Open source software and crowdsourced data for operational ANS performance analysis

Reproducibility in operational ANS performance benchmarking
Acknowledgment

This paper would not have been possible without

- the discussions and lessons learnt interfacing with
  - Enrico Spinielli, PRU Data Manager
  - Participants of the international benchmarking projects
    - US – Europe: FAA and EUROCONTROL supporting the European Commission
    - Singapore – US – Europe: CAAS, FAA, and EUROCONTROL
    - Brazil – Europe: DECEA and EUROCONTROL
    - China – Europe: CAUC and EUROCONTROL
  - European operational stakeholders challenging operational ANS performance results of PRU
- Organisations celebrating their latest operational performance achievements in press releases or associated communication material
- Technically, the feasibility study builds on
  - crowd sourced data: ADSB Exchange
  - open source software: R & Rstudio, and rmarkdown and tidyverse packages
Overview

- Problem Definition
  - feasibility study → computational reproducibility
- Background
  - operational ANS Performance
  - state of open data for ANS performance analysis
  - crowd sourced data – option for ANS performance analysis
- Methodological Approach
  - conceptualising the benchmarking process as a data analytical process
- Results
- Conclusions and Next Steps
The results are clear: look at these results taken from 17 airports in 2015:

- Based on 2.2 million annual departures...
  - 102,700 Tonnes of CO₂
  - 28,700 kg of SO₂
  - 34,400 Tonnes of Fuel Burn (-7.7%)
- 238,000 ATFM Delay Minutes (-10.3%)
- 2,200,000 Taxi Minutes (-7.0%)
- 26.7 M in Fuel (-7.7%)
- 15.5 M in ATFM Delay (-9.8%)

Total savings generated across 17 CDM airports in 2015 (based only on taxi-out times and ATFM delay improvements)

Real savings achieved with the project’s demonstration flights amounted to 86 tonnes of fuel savings and a reduction of 270 tonnes of CO₂ emissions. On an annual basis, the 33 optimised flows have the potential to generate fuel savings of 3,400 tonnes, which equals more than 10,700 tonnes of CO₂ emissions according to calculations by Eurocontrol.
Reproducibility

It wasn’t me !!

Huh !?!

What ??
Reproducible Research

- **Reproducible research [and analysis]** is the idea that data analyses, and more generally, scientific claims, are published with their data and software code so that others may verify the findings and build upon them.

- The need for reproducibility is increasing dramatically as data analyses become more complex, involving larger datasets and more sophisticated computations. Reproducibility allows for people to focus on the actual content of a data analysis, rather than on superficial details reported in a written summary. In addition, reproducibility makes an analysis more useful to others because the data and code that actually conducted the analysis are available.

- Roger Penn, John Hopkins University
Related Problem

4. Access, Data Sharing and Re-use

Licensing your data

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https://www.slideshare.net/dancrane_open/planning-for-research-data-management
Conceptual Idea - Computational Reproducibility

Data
- all (“ideal”)
- some (“representative”)
- “alternative” data

Computational reproducibility.
- to share / pass all of one’s data analysis, data sets, and conclusions to someone else and have them get exactly the same results on their machine.

Feasibility Study
Can we undertake an international operational ANS performance benchmarking with “alternative” data (i.e. crowd-sourced) and open software?
→ no financial costs?
Background – Operational ANS Performance

- ICAO promotes performance-based approach
- GANP DOC9750 update → ICAO Assembly; end 2019
- 16 proposed key performance indicators
- pick-up by international community
  - Singapore
  - China
  - Brazil
  - …
<table>
<thead>
<tr>
<th>Flight phase or event</th>
<th>ID</th>
<th>Name</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-blocks (OUT)</td>
<td>KPI01</td>
<td>Departure punctuality</td>
<td>Percentage of flights departing from the gate on-time (compared to schedule) [avg. per traffic flow, per airport or per cluster of airports]</td>
</tr>
<tr>
<td></td>
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<td><strong>Descent &amp; terminal area arrival</strong></td>
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<tr>
<td>Taxi-out</td>
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<td>KPI08 Additional time in terminal airspace</td>
</tr>
<tr>
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<td>Actual terminal airspace transit time compared to an unimpeded time [avg. per airport or per cluster of airports]</td>
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<td><strong>Take-off (OFF)</strong></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>KPI09 Airport peak arrival capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>The highest number of landings an airport can accept in a one-hour time frame (also called declared arrival capacity or airport acceptance rate) [per airport]</td>
</tr>
<tr>
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<td></td>
<td></td>
<td>KPI10 Airport peak arrival throughput</td>
</tr>
<tr>
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<td></td>
<td>The 95th percentile of the hourly number of landings recorded at an airport, in the “rolling” hours sorted from the least busy hour to the busiest hour [per airport]</td>
</tr>
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<td>KPI11 Airport arrival capacity utilization</td>
</tr>
<tr>
<td></td>
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<td>Airport arrival throughput (accommodated demand) compared to arrival capacity or demand, whichever is lower [avg. per airport]</td>
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<td></td>
<td>KPI12 Airport/Terminal ATFM delay</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>ATFM delay attributed to arrival flow restrictions at a given airport and/or associated terminal airspace volume [avg. per airport or per cluster of airports]</td>
</tr>
<tr>
<td>Taxi-in</td>
<td></td>
<td></td>
<td>KPI13 Taxi-in additional time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Actual taxi-in time compared to unimpeded taxi-in time [avg. per airport or per cluster of airports]</td>
</tr>
<tr>
<td>In-blocks (IN)</td>
<td></td>
<td></td>
<td>KPI14 Arrival punctuality</td>
</tr>
<tr>
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<td></td>
<td>Percentage of flights arriving at the gate on-time (compared to schedule) [avg. per traffic flow, per airport or per cluster of airports]</td>
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<td></td>
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<td></td>
<td><strong>Per flight phase or gate-to-gate</strong></td>
</tr>
<tr>
<td></td>
<td>KPI15</td>
<td>Flight time variability</td>
<td>Distribution of the flight (phase) duration around the average value [avg. per airport or per traffic flow]</td>
</tr>
<tr>
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<td></td>
<td>KPI16 Additional fuel burn</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Additional flight time/distance converted to estimated additional fuel burn attributable to ATM [avg. per flight, airport or per airspace volume]</td>
</tr>
</tbody>
</table>
ICAO GANP KPIs – Data Requirements

- (optional) flight identification / call sign, registration
  - Grouping variable: weight turbulence category (WTC)

- Movement times
  - Actual off-block (AOBT) / in-block time (AIBT)
  - Actual take-off (ATOT) / landing time (ALDT)
  - Actual crossing time for 40 / 100 NM and entry bearing / sector (C40/100T, C40/100_BRG/SECT)

- Scheduled movement times
  - Scheduled off-block (SOBT) / in-block time (SIBT)
  - or scheduled arrival (STA) / scheduled departure time (STD)

- Declared capacity values for airport and airspace

- Airport aeronautical data (grouping variable)
  - Runway Identifier (implicitly runway direction)
  - Stand / Gate Identifier
  - Airspace Volumes

- ATFM Delay (KPI07, KPI12)
  - Calculated take-off time (CTOT)
  - Delay attribution

- Fuel Conversion / Estimate (→ KPI16)
Background – Open Data

- Open Data for ANS Performance Analysis
  - About 70% curated by government organisations
  - US: DOT, FAA-ASPM (broadly OK)
  - Europe: EUROCONTROL NM & Data Policy (restrictive / legitimate use)
  - Other parts of the world: heavily regulated
- Future Research “Open Data Policy”
  - Europe: Opt-outs (IPR & license)

data
  - all (“ideal”)  
  - some (“representative”)  
  - “alternative“ data
Aviation Enthusiasts
Never Called It “Crowd Sourcing”

It is a genuine hobby !!!

http://www.blogto.com/upload/2007/05/plane_spotting/20070511_planespotting10b.jpg

(Some) Open Data collected by Crowd Sourcing

**Operational ANS Performance Analysis**

- Aircraft fleet data
  - Registration $\rightarrow$ a/c type $\rightarrow$ WTC

- Aeronautical data
  - Airports: runways, stands/gates
  - Airspaces: volume definitions
  - Points: procedures, NAVAIDS

- Trajectory data
  - 4D positional information

- Schedule data
  - Scheduled movement times

- ATFM data

**Aircraft, airport, airline “footage” focus**

- Some States (govt. orgs) non-computer readable
  - planespotter.net
  - ourairports.com

- Openflights.org

**Aircraft tracking focus based on enthusiasts network**

- Airfleet.net

**Flight tracking websites**

- FlightRadar24
- FlightAware
- Opensky
- ADSDExchange

(*)openflights.org
Feasibility Study – Methodological Approach

- Operational ANS Performance Analysis / Benchmarking
  = collaborative data-analytical process
  = “program” (computational reproducibility)
International Benchmarking – High-Level Data-Analytical Process

- Measured / reported data
- Data collection
- Data storage
- Source data
- Data preparation
- Analytic data
- Performance metric calculation
- Metric processing
- Perf. related data
- Monitoring / benchmarking production
- Publication & dissemination
- Perf. Report
- Scope of benchmarking data processing
benchmarking process

data
- all ("ideal")
- some ("representative")
- "alternative" data

computational reproducibility
Computational Reproducibility – Open Software Toolbox for Data Analysis

- R / Rstudio
- Rmarkdown
  - Packages
- Collaboration
  - Code-sharing
  - Joint development
  - Re-usability

Review Comment: Known Unknowns
RMarkdown

Literate Programming (D. Knuth) ~ programme to communicate to humans → text combined with code, including constructed visualisations

For example, Fig. 4 shows the trajectory data coverage for Europe based on the data feed of ADSB Exchange. Geographically, this data source covers most of Europe. The major traffic flows in Europe are visible. Noteworthy are areas of no coverage, e.g. the southern part of Italy, or the intermediate segment for traffic to/from Moscow and the eastern stretch of Europe.

```r
plot_traffic, echo=FALSE
# extract map defined by bounding box
base_map <- get_map(bbox_x)

# plot map and overlay with traffic data
ggmap(base_map) +
  geom_point(data = eur_tfc, mapping = aes(x = LON, y = LAT),
             colour = "red", alpha = 0.01, size = 0.2)
```

Europe The major traffic flows in Europe are visible. Noteworthy are areas of no coverage, e.g. the southern part of

Figure 4. ADSB Exchange Data Coverage in Europe
Utility of Open Data – Benchmarking the Benchmark

- ADSB Coverage
  - Varies, in general good / sufficient, exception ground (but improving)
  - In some place: no coverage; requires further promotion / incentives

- Aircraft databases
  - High level of detail
  - Regular updates / corrections

- Aeronautical Data
  - Several sources
  - Static data: very good
  - Dependent on community usage, updates / corrections
Feasibility Study – Additional Time in Terminal Airspace (ASMA)

Grouping of flights
- Aircraft class
- Arrival runway
- ASMA sector

Actual ASMA Time

Unimpeded reference (20\textsuperscript{th} pct.)

Additional ASMA Time
Feasibility Study – Putting it all together

- Process
- Data ~ ADSBExchange
- Analysis: additional time in terminal airspace (additional ASMA)

KPI: “estimate”; landing times determined from projection of final approach position

Completeness: for chosen airports > 97%; data property → could be improved with fleet database from data

Coverage: for chosen airports > 85% ~ fleet equipage

<table>
<thead>
<tr>
<th>Study airport</th>
<th>trajectory based results for 1 month of data (July 2016)</th>
<th>completeness</th>
<th>coverage</th>
<th>add.ASMA time (40NM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGLL</td>
<td></td>
<td>98%</td>
<td>84%</td>
<td>7.2 min/arr</td>
</tr>
<tr>
<td>EHAM</td>
<td></td>
<td>97%</td>
<td>89%</td>
<td>0.90 min/arr</td>
</tr>
<tr>
<td>LFPG</td>
<td></td>
<td>98%</td>
<td>87%</td>
<td>0.29 min/arr</td>
</tr>
<tr>
<td>EDDF</td>
<td></td>
<td>97%</td>
<td>85%</td>
<td>1.32 min/arr</td>
</tr>
</tbody>
</table>
Conclusions and Next Steps

- Feasibility study aiming at
  - Establishing “computational reproducibility” for operational ANS Performance benchmarking
  - Benchmarking process validation suitable for varying data availability (full study data, representative sample & alternative data)
  - Use of open source toolbox and crowd sourced data

- Positive feedback and results
  - Process; increased collaboration through sharing of code and data → focus on analysis steps & interpretation
  - Reproducibility == re-usability → sharing of state-of-the-art with other stakeholders
  - Demonstrated numerical results (given adequate coverage) “sufficient” for the validation of results

- Next Steps
  - Choice for R/RStudio/rmarkdown ecosystem → development of operational ANS performance benchmarking package
  - Use of rmarkdown to establish dashboard & benchmarking web-page
  - Exploitation of other features (e.g. bookdown, slides)
Take-away

- own reflections
- experience
- change & novel applications

Data ubiquitous
Open data reality
TBD: svc sep

Collaborative process

Computational reproducibility

R/RStudio-ecosystem
Non-financial costs →
Learning curve
contact: rainer.koelle@eurocontrol.int
Disclaimer

- The views expressed in this presentation are the author’s own and do not reflect a EUROCONTROL or Performance Review Unit policy or position.