Arrival Management with Open Data

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***Abstract*—In light of the on-going discussion on climate change, operational efficiency of air navigation has gained a higher visibility. Efficient operations will positively influence the fuel burn by airspace users. While the development and introduction of novel aircraft airframe and propulsion technologies, the global pickup rate of sustainable aviation fuel, and benefits mechanism of market-based measures promise a positive effect over time, » reducing unnecessary contraints on airspace users can be immediately deployed. There is still a considerable benefit pool for arrival operations. This proof-of-concept paper explores the use of open data for the analysis of operational efficiency within the extended terminal airspace. To characterise the potentail benefit pool, a method to quantify the spacing deviation between successive flights is developed. This paper summarises the conceptual approach and reports on the first findings of an use-case analysis for a subset of European airports. The results show the general feasibility of the approach and help to identify requirements for the further development of operational performance measures.**

I. Introduction

Operational efficiency is a key element of addressing aviation's contribution to climate change. Emissions may increase due to the expected growth in international air traffic until lower emitting technologies and fuels and other mitigating measures are developed and deployed .. ICAO adopted at its 41st Assembly a long-term aspirational goal for international aviation **icao2022?**. In support to the Paris Agreement, the goal is to achieve net-zero carbon emissions by 2050.

Levers for fuel reduction:
* operational efficiency
* market-based measures
* sustainable aviation fuel
* new aircraft propulsion and airframes

A wider use and pick-up of sustainable aviation fuel, and new aircraft propulsion technologies or aircraft design requires further research.

Despite the introduction of an initial market-based mechanism, immediate action to curb fuel burn and CO2 emissions rests with improvements of operational efficiency. ICAO has introduced the trajectory-based operations concept, which promises operational and environmental benefits to aviation. where the flight trajectory of an aircraft is flown as close as possible to the userpreferred route, with as little disruptions as possible through collaborative decision-making mechanism. This includes reducing potential conflicts and resolving demand/capacity imbalances earlier and more efficiently. TBO can therefore bring significant operational and environmental benefits to aviation.

The contribution of this paper comprise:

- conceptualisation of sequencing separation for arrival management and development of an open data and open software based implementation of the approach; and
- use-case application of the developed approach on a subset of airports within the European

II. Trajectory-Based Operations - Arrival Management

Trajectory-based operations (TBO) are a core element of the ongoing transformation programs for air navigation services (e.g. Europe/SESAR, US/Next Gen, Japan/CARATS). On the conceptual level TBO describe a move from clearance-based operations to a highly predictable and negotiated trajectory execution between airspace users and air traffic control. The TBO concept entails the successive refinement (i.e. negotiation) between the parties starting from an inital planned trajectory through operations and the actual execution of flight. TBO builds on higher levels of information exchange between planning and flow management systems and the airborne and ground systems during flight operations. Figure 1 shows the overall timeline and evolution of a trajectory.

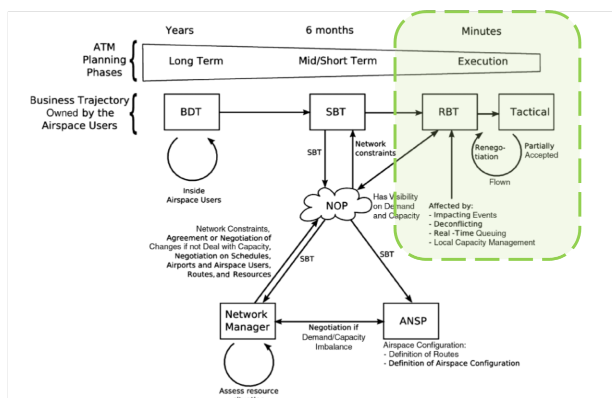

Figure 1: Trajectory-based operations - conceptual perspective

For this study we postulate the following goal of trajectory based arrival management: "… to reduce inefficiencies in the (extended) arrival phase by establishing an arrival sequence to require less costly sequencing close to the airport absorbing time/distance in more fuel efficient altitudes."

Conceptual approach := technology agnostic CONOPS may entail technological enablers and/or advanced procedures Performance objectives observed on concept functional level

[1]Performance Review Unit, EUROCONTROL. [2]Some corporation.
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III. Conceptual Approach and Data

A. Research Approach

This paper follows an exploratory research process (c.f. Figure 2). We frame the work as a operational performance analytical problem.

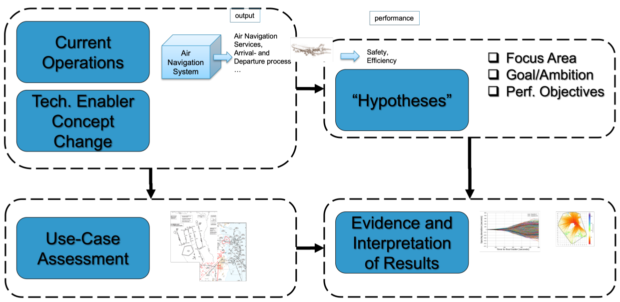

Figure 2: Exploratory research approach

B. Approach

data preparation

- trajectory data - Opensky Network, weekly downloads
- airport information - Openstreet Map

data downloaded & script development, data cleaning

1) Trajectory Flight Phase Segmentation & Milestone: Different approaches exists to detect and describe aircraft flight phases, e.g. recent machine learning algorithm [1]. This paper implements a heuristic approach with a focus on the detection of arrival traffic at the study airports. Figure Figure 3 shows the detected arrival flights for a single day.

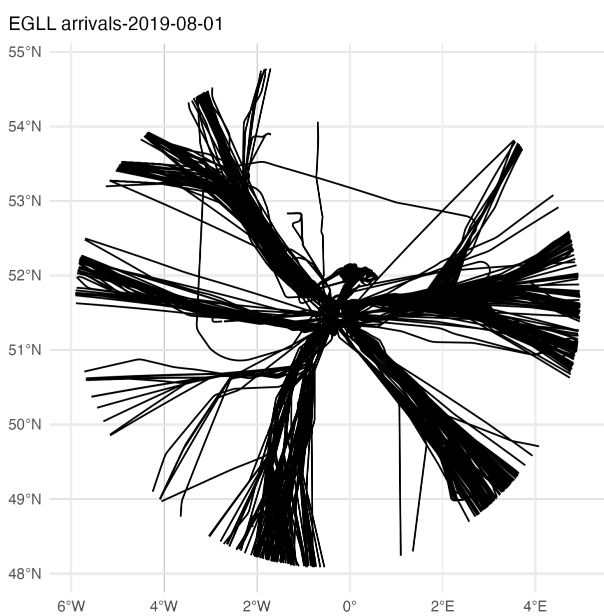

Figure 3: Arrivals at London Heathrow (EGLL) on sample day

2) Landing Runway Identification: The identification of the landing direction is based on a simple geospatial heuristic. Conceptually, aircraft are aligned with the runway (centerline) before landing. An aircraft is assigned to a landing runway based on the closeness of its pre-landing positions to the extended runway centerline.

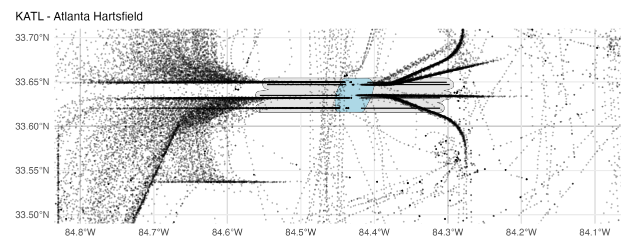

Figure 4: Arrivals at Atlanta Hartsfiled (KATL) on sample day

C. Generalisation of additional time in terminal airspace

The additional time in terminal airspace (c.f. ICAO KPI08, EUROCONTROL Performance Review System & European Single European Sky Performance Scheme) is typically expressed as the difference between the observed travel time of a flight entering the terminal area (e.g. 40NM or 100NM from the aerodrome reference point) and a respective reference time. The latter is defined as the travel time in non-congested situations. For practical reasons, the reference (or uncongested) travel times are determined based on a historical data analysis and sub-sampling the population of arrival flights per entry sector/fix, aircraft wake turbulence category and propulsion type (as a proxy of approach speed), and landing runway.

This notion of additional time can be generalised for every subset of points within the arrival airspace. On the basis of historic data, the travel time between such a set of points can be determined and compared to the flight time of an uncongested trajectory.

For practical reasons, this paper discretises the arrival airspace into cells. In particular, we are using hexogonal cells and the H3-indexing system [2]. Uber originally developed the Hexagonal Hierarchical Geospatial Indexing System (H3) as a grid system for supporting the optimisation of ride planning (and associated pricing and dispatch) and for visualisation purposes. H3 is available as an open-source library written in C and with bindings in several languages. We use hexagon-cells of resolution 8 with an average edge length of 0.5314 km.

D. Arrival Sequencing - Spacing Deviation

Let us consider a pair of consecutive landing aircraft denoted leader and trailer, with s being their temporal spacing (inter-arrival time). From an operational perspective, highly efficient operations will maximise the utilisation of the available

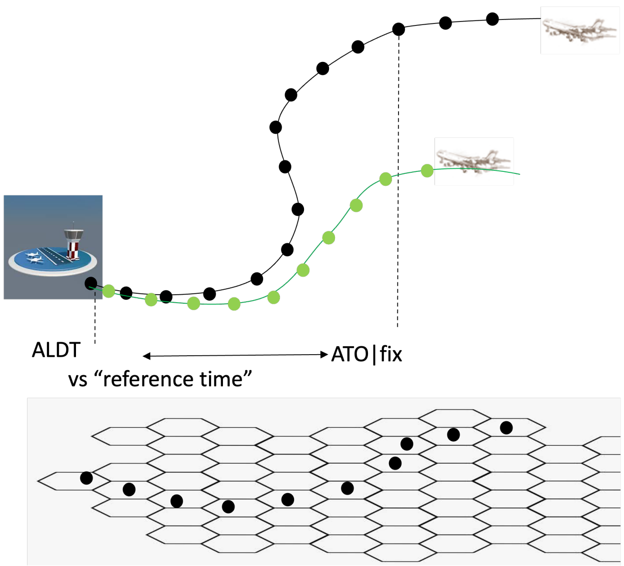

Figure 5: Spacing deviation concept

runway (system) capacity. Accordingly, we can assume that during peak times the temporal spacing at landing s accounts for the operational concept applied at the airport, and only comprises a minimal spacing error. Potential error sources include additional safety margins applied by the air traffic controller (or aircrew when landing under visual flight rules), variations of the arrival spacing due to reduction of airspeed during the flare. We consider the observed temporal spacing s_{ij} as a lower bound for safe operations.

Using the constant time delay principle, the spacing deviation (or spacing error) at time t considers the current position of trailer at time t, and the past position of leader at time $t - s$. Based on our approach, the spacing deviation is defined as the temporal difference between the respective reference times for the position of the leader and trailer:

$$spacing\ deviation(t) = ref\_time(trailer_{(t)}) - ref\_time(leader_{(t-s)}) \quad (1)$$

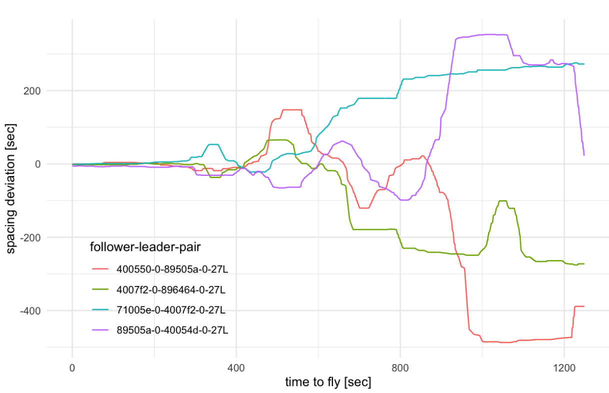

Figure 6: Example timeline of spacing deviations between interacting arrivals

Equation 1 does something.

IV. Case Study - Results

A. Data Sampling

At the time of writing no global open flight table exists. For this study, we validated the sample with reference data available to the Performance Review Unit. Under the EUROCONTROL Performance Review System, airport operators report movement data on a monthly basis [3].

V. Conclusions

Ambitious political targets for 2050 have been formulated to curb the contribution of air transportation to climate change and work towards climate neutrality. Policy and industry action revolve around a variety of measures. Within this context - and in light of the required lead time for a global pickup on sustainable aviation fuels, the introduction of novel airframe designs, or propulsion technology - increasing the operational efficiency is a declared now-term measure. There is a substantial benefit pool for the wider arrival phase covering the airspace within 200NM of the destination airport. Trajectory-based operations promise higher levels of predictability and reduced inefficiencies. The benefits of reducing spacing and flow synchronisation measures in the terminal airspace are therefore dependent on the capability of balancing out operational variations from delivery of the aircraft to the wider arrival airspace.

This proof-of-concept paper aims at operationalising a performance measure to characterise arrival management techniques, but also provide a basis to discuss the handover from the enroute phase to the wider arrival airspace.

This paper aimed at exploring a data-driven approach to measuring operational efficiency during the arrival phase. In light of the ongoing discussions about the climate impact of air transportation and the contr Arrival management based on open data.

The proposed approach builds on the generalisation of a well-understood key performance metric for the wider arrival airspace. It follows a data-driven approach that is independent of detailed local context modelling. For example, local airspace restrictions or procedures are embedded in the temporal-spatial framework. Measuring the spacing deviation between interacting arrival flights provides a basis for the analysis of approach concepts that can help to streamline the arrival sequencing and contribute to the further reduction of unnecessary fuel burn and emissions.

This proof-of-concept addresses the aspect of transparency by making use of openly available air transport trajectory data and open (analytical) software. The approach is readily transferrable to other regions.

The goal of this work was the initial development of an operational performance measure. Further validation is required at a larger set of European (and global airports). This will allow for the refinement of the parameterization of the approach. It is planned to roll-out the approach under the umbrella of the EUROCONTROL Performance Review System. This will provide European stakeholders with a means to address enhancement of arrival operations, and may help to build a catalogue of arrival management techniques that support higher levels of efficiency.

This paper demonstrated feasibility of the approach. While the proposed performance monitoring of the spacing deviation envelope provides a basis for identifying inefficiencies during the arrival flow, there is a need to account also for factors driving and impacting the observed performance. The temporal assessment of spacing deviation

- weather, wind
- runway system configuration, adjacent aerodromes/level capping

On the algorithmic level, future work should address the impact of the geospatial dimensions of cells and the method of their definition.

This paper applied a observational approach to determining the reference times per cell. This will pose challenges for longer time horizons as the continual update and processing of arrival trajectories would require substantial resources. A possibility is the use of data structures to support the continual online accumulation of statistics without the need to store the complete historic dataset or processed artefacts.

The results demonstrate the general feasibility of the approach. The proposed approach offers a measure to start the dialogue between operational planners and stakeholders to identify benefit pools during the arrival phase.

Reproducibility

This paper has been built with the R/RStudio ecosystem. The draft manuscript and its supporting data preparatory steps are archived at https://github.com/rainer-rq-koelle/paper-2023-ICNS.

Acknowledgment and Disclaimer

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The views expressed are the authors' own and do not represent a policy or position of DECEA or EUROCONTROL
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