Assessing the Global COVID-19 Impact on Air Transport with Open Data

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***Abstract*—The COVID19 pandemic shifted the focus and attention of political decision-makers and strategic planers over the past years. There is an emerging need to address the local and regional differences of the impact of policies and demonstrate to airspace users and the travelling public how the air transportation system responds to such large-scale events. This paper approaches the impact of the COVID-19 pandemic as a massive air service disruption of the pre-pandemic global connectivity and regional air transport networks. A resilience based approach is followed to identify and quantify the impact levels. For this initial application the parameters have been chosen in accordance with the operational experience of the authors. This paper applies a data driven approach and uses open and crowd-collected data to assess the impact of COVID-19. This included data preparatory action to augment the ADSB based data set with other publicly available data sources to provide a basis for the analysis of three major regional air transport networks. The analytical results were obtained for the United States, Europe, and Brazil for the pandemic period 2020 and the first half of 2021. The year 2019 is used for reference purposes and to establish a baseline for the impact evaluation. The analysis of the developments in Brazil, Europe, and the United States showed similarities but also stark differences in terms of the response to curb the spread of COVID-19 and associated travel policies. The results obtained demonstrate the feasibility to address global air transport problems with open and crowd sourced data. Future work to harmonize the open data collection and utility can provide a basis for a more open and transparent management of air transportation crisis response, evaluation, or strategic planning. The initial approach to address resilience can further inform the on-going work of the ICAO performance expert group under the Global Air Navigation Plan.**

Keywords—COVID-19, disruption, resilience, air navigation system, air transportation

I. Introduction

Throughout the past decades, the focus of the global air traffic management community was on the evident problem of imbalances between capacity and demand. The continual growth of and increasing demand for air transport registered in the last decade not only has already produced challenging delay management practices, but also fostered projections of even worse scenarios. EUROCONTROL [1], for example, argued that delays in Europe could reach up to 20 minutes per flight in 2040, in stark contrast to the 12 minutes per flight, as registered in 2016.

In a capacity constrained network, disturbances on the air navigation system will ultimately pose challenges to multiple stakeholders. Underlying causes of such events include – inter alia – extreme bad weather, unexpected interruptions of air navigation services, changes to the regulatory framework and others. These causes may trigger disruptions that may result in more delay and associated propagation effects (e.g. flight cancellations). With a view to mitigate the impact and consequences of such disruptions, the concept of resilience of the air navigation system became gained higher visibility. Arguably, a resilient ATM system could mitigate the negative effects of excessive demands on insufficient capacity and their respective constraints and bottlenecks.

On March 11, 2020, the World Health Organisation declared the novel coronavirus (COVID-19) outbreak a global pandemic [1]. The COVID-19 crisis posed a completely different, unexpected and inverted challenge. Communicable disease control resulted in massive restriction]s on international and regional/domestic air traffic and passenger travel. In many places, demand for air transport dropped as low as 90% of the previous "normal". Where the lack of capacity was previously the issue, now the lack of demand threatened the ATM system stability. On the financial side, airlines and airports had to deal with an unprecedented decrease in revenues while facing requirements to open and operate services and assets/infrastructure. At the same time, air navigation service providers collected less fees for their services, due to significantly fewer flights. In many instances, governments had to support their operators through loans or bail-outs. On the operational side, pilots and air traffic controllers practiced less, and concerns emerged about the proficiency of actors during a future recovery phase.

The unprecedented decline in air traffic demand resulted in severe financial strains on the air transport industry. The financial support or lack thereof for airlines and airports has been widely covered in the media. A variety of studies showed the interplay or consequences of the travel constraints. To date, lower attention was given to the inherent change in terms of air transport services. This paper approaches the impact of the pandemic as a massive service disruption of the pre-pandemic global connectivity and regional air transport networks. In particular, the project aims to provide data analytical evidence for policy success and transformation of the air transportation system.

This paper utilises a data-driven approach. Despite the fact that aviation is a data rich environment, operational data on the previous and current traffic levels are not consistently available. This study used data from an open and community fed sensor network, Opensky-Network [3]. The operational flight data was enriched with other publicly available dataset supporting the description of the level of the COVID pandemic and national/regional responses to the pandemic.

The contributions of this paper are:

- conceptualisation of the COVID-19 impact on air transportation as a resilience problem;
- novel methodology to describe disruption, transformation, and recovery phenomena of the air transport network; and
- identification of patterns and/or measures to describe and quantify/evaluate the level of the impact of COVID-19 on air transport and the level of recovery (or disruption) of air navigation on the basis of open data.

II. Background

A. COVID-19 and Air Transportation

On 11. March 2020, the World Health Organisation reacted to the steadily increasing of infections and global spread of a newly detected Corona-Virus by declaring a pandemic [2]. Fig.1 shows the tremendous growth of COVID-19-related cases on a global scale. By end May 2021, a total of just under 175 million cases were reported [4][5]. The kick-off of the surge of cases correlates with beginning of March 2020. As an immediate response, many governments reacted by imposing controls to curb the further spread of communicable disease. Next to social distancing and recommended hygiene measures, this resulted in massive restrictions on international and regional air traffic and

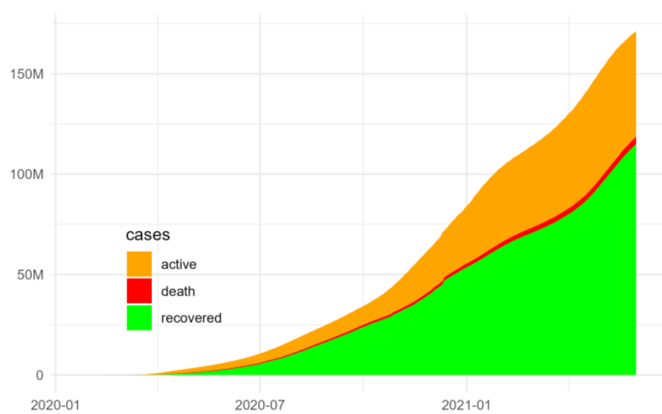

Fig. 1. Reported number of cases (22. Jan 2020 through 27. May 2021)[4] based on data from John Hopkins University [5].

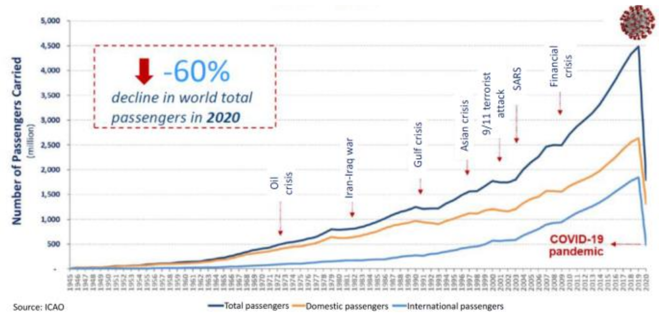

Fig. 2. Evolution of World Passenger Traffic 1945-2020, PRU analysis based on data from ICAO [10][11].

passenger travel. Fig. 2 highlights the sharp decline in passenger traffic showing also the impact on domestic and international traffic [11].

For example, on March 12, 2020, the United States suspended most travel from the European Schengen area [6]. A few days later, European Commission President Ursula von der Leyen announced a similar measure, proposing for EU Member States to apply restrictions on non-essential travel. By that time, several countries, such as Austria, Germany, and Poland had already implemented border check controls, while Portugal, Italy, and Spain imposed lockdowns [7]. At the same time, Australia imposed a severe arrival block on all non-citizens and non-residents at its airports [8]. In South America, Brazil, Chile, Argentina and other countries also followed the trend and closed their borders, totally or partially [9]. As a result, an unparalleled air traffic decline was seen worldwide [10]. Fig. 2 also provides striking evidence of the magnitude of COVID-19 compared to other aviation crises both in terms of global impact and the duration of disrupted services (c.f. analysis in this paper). At the end of 2020 a decline of 60% in passenger numbers compared to the previous year was observed.

B. Resilience

Resilience is a well-researched topic. The term is used by a diverse set of domains, communities, and research areas. This led to an abundance of theoretical definitions in the literature. Numerous concepts emerged from theses definitions and expert domains with slightly varying notions. The term originates from physics and is nowadays used with reference to safety, security, environment and ecological systems, mental health/psychology, biological system, and others. Despite the varying contexts, across all of these disciplines the concept of resilience is closely related with the capability and ability of the focus of concern. The latter is typically a system or agent, and resilience describes the level of response to return to a stable state after a disruption impacted the original system state or actor context.

In light of COVID-19, the term is frequently used on the political and strategic level. Policymakers, operational experts, and academics concur that the concept of resilience plays a major role when addressing and assessing the extent to which organisations and systems are prepared and capable to respond to and recover from disruptions.

Within air navigation, the term ‘resilience’ has been picked up by several communities, both operational and scientific. The concept first appeared in this context as a definition proposed by EUROCONTROL: "Resilience is the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions."[12] Later, Gluchshenko (2012) proposed a widened view, including definitions for resilience, robustness, disturbance, stress, and perturbation [13]. In addition, the work marks the first proposition for a framework of different levels of stress and perturbations. This included a first proposal for metrics for resilience (both quantitative and qualitative). In [14], these ideas are repeated and complemented by a performance-based approach and an algorithm to investigate resilience.

Based on these foundations further studies regarding resilience within the air navigation context were conducted. For example, the Project Resilience 2050 [15] addressed the previous definitions and other technical tasks. The project ran from June 2012 and lasted 43 months, evolving the way to measure resilience. The project considered not only the time of deviation and time of recovery. Instead, it measured resilience as the relative difference of rate of delay correlation, or $R = (ax_1 - dx_1)/dx_1$; as a difference between two pearson correlations, it has no unit adopted. Finally, Koelle (2015) proposed to address resilience as a situation management and state-oriented problem [15]. Through two case studies, the author argued that "there is a lack of fit of the current operational ANS performance indicators to address the impact of disruptions as they are primarily based on actual timestamps or transition times." To describe the system state as set of variables (or features) is required.

The unprecedented decline in air transportation since March 2020 has triggered a re-emerging interest in the resilience topic. For example, under the umbrella of the ICAO Global Air Navigation Plan Study Group, an expert team is currently working on refining the performance framework to better address the resilience perspective. With a view to COVID, there is a dual interest in understanding resilience in air navigation/transportation:

- political level: The continuity and sustainability of a stable air traffic system supports and affects other dimensions of political interest, such as commercial relations, tourism industry, public health policies, among others. As a result, at a political level, it is of the utmost importance that the air navigation system remains functional. In that understanding, political acts were necessary in face of the pandemic crisis effects on aviation. For example, many governments injected financial support in the airline sector in order to help them survive the worst periods. In addition, measures such as tax deferrals to air navigation services providers were also adopted. Therefore, understanding how the air navigation system can exist in a more resilient manner is certainly beneficial for many political agents.

- operational level: While efficiency, delay management, and capacity constraints were previously the main problems affecting resilience, now the concept must be broadened to an inverted scenario. Airlines, ANSPs, airports, and other stakeholders in the industry must remain and manage resilience not only in order to recover from disruptions caused by excessive demand, but also from insufficient demand. If delays are no longer the main threat, others arise, such as insufficient funding, lack of training, and traffic unpredictability.

This paper addresses the operational dimension. Being able to characterise resilience within the operational domain will enable to address the more strategic and political decision-making.

III. Method and Materials

A. Research Approach and Toolset

This work followed a data-driven approach and is based on the reproducibility paradigm. By design open data sources/sets have been identified and used. The associated data analysis was conducted using the open-source software and toolkit R, RStudio [17][18][19], and various packages of the so-called "*R-ecosystem*". The roots of R are with the statistical community focussing on statistical reporting and computing, methodology development, and visualisation. The R-ecosystem is actively expanded in all fields using data science techniques through sharing of packages that augment the core functionality. This paper utilised – without limiting the impact of other packages – knitr and RMarkdown for the production of the paper, ggplot for visualisation, and a set of packages now summarised under the idiom "*tidyverse*". Rmarkdown documents are plain text files that support the combination of text, analytical code, and graphics. For archiving and distribution, the duo Git/Github was used to manage the code and script repository. The underlying source code of this paper and its supporting datasets or code to retrieve the data have been archived and are freely available via the git repository (c.f. acknowledgment).

Fig. 3. shows the overall approach workflow for this paper. The primary open data source for air traffic data is the global daily flight data set of Opensky-Network (https://opensky-network.org). To support research, Opensky-Network publishes on a monthly basis a global flight data set via zenedoo [20]. Supporting aeronautical information on airports, i.e. the association of the airport location indicator with nation states, is taken from ourairports (https://ourairports.com/). To augment the flight-by-flight records with georefernces (c.f. next section), associated geospatial data sets from the Flanders Maritime Institute [21] were used. The data cleaning of the source data resulted in an integrated flight-by-flight dataset with identifying the origin and destination countries and global regions.

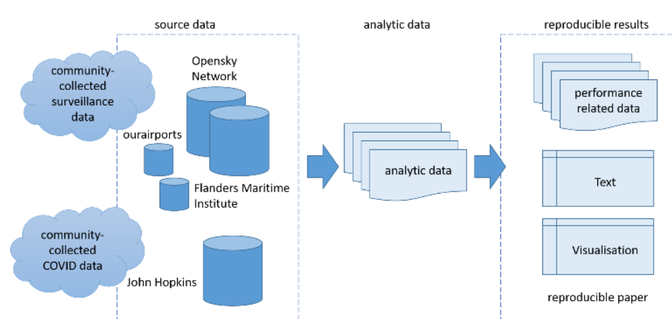

Fig. 3. Reproducible Research Approach

The results of this study are derived from the associated analytic dataset.

B. Open Source Air Traffic Data

This study builds on publicly available data. Opensky-Network collects crowdsourced air traffic data from more than 2500 feeders (sensor stations). To support the process of illustrating and studying the impact of the COVID pandemic on air traffic demand, a flight-by-flight dataset is provided on a monthly basis [20]. The data for this paper spans the period 1. January 2019 – 30. June 2021. Table I provides an overview of the data volume downloaded. Fig. 4 shows the number of daily flights tracked by Opensky-Network globally. The observed continual increase throughout the first six months in 2019 is driven by the increasing rate of ADSB equipage. Particularly, air transport operators in the United States or operating to the United States established compliance with the ADSB mandate applicable as of 1. January 2020. In 2019, the peak daily number of tracked flights ranges just under 104000. The negative spike observed on 2019-09-22 is linked to a data outage. Throughout the second half of 2019 the median number of flights ranged just under 88000. Tracked aircraft also include non-commercial operations of light aircraft (e.g. private flying) transmitting Mode S or ADSB. At the same time, there is a share of the commercial fleet that – dependent on the regional requirements – is not yet ADSB equipped. This needs to be taken into account when comparing Fig.4 with Fig. 2, for example.

The global daily flight dataset by Opensky-Network identifies a flight based on a series of received messages of 15 minutes or more [3]. The flight records provide flight identification information (i.e. transmitted ICAO24 bit address and 'callsign'), 4-D position with a complementary geo-altitude, and positional information of the first and last position. As the sensor network does not cover the whole globe/airspace, a consistency check is made for flights leaving the coverage area and entering again (e.g. oceanic area). Opensky-Network applies a heuristic algorithm for the identification of departure and destination airports based on the vertical movement and altitude for each trajectory. While there are uncertainties in the data based on this heuristic, the dataset ensures detection of flights within certain geographic regions even without a positive departure and/or destination aerodrome identification.

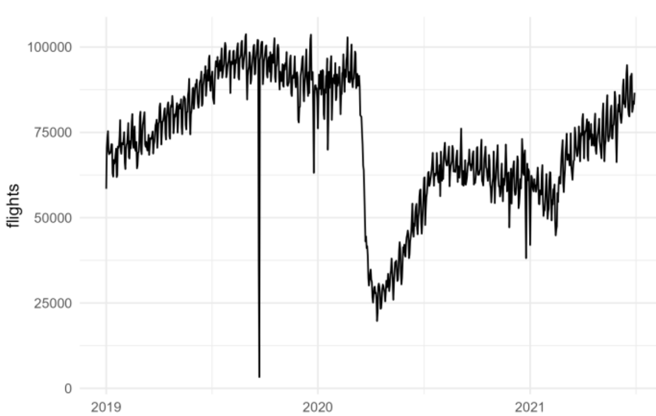

Fig. 4. Number of global daily flights tracked by Opensky-Network.

TABLE I. OPENSKY-NETWORK DATA GLOBAL FLIGHT DATA SET

Year	Global Opensky-Network Flight Data			
	period	***Files***	***Sum file size***	***flights***
2019	January - December	12	1625.7 MB	30 989 673
2020	January – December	12	1160.3 MB	22 494 625
2021	January – June	6	642.9 Mb	12 526 832

For flight records without an identified origin or destination, we georeferenced the flight based on the reported first or last LAT/LON position. For this we made use of geospatial data for each country, including coastal waters and its exclusive economic zone [21]. Based on our operational experience we labelled flights below an ADSB-transmitted altitude of 5000m as "local" flights and assigned a national code based on the georeference. This reduced the number of flights with non-associated departure or destination countries to under 300 flights per day. With the aforementioned daily median this represents a negligible share of about 0.34%.

For the further study we focus on commercial air traffic. While it is not possible to positively filter exclusively passenger flights, the global flight data is further merged with an aircraft database that provides for the aircraft engine type. For the further analysis we remove helicopters and piston engines. This decision is motivated by our operational experience. The majority of helicopter flights is performed for special missions, e.g. emergency, law enforcement, television/broadcasting. Initial flight training and primarily recreational motivated flying is performed with light piston types. While this filtering contains uncertainties, the total numbers for the United States, Europe, and Brazil match with the authority reported traffic numbers. The validity of these assumptions will have to be verified if studying other regions.

C. Measuring Resilience

The concept of resilience (and robustness) is intimately linked with the construct of disruptions. Any given disturbance forces a disruption in the level of service. Following [13], the longer the system takes to recover to a previously unperturbed state, the less resilient the system is. In complement to [15], the deeper the level of disruption, also less resilient the system is. As a result, a possible interpretation for resilience metrics is found considering both the duration of the disrupted service performance, and its disruption level - or how much a system level of service is affected.

Consequently, resilience R can be conceptually measured as the observed loss in quality of service (performance) over the time to recovery, t_1-t_2, for a certain level of disruption. Thus, mathematically, this represents the area covered by

$$\int_{t1}^{t2} [THR - LOS(t)]dt \qquad (1)$$

as presented in Fig. 5 (*LOS*: loss of service / performance level, *THR*: associated threshold). Based on this conceptual considerations, Fig. 6 shows the air traffic evolution for the

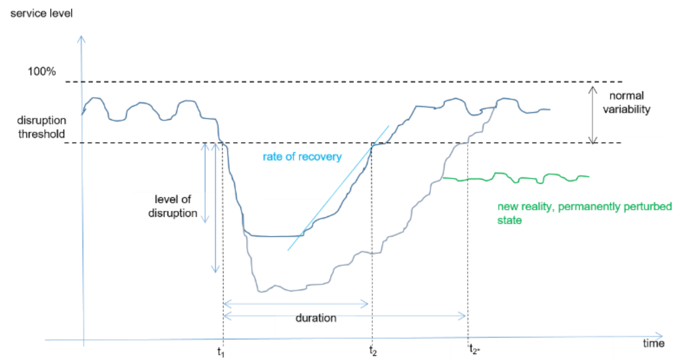

Fig. 5. Resilience as a function of disturbance impact

period 1. July 2019 – 30. June 2021 for the United States. As a base-level the 80th percentile of the observed traffic in the 2nd half of 2019 was chosen. This allows to introduce further levels to differentiate between nominal and non-nominal (disrupted) traffic levels. This paper applies a cut off of -20% from the base-level as a threshold to label traffic as disrupted. In Fig. 6 and throughout the paper, measurement points are coloured differently for each of the level bands for presentation purposes.

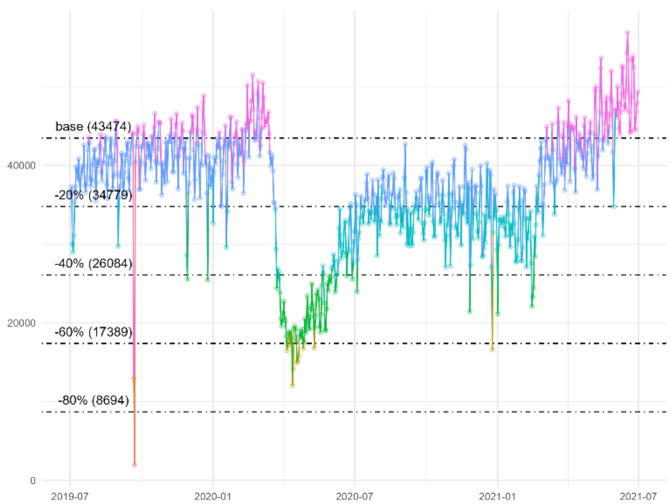

Fig. 6. Resilience concept applied to observed US air traffic development

However, an evident question arises from this approach: what is the proper threshold for the service to be considered disrupted? Certain that, for some indicators, this could be a fixed value, this paper proposes an alternative method. The disruption threshold can be view as an adaptive function of the recent traffic levels. As a result, the disruption threshold level would not be a fixed value, but a variable one, taking into account the recent trends to define a normal band based on moving windows. Fig. 7 shows this approach. Instead of a horizontal line (fixed value), the disruption threshold adapts according to the recent trends in traffic. In Fig. 7, the red line is the disruption threshold, defined as the 20th percentile of the daily traffic considering the previous 60 days. Naturally, those are empirically suggested values that could be adapted according to any particular needs. In addition, the blue line is set to be a potential indicator of disruptions in the opposite direction, i.e. a positive disruption,

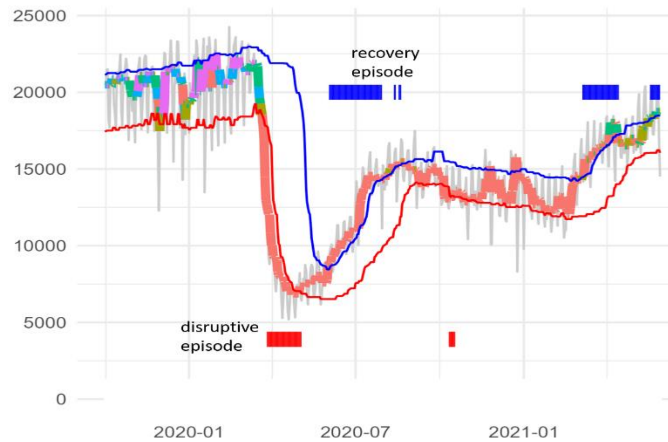

Fig. 7. Sliding Window Approach with Upper and Lower Bounds

caused by an abnormal excessive demand. With this refinement of the approach/concept presented in Fig. 5 a revised general resilience index can be determined.

The lower and upper bounds of the sliding window support also the identification of episodes as they act as a low pass filter with the pre-set time lag. Traffic levels falling below the 20th percentile limit are considered as phases of decline and disruptions, whereas a recovery phase is characterised by the actual observed traffic levels exceeding the upper limit of the rolling 80th percentile limit.

IV. Results and Discussion

A. *Network Level Assessment for Brazil, Europe, and the United States*

Based on the study dataset Fig. 4 provides a global perspective on the air transport evolution. This paper zooms in on comparing the situation in Brazil, Europe, and the United States. Fig. 6 and Fig. 8 depict the different network level responses to the regional/local air traffic constraints for the period 1. July – 30. June 2021. Different behaviours can be observed in each region. Air traffic in all regions declined sharply following the initial government restrictions imposed in early to mid March 2020, however, different patterns emerged showing differences in the response to COVID-19.

Fig. 6 introduced the concept for the United States. Following the initial decline of traffic in March 2020, traffic recovers continuously and plateaus for the 2nd half of 2020 at a level of -20% from the base traffic level. Following the holiday season there is a short decline, however, as of February/March,

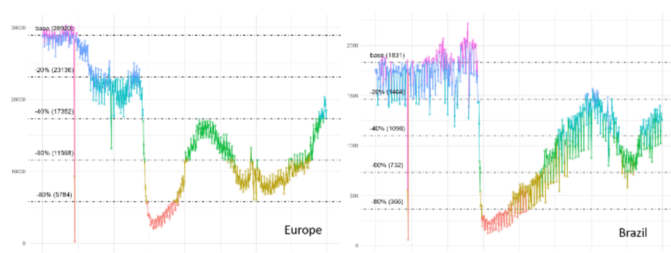

Fig. 8. Flight Demand Timeline for the United States, Europe, and Brazil.

traffic rebounced and ranges above the chosen disruption threshold. With March 2021 traffic even increased above the base level suggesting a full recovery.

A wave-form pattern is observed for Europe. Following an initial recovery – similar to the United States – in summer 2020, traffic declined towards autumn and the holiday season 2020/2021. This is in sync with the piecemeal approach of national lockdowns and relaxation of travel restrictions for the summer vacation followed by another surge of infections following the mingling of travellers. With April/May 2021 traffic increased again in Europe continuously and ranged in the lowest disruption band (-20% to -40% of baseline traffic).

Brazil also experienced the sharp decline in traffic in March 2020. Similar to the US, traffic in Brazil showed an initial continual increase reaching the lowest disruption band around the holiday season. However, following the holidays 2020, traffic continuously declined in the first quarter of 2021. Brazil had to impose higher restrictions in light of the increasing infection rates.

Based on (1) Tab. II summarises the overall resilience impact for the 3 regions. Of the 3 regions analysed, Europe was hit hardest, both in terms of disrupted days and the total resilience impact.

Regional Resilience Characteristics			
Region	***Year***	***Disrupted Days***	***Total Resilience***
US	2020	201	1 464 655
US	2021	45	183 491
EU	2020	355	4 008 887
EU	2021	179	2 162 287
BR	2020	292	223 532
BR	2021	169	61 979

B. *Traffic Development – Connectivity – COVID-19*

The previous analysis focussed on the identification of the start of the network disruption, its duration, and overall impact. With a view to link this to the driver of the policy decision-making, the next step investigates the relationship between the regional infection rate. We use the number of confirmed deaths as a proxy for the pressure on the political decision-makers to address travel restrictions. The following example shows the observed departure traffic in Brazil and its destinations. Traffic to the United States and Europe form a small share of the international traffic. Other traffic includes traffic to South-American countries. Traffic levels are considered disrupted on 15. March 2020. International traffic started to decline a few days earlier. This is in line with the ramp up to 11. March at which the WHO declared COVID-19 a pandemic and various countries and airspace users already starting to introduce travel restrictions from different countries. At the same time, repatriation flights were launched to support the return of citizens from across the world. Brazil opted to not curb the initial recovery throughout the 2nd half of 2020. However, the steady increase in COVID-19 related deaths was a continual pressure.

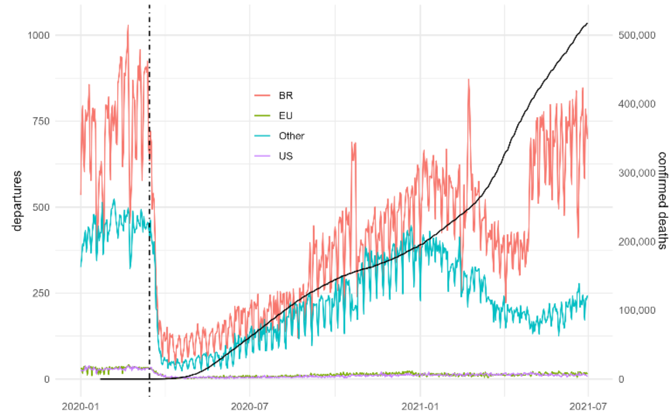

Fig. 9. Example – Regional Traffic and COVID-19 deaths in Brazil.

The steady increase of death cases increased as of late January 2021 and resulted in a stronger reduction of travel, both for domestic and international traffic. It is noteworthy that as of April 2021 domestic travel increased despite the continual COVID-19 cases.

C. *Airport Level Connectivity*

For the airport level comparison, we reviewed the top-5 airports in each region and selected airports showing distinct and characteristic patterns (c.f. Fig. 9). For the assessment of the airport level role in the regional networks, we built on the degree rank from complex networks and determined the share of regional departures.

The share of national traffic at Atlanta remained fairly stable ranging around 80%. The contraction of the traffic is in line with the overall traffic pattern and decrease observed for the United States. London Heathrow (EGLL) showed a different behaviour. As one of the major European hubs, EGLL had a significant share of regional (pan-European) traffic (about 60% regional to 40% international traffic). As Europe had no consolidated approach to restricting air traffic and a variety of travel corridors between different European countries. This results in a reduction also on the pan-European level with a significant drop of regional departures to about half of the pre-pandemic level. The identified pronounced 2nd wave observed in Brazil played also out at São Paulo/Guarulhos (SBGR). As one of the major Brazilian airports with a high level of international air traffic, SBGR experienced a contraction of the traffic in sync with the imposed travel restrictions. The importance of local traffic (intra-Brazil) can be seen in the increase of the share of regional departures while the number of international departures reduced.

The airport level perspective provides insights in how local/national travel restrictions and the wider global response including the wide-ranging travel bans rippled down and put pressure on the airport operators.

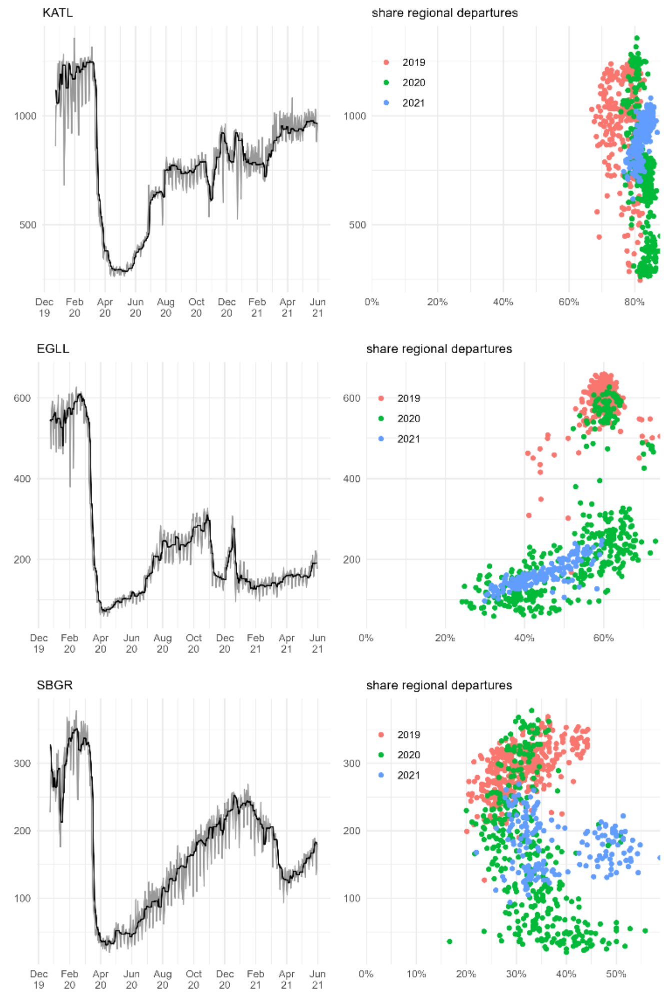

Fig. 10. Airport Level Analysis for Atlanta (KATL, United States), London Heathrow (EGLL, Europe), and São Paulo/Guarulhos (SBGR, Brazil).

V. Conclusions and Future Work

The unprecedented decline in air traffic due to the global response to restricting the spread of COVID-19 impacted air transportation stakeholders across the globe. Local and regional response measures and the impact varied. However, the drop in air transport demand challenged the sustainability of operating the air transport system. Restrictions were more commonly lifted with the second quarter of 2021. However, the success of increasing vaccination rates and local/regional travel policies is still uncertain. The first signs of recovery need to be balanced against the overall system efficiency and performance. This is particularly relevant as higher levels of efficiency will support the political ambition to address the contribution of aviation to the environmental sustainability discussion.

To augment the current performance measurement toolset, this paper took an initial look at describing the impact of COVID-19 as a large-scale air transportation system disruption. This paper addressed the identification and description of disruptions, associated transformation, and recovery phenomena of the air transport network. The methodology will be useful to support the monitoring of the recovery levels across the globe. It complements the toolbox for policy makers and strategic planers to determine priority measures in support of the anticipated air travel demand recovery with the roll-out and increasing levels of vaccination.

The regional comparison of Brazil, Europe, and the United States revealed differences patterns on both the national/regional level and the local airport level. With the assumptions made in this paper and applying the developed methodology, the air transport network in the United States can be considered as fully recovered as of early March 2021. It further shows increased traffic with respect to the base-level derived from the pre-pandemic period. In terms of overall impact, Europe appeared to be hit significantly. The observed resilience impact exceeds the value measured for the United States by an order of 3 and lasted for a significant longer period. There is a clear association with the fragmentation of Europe. As a federation of independent states, European countries did implement varying policies. In particular, the repercussion of bi-national travel restrictions and varying quarantining rules impacted also the regional connectivity. Brazil experienced a wave pattern following an initial recovery during the 2nd half of 2020. The analysed pattern at SBGR also shows the relevance of domestic (intra-Brazilian) traffic. In 2020 and the beginning of 2021, the share of domestic traffic ranged higher at SBGR. Atlanta (KATL) is an example for a dominant domestic network role. The traffic share remained fairly constant throughout the study period. This suggests that local operators scaled down their operations to meet the demand levels.

The paper demonstrates the feasibility to refine the existing body of knowledge on resilience and adapt the concept to air transport network assessments. While the recovery from COVID-19 is still underway in many countries across the globe, the presented approach offers the opportunity to quantify the resilience impact and construct characteristic measures for the domestic/regional network level and the airport level. An extension of this work will be to abstract the global and regional connectivity in form of airport clusters or country networks. This can inform policy and strategic planning.

A key aspect of the work presented is the use of open data as no public global data set on air traffic exists. While there is sometimes criticism about crowd sourced data, the comparison with respective formal monitoring data available to the authors showed a good match. However, the results need to be interpreted on the basis of the made assumptions. Future publications of assessments based on authority approved data may differ. The combination of different open source data sets identified a need for a wider community discussion on data formats and storage standards. The flight association used in this paper is based on the operational experience of the authors. The use of pattern recognition or clustering techniques may help to augment the association of tracked flights in future work.

The study built on open air transport data and applied a reproducible research approach. Interested practitioners and researchers are able to access the underlying data and validate the results of this paper via the source code hosted on github (c.f. acknowledgement below). As part of this project, the requirements for an open data based flight table for the evaluation of the global air transportation network are refined. The results and insights of this work will be shared with the wider effort of the ICAO GANP expert group on performance and may help to refine the existing ICAO performance framework.

ACKNOWLEDGMENT

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Details on the access to the underlying data, its processing, and the analytical modelling can be accessed via https://github.com/rainer-rq-koelle/paper-2021-DASC-COVID19.

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