Building Back Better – Democratization of Performance Monitoring with Open Data

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***Abstract*—The COVID-19 pandemic accelerated the use, sharing, and distribution of data on a global basis. Higher levels of transparency were achieved with continual updates of pandemic related information. The air transportation sector – while by definition an information rich industry – is a notable exception. While different organizations offered aggregated data on air traffic developments on national or airport level, complementary data on air traffic movements for further analysis are not available publicly. This creates a deadlock between addressing the societal needs of monitoring how aviation recovers from the COVID-19 pandemic and addresses the aspirational environmental goals. This paper investigates the feasibility of utilizing open data for the operational performance monitoring at airports. The exploratory work focusses on a subset of the indicators proposed under ICAO's Global Air Navigation Plan used to assess the operational performance in the arrival phase. A novel approach to characterize and assess the arrival flow management and level of traffic synchronization is presented. This will allow to evaluate on-going air traffic recovery and identify operational bottlenecks. The study is performed as a use-case analysis for three major European airports by comparing the observed performance in the months of March and May for the successive years 2019, 2020, and 2021. The results demonstrate the general feasibility and utility of open data for operational performance monitoring. The classical performance measure for the arrival flow are determined based on the open trajectory data. A geospatial-temporal evaluation support the tracking of traffic synchronisation effort. A higher level of transparency therefore available to the interested public, policy decision-makers and strategic planners with direct feedback on the recovery and actual operational performance. The suitability of the traffic synchronization measure and its parameterization requires further validation across a wider set of airports and will be iteratively refined.**

Keywords—operational performance, open data, arrival management, traffic synchronisation

I. Introduction

The COVID19 pandemic shifted the focus and attention of political decision-makers and strategic planers over the past year. The unprecedented decline of regional and international air traffic poses challenges in terms of funding of the air transportation system in general and planned air traffic management modernization. While it is unclear how today's travel constraints and the vaccine roll-out will play out, both airspace users and air traffic service providers are committed to "build back better." This will include a higher emphasis on operational excellence. Higher levels of operational efficiency are considered to be enablers for reduced queueing, both in the airspace and on the ground, and lower associated fuel burn and emissions. It will be essential to ensure that with increasing traffic levels, inefficiencies are immediately tracked and remedied.

Air transportation services are by definition an information rich environment. However, today, the access and availability of open data for the monitoring and validation of air transport /air navigation system performance or related published results of studies and research exercises is limited [1][2]. Within this context, crowd collected open data gains a higher momentum and visibility. Opensky Network became a key resource for open air transport data during the COVID-19 pandemic [3]. Opensky Network provides a global flight-by-flight record of observed tracks on a monthly basis for interested researchers or practitioners [4]. For detailed studies, the associated trajectory data can be accessed via the Network resources. There is an active community establishing tools for the extraction and processing of the data. Demonstrating the feasibility and utility of using an existing open data source to assess the current air transportation system performance, and trace the development of the performance levels with returning traffic demand is vital.

The paper follows a data-driven exploratory approach. Based on the operational performance indicators promoted by ICAO, a performance monitoring toolchain is developed building on the open air transport data. The public availability of the data in a near real-time set-up ensures that independent validation of observed operational performance is available to policy makers, strategic planners, practitioners, and researchers. A novel traffic synchronization oriented performance metric is developed. The metric aims to isolate operational and airspace related dimensions or inefficiencies. The approach will be presented as use-case analysis of three European airports that show significant differences in traffic patterns and approach concepts. The analysis of the arrival management techniques will support the evaluation of the achieved performance levels in terms of ground-based or airspace holding/queueing and delay absorption.

II. Reboot: from COVID-19 to Operational Efficiency

On March 11, 2020, the World Health Organization declared the novel coronavirus (COVID19) outbreak a global pandemic. Initial cases were reported in Wuhan, China, in December 2019, and spread rapidly around the world causing severe acute respiratory syndromes. Communicable disease control resulted in massive restrictions on international and regional air traffic and passenger travel. The unprecedented decline in air traffic demand resulted in severe financial strains on the air transport industry as revenue streams were disrupted. For example:

- Airlines reduced air transport services) to a minimum resulting in the grounding of substantial portions of the aircraft fleet due to the lack of passenger demand based on social distancing requirements, travel restrictions and bans [5][6];
- Airports had to reduce their operations, including closing down terminals and runways. The latter often to offer parking space to the grounded fleet [6][7].
- Air navigation service providers trimmed down staffing and operations in response to the decline in traffic
- Support industry (aircraft manufacturers, maintenance and servicing) had to reduce to minimum staffing or shut-down their production [9].

The financial support or lack thereof for airlines and airports has been widely covered in the media. The COVID-19 pandemic triggered the research interest by different disciplines or research directions. Sun et al. [10] identified a "*paper tsunami*" attempting to group related research in broad categories/application domains: (i) analysis of global air transportation system, including aviation as a transmission means, (ii) passenger facilitation and flight experience, (iii) long-term impacts regarding system financing, passenger demand, and associated challenges.

The study cuts transversal through the aforementioned domains. A variety of studies showed the interplay or consequences of the travel constraints, however, a link with the observed operational performance was not made. This is of particular interest as the crisis provides a "*[...] chance for rethinking global transportation and consider the opportunity of a reboot*." [10] The inherent change in terms of air transport services and operational performance provides a bridge to the pre-pandemic priorities.

During 2018 and 2019 the focus was on solving the en-route crisis in Europe. This also sparked discussions about the environmental footprint of aviation and its impact on green-house gas emissions (e.g. CO_2, NO_x). Research showed that aviation is the fastest growing activity in terms of green-house gases. Dependent on the scope, the numbers differ and aviation accounts for approximately 2 to 3% of the current total global annual CO_2 emissions [11] and under 5% of the man-made global warming effects [12]. As a result of the COVID-19 pandemic and the decline in air traffic, CO2 emissions from air transportation reduced significantly in 2020. In [13], PRU referenced a reduction of more than 50% compared to 2019 levels. This observation puts a strong emphasis for operational excellence throughout the anticipated COVID-19 recovery phase. Other measures such as new aircraft technology (e.g. engine generation, propulsion techniques), increased global use of sustainable aviation fuel, and accompanying economic incentives (e.g. fees, taxation) will see a longer implementation time-frame.

With the higher visibility of Greta Thunberg's "*Flygskam*" (flight shame) [14], national and international regulatory bodies started initiating policies and incentivized action by aviation stakeholders. These policies are typically referred to as the "Green Deal" and comprise hooks addressing the environmental. For example, within the European context the greening of the transport sector is a declared goal with an ambitious target. The – overall – transport industry accounts for approximately 25-30% of the total greenhouse gas emissions and evidently requires action. Back in 2011, the European Union published a whitepaper with a view to establish an efficient and environmentally sustainable transport system [15]. The declared goal was to reduce the dependence on fossil fuels and cut the CO_2 emissions by 60% until 2050. Next to measures for other transport modes, the whitepaper aimed at achieving an utilisation rate of 40% of sustainable aviation fuel (i.e. low carbon emissions).

Throughout 2020 and in early 2021, the political agenda emphasized the "building back better" paradigm. Discussions on linking the financial support for air transportation stakeholders culminated in requirements such as reducing the frequency or omitting completely short-range connection or where alternate high-speed train connectivity exists. For example, the French and Dutch government comes with heavy strings attached (cutting CO_2 emissions per passenger kilometre by 50% compared to 2005 by no later than 2030, cancellation of short-haul connections where rail connections exist) [16]. In other cases older and potentially higher emitting aircraft/engines should be removed from the fleet. Further flagship initiatives for the transport sector in general and aviation in particular were identified with a clear link between energy reduction and decarbonisation (e.g. [15] totalling about 1.4 trillion EUR).

While in early 2021, the financial fallout of the impact of COVID-19 on air transportation is still in the making, the political call for action is non-reversible [17]. This poses a challenge for the air transportation sector, as resources needed to stabilise operations will depend on pickup rate and implementation of measures to address the overarching emission reduction goals. Within that context, the necessity for operational efficiency is a key driver for the foreseeable future.

III. Material and Methods

A. Operational Performance Monitoring

ICAO promotes a performance-based approach to encourage the promotion of best practices, excellence in operations, and an efficient and effective use of resources [18]. To support strategic and organizational decision-making, performance monitoring shall be data-driven and based on scientific practices. These principles are encoded in ICAO Performance Framework under the Global Air Navigation Plan (GANP). The most recent edition of the GANP comprises a set of operational key performance indicators (KPIs).

Within the European context, EUROCONTROL established an organization-wide performance review system and a performance review commission (PRC). The latter reviews annually the performance of the European air navigation system through its annual performance review report (PRR, [13]). The European Commission adopted the principles of a performance-based approach as part of its Single European Sky initiative. The associated performance scheme is now applied in its third reference period (2020 – 2024). The performance scheme builds on measures established under the EUROCONTROL performance review system.

Under the umbrella of the GANP, ICAO established a study group that is tasked to further harmonize the different efforts. Table I summarizes the current proposed KPIs. The KPIs 01-16 were complemented by 3 additional KPIs (17-19) with the recent GANP update (6th edition, 2019):

TABLE I. ICAO GANP KPIs

KPI Overview			
KPI ID	***KPI Title***	***Scope***	***Data Type***
KPI01	Departure Punctuality	Airport	Movement
KPI02	Taxi-Out Additional Time	Airport	Movement
KPI03	ATFM slot adherence	Airport/En-route	Flow management (en-route)
KPI04	Filed flight plan en-route extension	En-route	Flight plan trajectory
KPI05	Actual en-route extension	En-route	Actual trajectory
KPI06	En-route airspace capacity	En-route	En-route capacity declaration
KPI07	En-route ATFM delay	En-route	Flow management
KPI08	Additional time in terminal airspace	Airport	Movement and trajectory crossing positions
KPI09	Airport peak capacity	Airport	Airport capacity declaration
PI10	Airport peak throughput	Airport	Movement
KPI11	Airport throughput efficiency	Airport	Movement and (airport) capacity declaration
KPI12	Airport/terminal ATFM delay	Airport	Flow management (airport/terminal)
KPI13	Taxi-in additional time	Airport	Movement
KPI14	Arrival punctuality	Airport	Movement
KPI15	Flight time variability	Flight Phases	Movement
KPI16	Additional fuel burn	Flight Phases	Movement, trajectory, and fuel born/CO2
KPI17	Level-off during climb	Airport (200NM)	Trajectory
KPI18	Level capping during cruise	En-route	Trajectory
KPI19	Level-off during descent	Airport (200NM)	Trajectory

B. *Measuring Arrival Flow*

The overarching objective of air navigation is the “safe, efficient, and orderly flow of air traffic” [19]. Airport operations on and within the vicinity of the airport pose a challenge. Arrival management aims at reducing the sequencing measures by air traffic controllers and reducing related procedural or tactical extension of the path. A reduction of such traffic sequencing operations leads to lower fuel consumption in unfavourable altitudes within the proximity of an aerodrome. Reduced fuel burn directly reduces emissions and contributes to lower noise. Streamlines arrival flows ensure further an increased usage of the available runway system capacity and airport operations.

With Table I there exists a good set of airport oriented operational performance measures. For historical reasons, these indicators are based on movement milestones, i.e. movement events and associated timestamps. The key indicator for the assessment of the efficiency of the arrival flow is KPI08 additional time in terminal airspace. With the increasing interest in fuel efficiency, the update of the GANP KPIs included the inclusion of the vertical flight efficiency, i.e. level-off during the descent phase.

- The additional time is determined comparing the actual arrival travel time with an associated reference time. The arrival airspace is approximated by a cylinder of 40 or respectively 100NM. The reference time is determined for the subset of flights showing similar arrival characteristics in terms of arrival entry fix/area, landing runway, and aircraft weight turbulence category.
- Vertical flight efficiency is based on determining level segments during the last 200NM. For this part of the flight, the level segments of a trajectory are determined. Level off is defined as maintaining the altitude or not changing it within a certain vertical limits within a 30 second time span.

With a view to developing the future concept of operations, but also adhering to reduce fuel burn due to procedural aspects, there is an interest to reduce holding or path extension in less favourable, i.e. lower, altitudes and enable aircraft to descend smoothly and continuously. The absorption of such traffic synchronisation measures needs to be balanced against the loss of predictability and higher levels of uncertainty. Holding aircraft in close proximity to the arrival airport supports to optimise the runway occupancy in terms of establishing a continual sequence and keeping the “pressure” on the runway (threshold). This increases the flexibility of air traffic controllers to react to changes and fine-tune the arrival sequence. Next to classical vectoring, this benefit can also be achieved with stack holdings close to the airport or point-merge procedures. The absorption of additional time in the extended airspace reduces the flexibility while benefitting a more fuel efficient flight.

Next to the operational questions, the ICAO GANP KPIs are historically predominantly based on timestamps. This is related to the data processing capabilities in the past. There is a discussion on-going – in particular with respect to the arrival flow indicators – whether the assessment of performance shall be based on distance rather than time. The latter may be more relevant for airspace users, as time directly links to engine time and thus fuel burn. From an air navigation perspective, flown distance may be the more appropriate way of measuring performance within the further aerodrome context, as the time measurement may be influenced by weather phenomena (e.g. strong winds). It will be vital to study this time-distance relationship in future updates. Within this exploratory study, we utilise both dimensions benefitting from the accessibility of flight trajectories.

C. Study Data

This study builds on data collected by Opensky Network (https://opensky-network.org/). The Opensky Network community operates a sensor network of more than 3000 receivers across the globe [3]. The crowdsourced data collected by Opensky Network is available to research, non-profit and government organisations. To support the on-going efforts with a view to COVID-19, the network provides a preprocessed data set of flight data. This data can be downloaded from CERN's Zenodo repository: https://doi.org/10.5281/zenodo.4893103 [4]. It provides global flight data covering January 2019 through today. This data set is used in [22] and supports the analysis of air traffic development pre-COVID-19, during COVID, and the current recovery. Fig. 1 shows the total number of collected daily flights for the period 1. January 2019 through 30. June 2021. The peak daily number of tracked flights ranges just under 104000. The decline of traffic during the COVID-19 period is clearly identifiable. Opensky Network coverage varies across the world. As we are focussed on the European context, the coverage is highly sufficient.

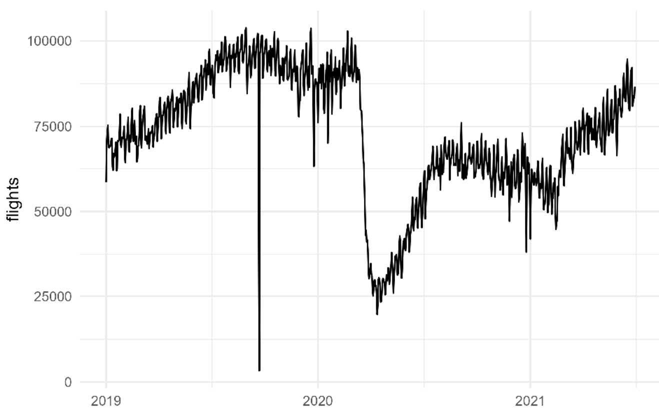

Fig. 1. Number of global daily flights tracked by Opensky-Network.

For this study the lower level trajectory data is used. The data was downloaded from Opensky Network making use of the *traffic library* [21]. The library supports the targeted extraction of trajectories landing and departing from the chosen airports. The respective trajectory data for March and May 2019, 2020, and 2021 was downloaded.

The validity of the data was checked by comparing the extracted data with the airport operator flow (APDF) of EUROCONTROL's Performance Review Unit. The APDF data is collected monthly in accordance with the associated data specification. The data is used for the regular performance monitoring under the EUROCONTROL Performance Review System and the European Sky Performance Scheme. As can be derived from Fig. 2 the actual tracked flights in Opensky Network cover a significant share of the traffic at the study airports. The offset observed in Amsterdam (EHAM) is driven by the reasonable share of feeder flights and thus aircraft not requiring immediate equipage. While there is a portion of smaller aeroplanes also not tracked by Opensky Network at EHAM, the offset at Zurich (LSZH) is explained by these flights. While the offsets may influence the measures presented for 2019, the fit of the data set for 2020 and the 2021 is given with the majority of operations performed by commercial operators with the younger generation of their fleet.

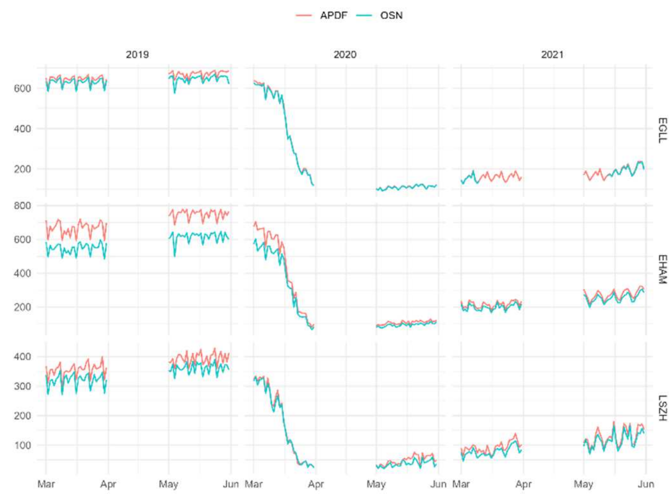

Fig. 2. Comparison of APDF and Opensky Network timeline for arrivals at the study airports.

D. Analytical Approach

The access to historical ADS-B data was provided by Opensky Network (OSN) [20]. OSN is a collaborative crowdsourcing platform collecting ADS-B/Mode S messages shared by aviation enthusiasts around the world. OSN provides free access to its data for research purposes. For this study we collected trajectories for movements at 3 European airports, namely London Heathrow (IATA: LHR, ICAO: EGLL), Amsterdam Schiphol (IATA: AMS, ICAO: EHAM) and Zurich Airport (IATA: ZRH, ICAO: LSZH), for the months of March and May of 2019, 2020 and 2021.

For the collection of ADS-B data and the extraction of arrival runway (RWY) and landing time, we used the traffic Python library [21]. The traffic library converts the data from OSN to structures wrapping pandas data frames. For the processing of these data frames it provides specialised semantics for aircraft trajectories (e.g., intersection, re-sampling or filtering). Given an ICAO 24-bit identifier, it iterates over trajectories based on contiguous timestamps of data reports.

Fig. 3 shows the code to download one day of traffic departures from and arrivals to EGLL. It keeps only portions within 200 NM from the airport and resamples each trajectory at 1 second before storing in a file.

```python
from traffic.data import opensky
from traffic.data import airports
import pyarrow.feather as feather
import os

airport = 'EGLL'
date = '2021-04-04'

prj_dir, _ = os.path.split(os.path.realpath(__file__))
adsb_file = f'{prj_dir}/{airport}_{date}_history.feather'

# retrieve from OSN
t = opensky.history(date, airport=airport)
t_prep = (
    t.resample("1s")
    # keep only flight portions within 200 NM
    .distance(airports[airport])
    .query("distance <= 200")
    .eval(desc="preprocessing", max_workers=4)
)

feather.write_feather(t_prep.data, adsb_file)
```

Fig. 3. Example of extracting trajectory data from Opensky Network using the Python traffic library

To validate the runway association module developed for this study, we also extracted the landing runway and landing time with the help of the traffic library (c.f. Fig. 4). The traffic library implementation considers only arrival trajectories, i.e. landing_at_{airport}, and extract portions aligned with the different runways, i.e. aligned_on_{airport}. The runway association is based on meeting this condition the maximum number of times, i.e. ILS_max. Our goal was to reproduce the operational performance monitoring. The cut-off by the traffic library assigns the timestamp of the last-best position report. Our analysis showed that dependent on the coverage of the final segment better estimates for the landing time could be derived when interpolating the trajectory to the landing runway. Our implementation is based on an average observed groundspeed on final and determines the time over the threshold. We add 5 seconds to account for the average distance of 1000ft between the runway threshold and ground-point-of-intercept.

```python
from traffic.core import Traffic
import os
import pandas as pd

airport = 'EGLL'
date = '2021-04-04'

prj_dir, _ = os.path.split(os.path.realpath(__file__))
adsb_file = f'{prj_dir}/{airport}_{date}_history.feather'

# read, process the data and store results
t = Traffic(pd.read_feather(adsb_file))
arrs = (t.landing_at(airport)
    .next(f'aligned_on_{airport}')
    .summary(['callsign', 'stop', 'ILS_max'])
    .to_csv(f"{prj_dir}/{airport}_{date}_arrivals.csv")
)
```

Fig. 4. Example of extracting landing data from Opensky Network using the Python traffic library

The previous steps resulted in an analytical and labelled data set of arrival trajectories for the study airports and chosen months. The next step included:

- Validation of the determined landing times: this was done on the basis of comparing the trajectory based landing time estimation (c.f. above threshold time & 1000ft GPI allowance) with the landing times reported by the APDF reporting entities.
- To replicate the additional time in terminal airspace KPI, the trajectory data was labelled with aircraft type and associated WTC. For this we used the Opensky Network aircraft databased that is build on the observed traffic.
  The conversion of the additional time metric in distance is based on the determining the cumulative path flown for the respective aircraft.
- For the development of the synchronisation measure, reference times/distances for a geographic position needed to be generated. We deviated from previous work applying a LAT/LON generated mesh gridding approach [23]. We build our toolchain on the basis of Uber's h3 hexagonal hierarchical geospatial index. We applied a resolution of 8. This resolution provide for a hexagonal edge length of approx.. 0.461 km similar to [23]. However, the indexing system allows to readily identify neighbours, or encompassing (higher order) or subsetting (lower order) fields to augment the estimation of statistical properties of adjacent hexagons. This behaviour will be relevant for future research and fine-tuning of the algorithm.

IV. Results and Discussion

A. *Overall Traffic / Demand Pattern*

From Fig. 1 follows that with March and May 2021 traffic in Europe showed a mild but discernible increase in air traffic. The comparison of the months highlights the decline in air traffic in 2020 by about 80% when compared to 2019 traffic levels. Contrasting March and May 2021 with 2020 gives the indication of a starting recovery. This is in line with the relaxation of travel constraints across the majority of European states in view of the summer holiday season.

The chosen 3 airports are part of the major hubs in Europe and typically also observe a good share of international (non-European) air traffic. Accordingly, the traffic recovery is primarily driven by the regional (pan-European) traffic. With wider global changes, it is anticipated that the growth rate of traffic will increase at these airports.

From a conceptual perspective it follows that traffic in March and May 2020 and 2021 does not suffer from the operational pressure and level of congestion observed in 2019. Arguably, it can be expected that the operational efficiency should be higher in both years than in 2019 and pre-COVID-19 crisis traffic levels.

B. *Classical Performance Measure*

Table II summarises the monthly results for the study airports. Validation with the official monitoring and reporting via the APDF process showed that the application of the ICAO GANP algorithm revealed the same trends for all airports. The ICAO algorithm uses a 20th percentile approach over the observed population. On average the determined additional time value ranges about 1-0.7 minutes per flight lower than the APDF reporting for EGLL. At EHAM the determined additional time ranges higher compared to the PRU reporting. This suggests, given the tracking of most of the traffic at EHAM in 2020 and 2021, that the official reference time is subject to a scale effect benefitting the overall performance measurement (i.e. the average additional time is determined based on the observed traffic, higher traffic levels will result in a lower additional time). The obtained results for Zurich (LSZH) range above the APDF reporting values by about half a minute. Given the lower traffic at LSZH compared to the other 2 airports, the scale effect seems not to benefit the actual metric calculation. An interesting observation is that a general sequencing effect is inherent in the recovering operations at all 3 airports. The associated additional time accounts for approximately 1 minute per flight. It will be interesting to see whether this "base" level increases with more traffic returning.

TABLE II. ADDITIONAL TIME BASED ON TRAJECTORY

KPI Overview			
Airport	***Year***	***Month***	***Avg. Add. Time (minute/flight)***
EGLL	2019	March	6.61
EGLL	2019	May	5.25
EGLL	2020	March	4.62
EGLL	2020	May	-0.13
EGLL	2021	March	1.06
EGLL	2021	May	0.96
EHAM	2019	March	3.28
EHAM	2019	May	2.64
EHAM	2020	March	0.29
EHAM	2020	May	1.02
EHAM	2021	March	1.16
EHAM	2021	May	1.03
LSZH	2019	March	3.92
LSZH	2019	May	3.81
LSZH	2020	March	2.07
LSZH	2020	May	0.52
LSZH	2021	March	0.95
LSZH	2021	May	0.91

C. *Sequencing – Arrival Management*

The utilization of open data to assess operational efficiency in the arrival phase is a driver of this work. Fig. 5 depicts the arrival trajectory of flight SIA322 at London Heathrow (EGLL) on 1. March 2019. The figure shows how the flight was prolonged by a continued North-westerly heading taking the flight to the north of the airport before turning it towards the arrival holding stack area. The heatmap coloring (blue ~ cold ~ little/no additional sequencing, red ~ hot ~ substantial sequencing) shows the flight entering a trombone pattern to absorb further flight time before being turned onto a baseleg to intercept the final approach. With joining the baseleg, the flight follows an efficient path to the landing runway.

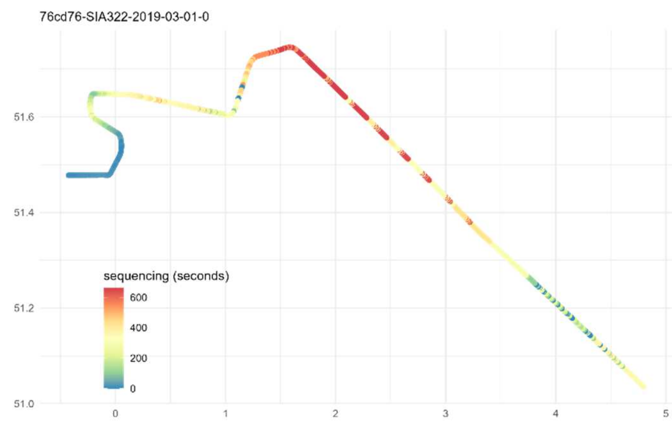

Fig. 5. Example of the sequencing effort along the flown trajectory.

Based on Fig. 5 we can now determine in a temporal-spatial manner the synchronisation effort per flight. Fig. 6 depicts the temporal profile of another arrival flight. The alignment on the ILS with the landing runway offers a lower bound for estimating the procedural "efficient" flight to the runway. The profile also shows the additional holding for a good part of the arrival (center part of Fig. 6). Following this sequencing activity, the aircraft enjoyed a direct towards the final approach segment. The spike before the alignment with the ILS and final approach can be linked to potential sequence vectoring of the flight.

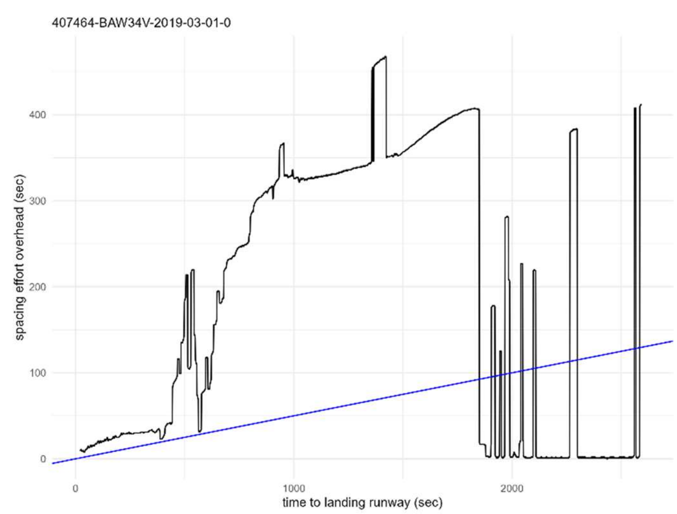

Fig. 6. Proposed approach to evaluate synchronisation effort per flight.

The exact placement of the lower bound is subject to further research and validation. As a general observation this work showed that today, the majority of sequencing action is still executed within the last 30 minutes of an arriving flight and a strong trend towards the landing airport. This pattern has not changed during the COVID-19 period. Based on this exploratory study, it appears that a metric can be constructed based on the geospatial dimensions. By integrating the time or flown distance with respect to a defined lower bound a characteristic value per flight can be obtained. This also provides a basis for the comparison of different arrival techniques or sequencing practices at different airports. The latter might inform strategic planners with respect to best practices.

V. CONCLUSIONS AND FUTURE WORK

There is a societal interest in higher level of transparency of the operational performance of the air transport system. The increased global vaccination rate resulted in the withdrawal of travel restrictions and the 2nd quarter of 2021 showed higher levels of air traffic in Europe. With the mental orientation towards a post-COVID-19 world, the public and political expectations on aviation to curb its environmental impact gain a higher priority again picking up on many initiatives launched before the pandemic.

Data availability is a key for developing an understanding of the dynamics of the COVID-19 recovery and operational performance. This also applies for the success of novel big data and artificial intelligence based methods. The results demonstrate the principal feasibility of a data-driven open data based approach for performance monitoring of air transport. This enables the day-to-day evaluation of operational excellence in an open and transparent manner. Operational excellence and the impact of varying operational concepts or benefit of technological enablers will become immediately visible. This will allow a closer evaluation of performance benefits, change implementation, and careful tracking of inefficiencies with the anticipated steadily increasing traffic levels in a post-COVID world.

This paper builds on the Opensky Network data. The collected ADS-B/Mode-S data support the development of a toolchain to monitor the operational performance. The feasibility study was performed for the airport context. A fundamental constraint is the coverage of the crowd collected data. By definition, community contributors place sensors on a best effort basis. Therefore coverage of ground movements is limited at the time being to a small number of airports. As a take-away from this work, the Performance Review Unit and Opensky Network look into orchestrating sensor placements at European airports.

A key aspect of this feasibility study was the development of an initial version of a toolchain. Based on the data exploration, open source software modules were developed. The use-case analysis of three airports proofed to provide sufficient operational variation to identify an initial set of assumptions and parameters. To mature the algorithms and introduce the modules to the day-to-day monitoring, future work requires a wider validation across a larger set of airports. The work presented in this paper was performed on standard office computers. The workflow of downloading the data and storing it for further processing, including saving out interim results consumes a considerable amount of resources and time. While this is acceptable on the basis of use-case analyses, an operational use will require the deployment of processing modules with the underlying data infrastructure or appropriate dimensioned and scalable cloud computing. As an initial step, the development of an open flight table comprising the identified key events and milestones for further performance analyses was initiated.

While similarities exists, the analysis revealed that there are differences in the arrival management concept at the studied airports. It will be interesting to follow the development of the novel performance measure during the COVID-19 recovery.

The results will be used to inform the work of ICAO's global performance expert group with a view to help prioritizing concepts and capabilities of the airspace building blocks. This can form the basis for an extension of the currently proposed indicator set. It may serve as a basis to evaluate to what extent the industry meets the aspirational goals put forward and "builds back better!"

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