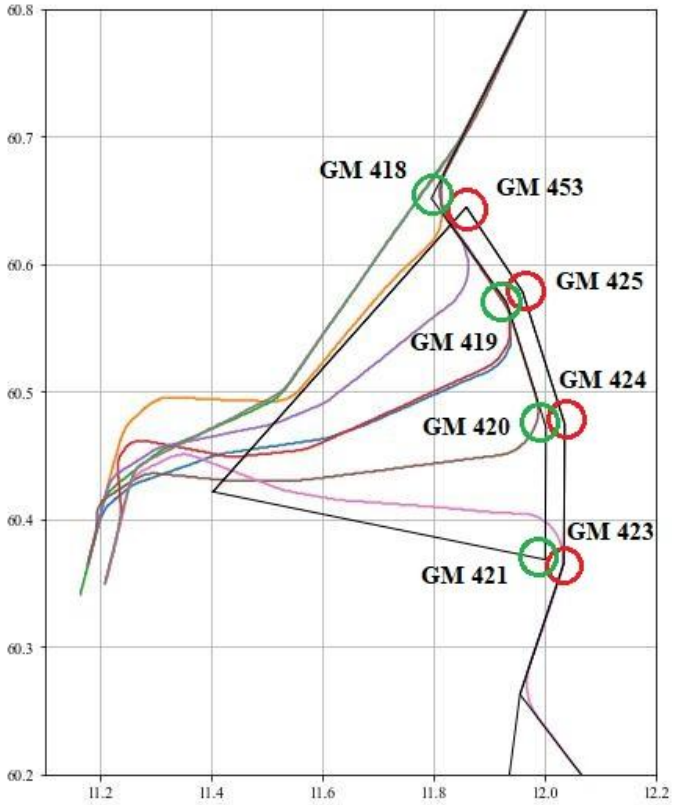
PM Metrics: NEW

PM Arc Utilization

- Proportion of the length of the PM sequencing leg flown
- Each system divided into three segments
- Waypoint catch area circle radius ≈ 2 NM
- Distance measured from PM start point until turn point

PM Utilization

- Percent of flights performing PM in the full dataset



Performance Evaluation: Results

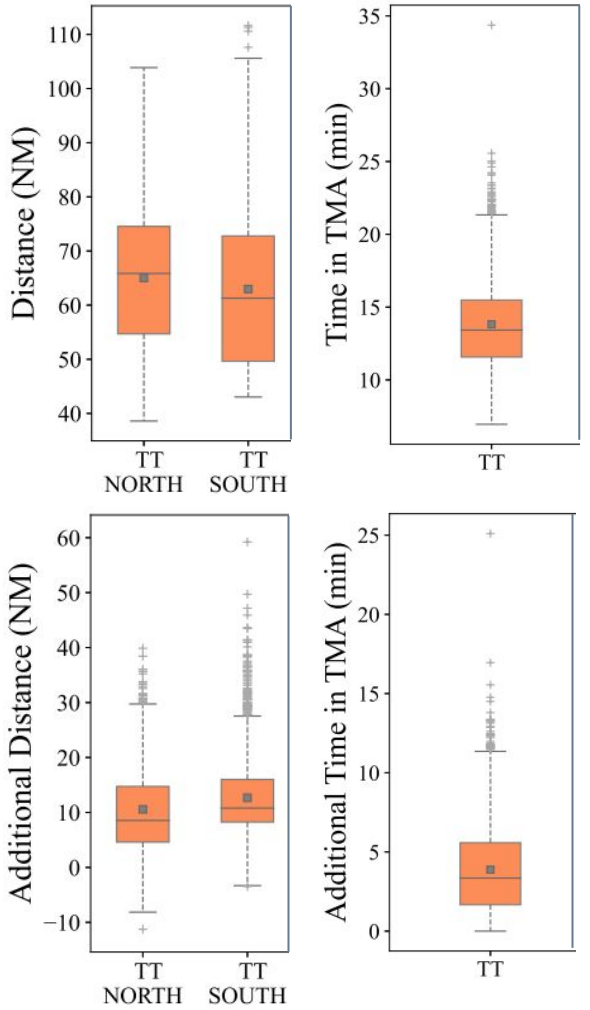
Evaluation Strategy

- Overall peak-period evaluation
  - *TT* dataset
  - Flights that do and do not follow PM

- Point Merge vs non-Point Merge operation evaluation
  - *PM* vs *non-PM* dataset

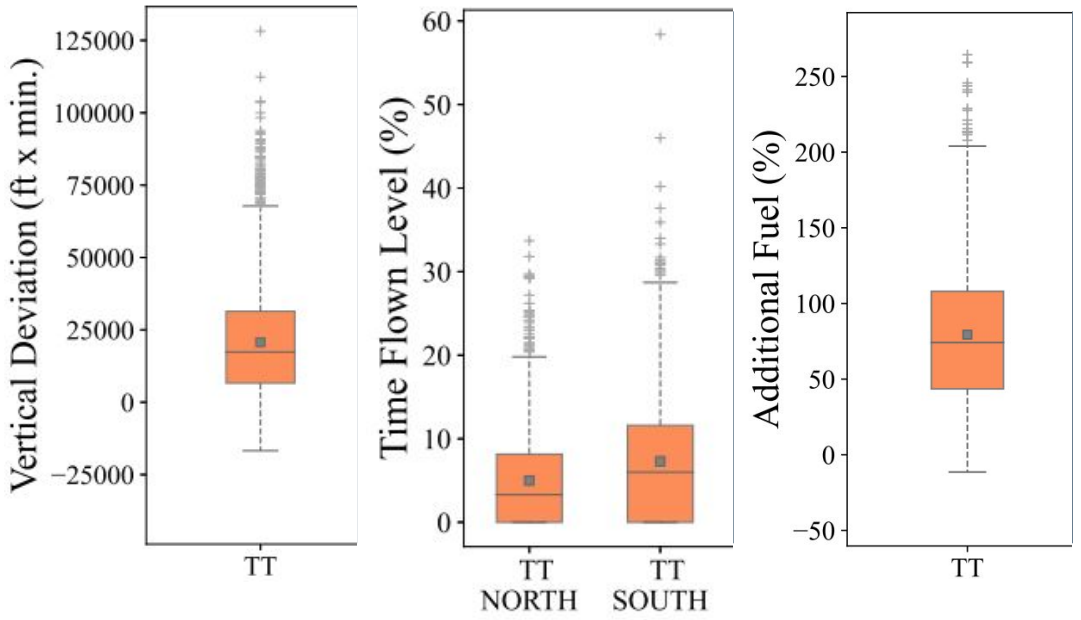
Peak Period Performance

- Distance greater for *North* (65.0 vs 63.0 NM)
- Additional Distance greater for *South* (12.7 vs 10.6 NM)
- Additional time in TMA 3.9 min: Outstanding performance!



Peak Period Performance

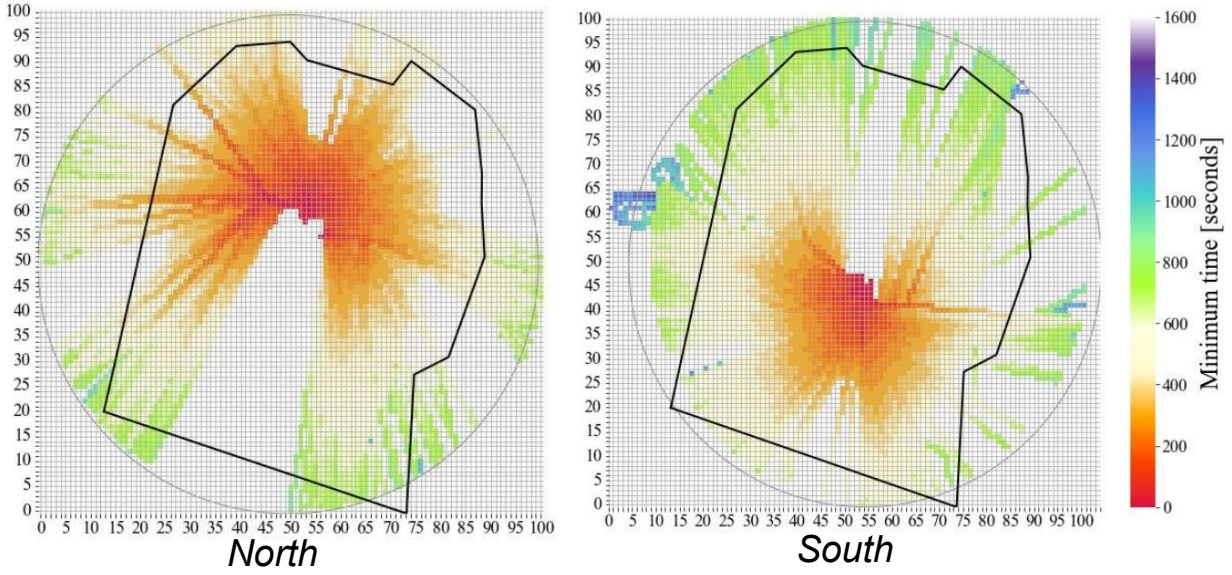
- Time Flown Level slightly lower for *North* (5.0% vs 7.3%)
- 31% of the flights have no levels
- Vertical Deviation 20,700 ft·min
- Additional Fuel Burn 79%



Sequencing and Spacing

Minimum Time to Final

- Slightly higher for *South*
- Different size of arrival flows in *North* and *South* affects the results
- Stack patterns in some west arrivals add to the minimum time to final

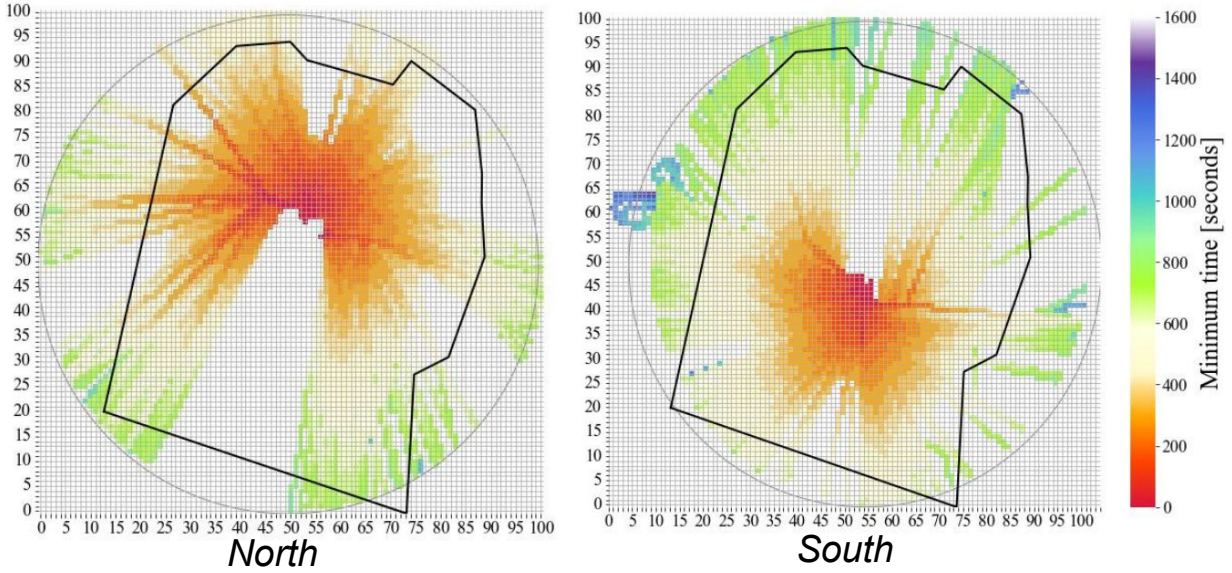


Sequencing and Spacing

Horizontal Spread

- *Full TT: 80.4%*
  - *North*: 63.3%
  - *South*: 66.9%

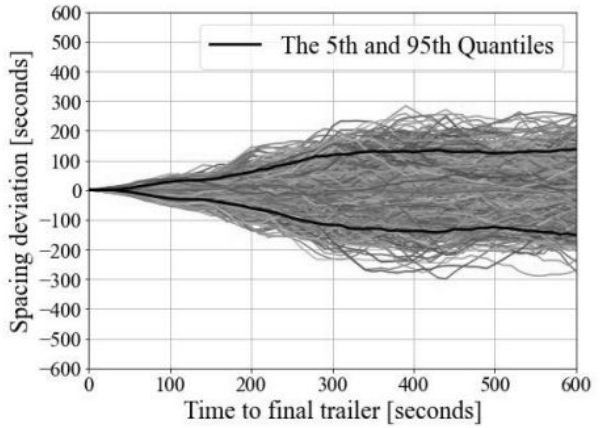
- Significant proportion of TMA used by arrivals



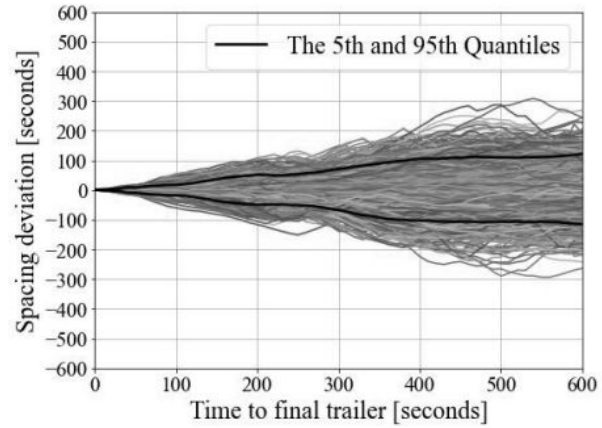
Sequencing and Spacing

Spacing Deviation

- Maximum absolute, average, and median values quite similar
- Value of the 90th quantile width varies significantly - indicates that the higher traffic volume on southern runways is still well-managed
- PM systems enable smooth and continuous convergence of the arrival sequences to the final



North



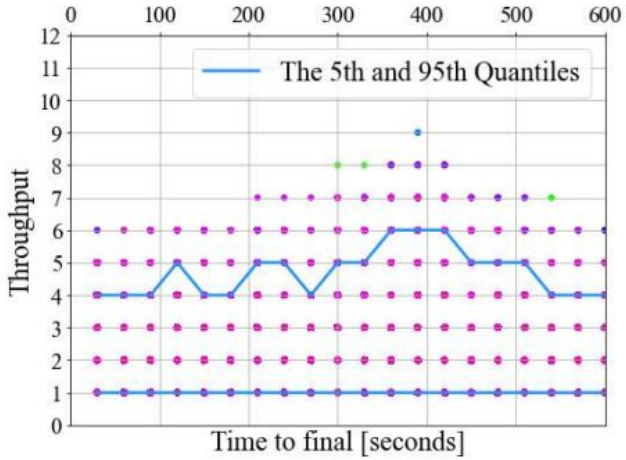
South

Sequencing and Spacing

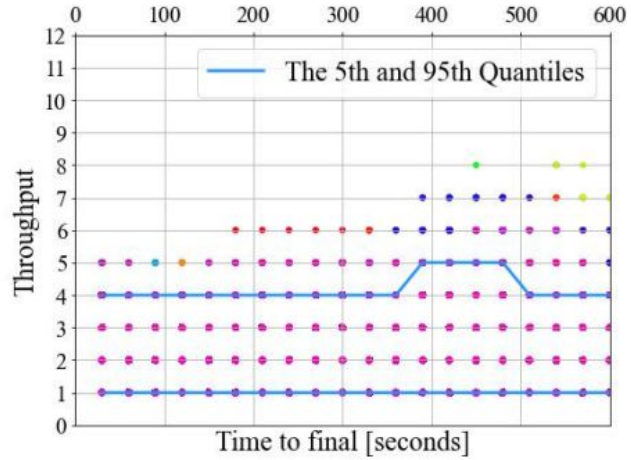
Throughput

- Maximum and average values quite close
  North: 9 and 2.5
  South: 8 and 2.1

- Indicates stable Throughput in the TMA in both directions



North

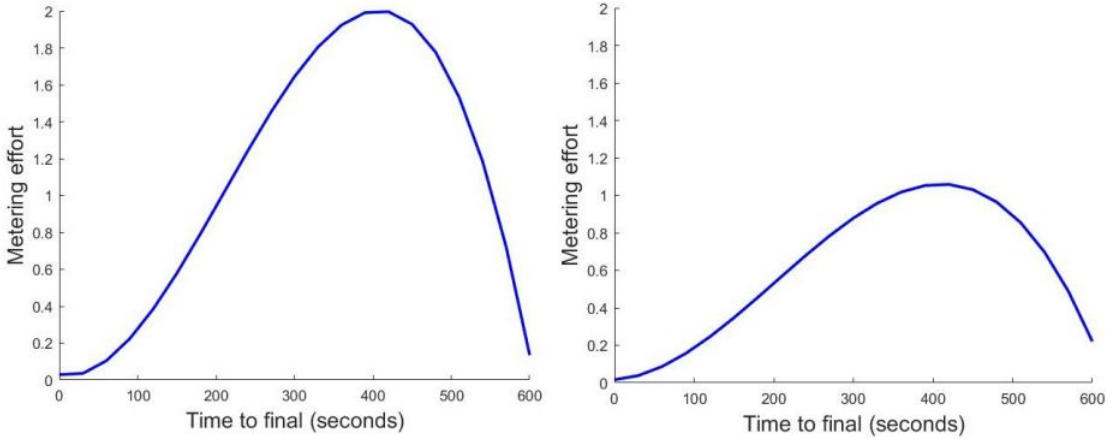


South

Sequencing and Spacing

Metering Effort

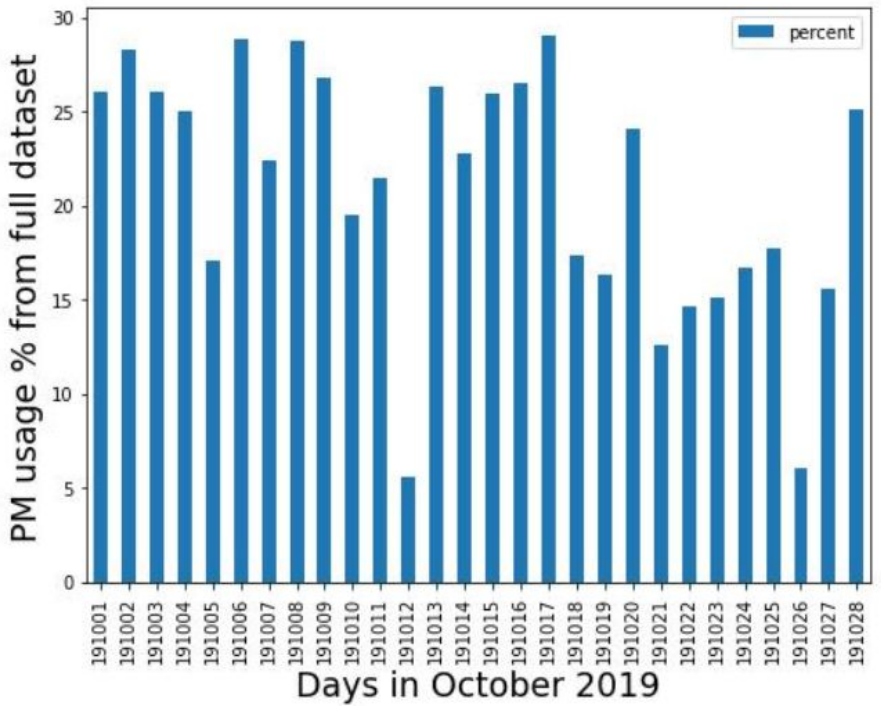
- Higher values of the maximum and average for *North* compared to *South* (2 and 0.7 vs 1 and 0.2)
- More control effort is applied in the northern part of the procedures, even though the traffic intensity is much lower here
- Slopes and the peaks of the curves illustrate when the sequencing and metering techniques are applied

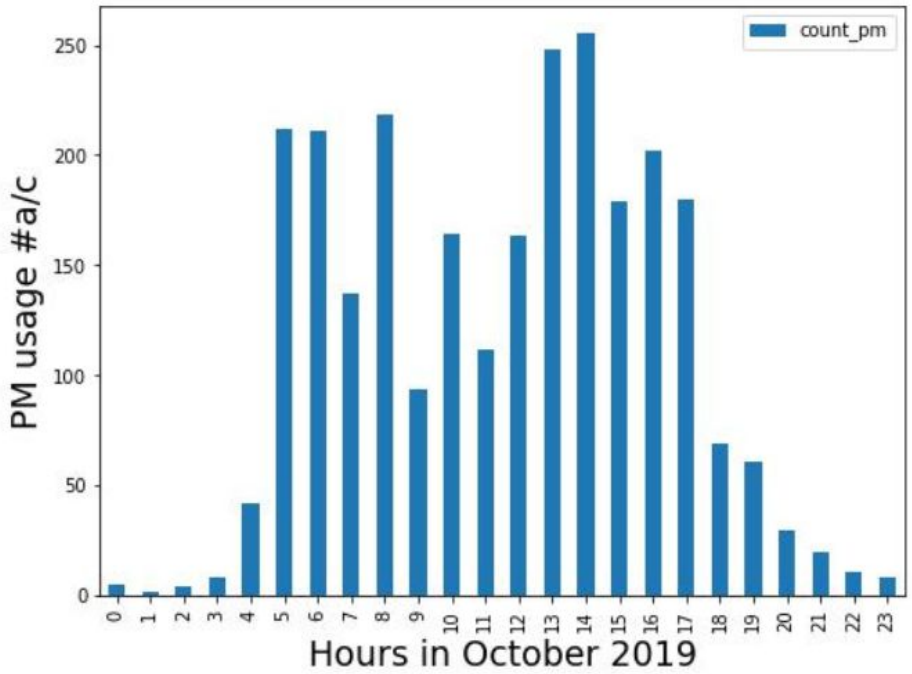


North South

PM Utilization

- Utilization per day 5-30%
- Low utilization during low-traffic hours, especially between 12 am and 6 am (local time)





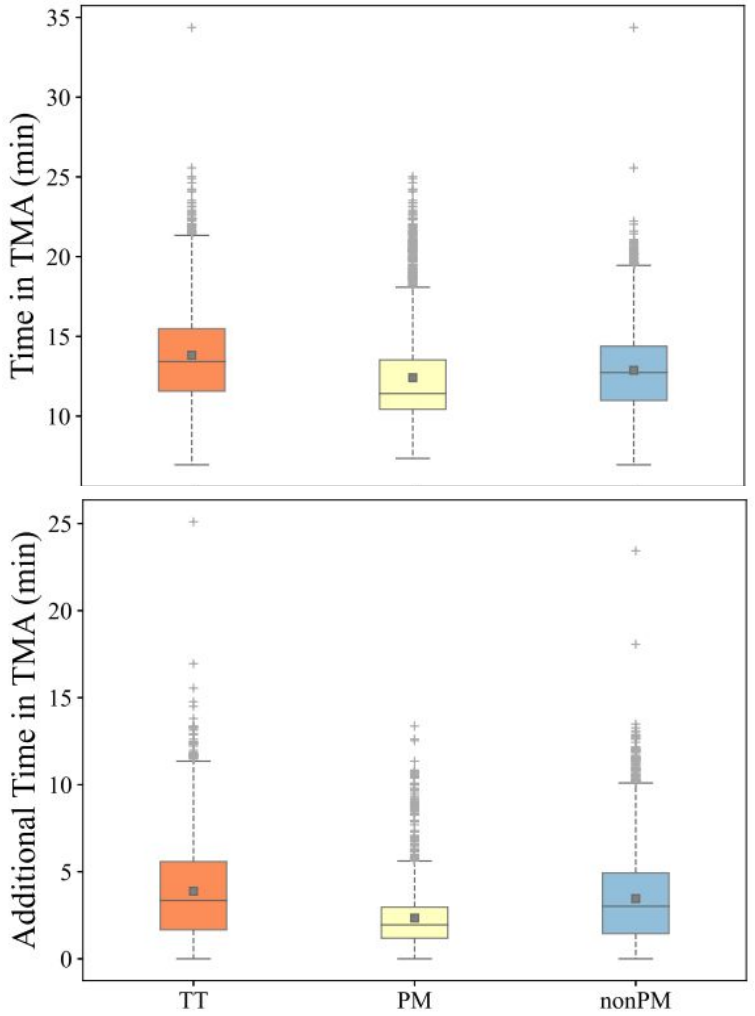
PM Arc Utilization

- Similar distribution for all PM systems
- *19 West* PM system used the most
- 82% of flights do not use PM
- Spare capacity for additional flights

PM System	No arc	1/3	2/3	Full arc
19 West	72.6%	19.5%	4.3%	3.6%
19 East	84.3%	13.5%	2.3%	0%
01 West	84.2%	12.0%	3.1%	0.7%
01 East	85.3%	11.3%	2.7%	0.7%
ALL	82%	13.4%	3.2%	1.3%

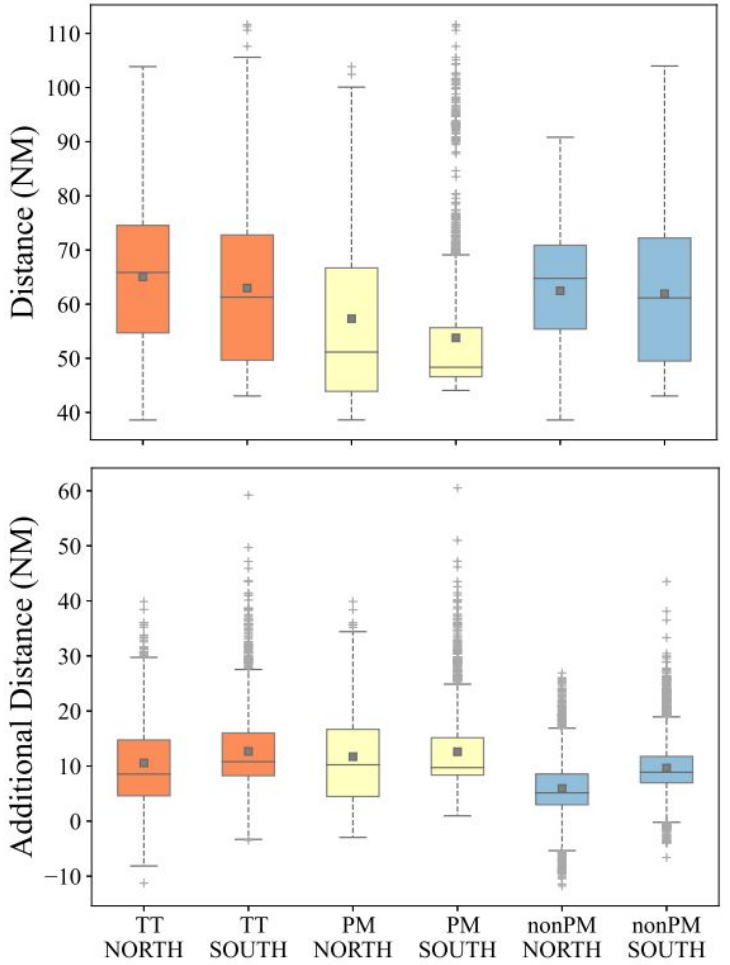
PM Performance

- Time in TMA lower for *PM* compared to *non-PM* (12.4 vs 12.9 min)
- Time in TMA difference explained by:
  - Low number of flights use PM
  - Higher percentage of flights in *non-PM* dataset land in opposite direction
- Additional Time in TMA lower for *PM* compared to *non-PM* (2.3 vs 3.5 min)



PM Performance

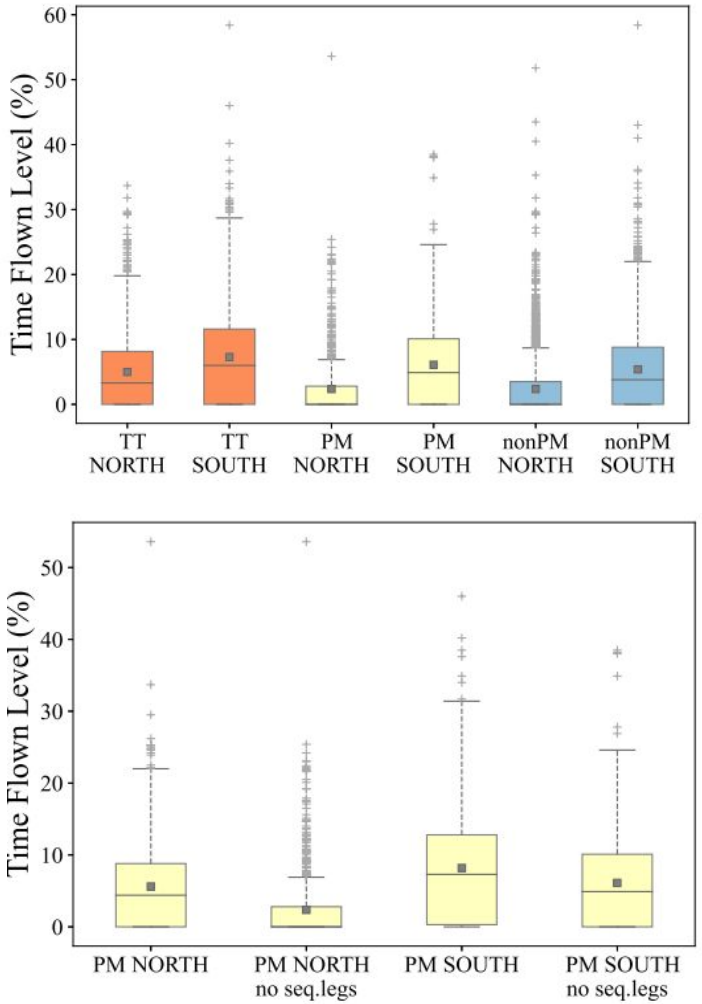
- *PM North* Additional Distance slightly lower than *PM South* (11.7 vs 12.6 NM)
- *non-PM* Additional Distance noticeably lower than *PM*
  - Explained by deviation from the reference trajectories
- *PM* Distance in TMA significantly lower than *TT* and non-*PM*
  - Flights fly shorter with PM
- *PM* and *TT* additional distance similar
  - TT dataset represents the peak-hour performance
  - May assume that PM procedures do not necessarily lead to the degradation of the horizontal performance



PM Performance

- *PM* Time Flown Level (arcs excluded) very similar to non-PM
- *PM* and *non-PM* vertical performance better than *TT*
- Vertical performance better for *North* compared to *South*

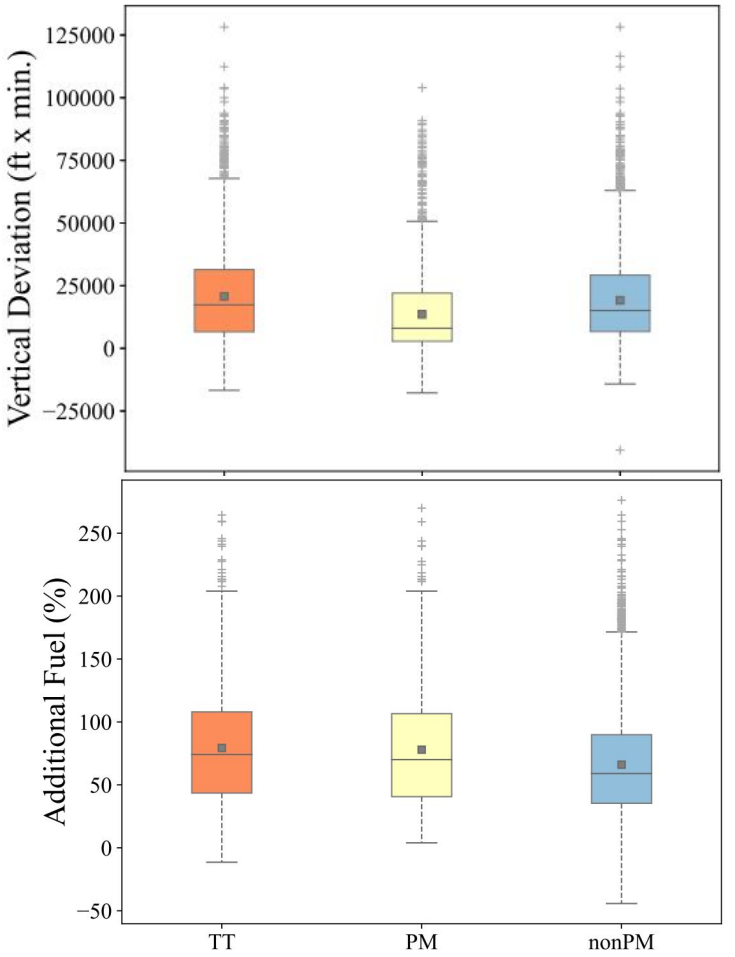
Dataset	% non-level flights
TT	31
TT_{North}	40
TT_{South}	26
PM	44
PM_{North}	66
PM_{South}	34
non-PM	49
$non\text{-}PM_{North}$	63
$non\text{-}PM_{South}$	35



PM Performance

- *PM* Vertical Deviation lower compared to *non-PM*

- *PM* Additional Fuel higher compared to *non-PM* (78% vs 66%)
    - Originated from the slightly increased Additional Distance (PM vertical efficiency better)



Conclusions and Future Work

Conclusions

- Overall performance of the Oslo Gardermoen airport is outstanding from many perspectives
- Design of its arrival procedures can be used as a good example for future PM implementation
- PM Systems not utilized to the full extent – may indicate that the airport has a spare capacity
- PM procedure adherence does not result in the significant performance degradation (confirmed by all PIs except for the additional distance and the fuel efficiency connected to it)

Future Work

- Dynamic usage of PM – how to plan the dynamic operational regimes to maximize the airport throughput

- Additional environmental performance metrics:
  - Noise
  - Emissions

Thank you.

Questions?