

User-centric Cost-based Flight Efficiency and Equity Indicators

Javier López-Leonés, Manuel Polaina Morales

Boeing Research and Technology Europe
Madrid, Spain

{javier.lopezleones, manuel.polainamorales}@boeing.com

Pablo Sánchez Escalonilla, Damián Ferrer Herrero,
Marcos Sanz Bravo, Fernando Celorrio Cámara, Ángel
Martínez Mateo

CRIDA, ATM R&D Reference Center
Madrid, Spain

{psescalonilla, dfherrer, msbravo, fccamara,
amartinezm}@e-crida.enaire.es

Abstract—Flight efficiency is a generic term that varies depending on the agent's viewpoint. Whereas Air Navigation Service Providers (ANSPs) take a wider look at efficiency, considering components such as sector capacity, air traffic controller's interventions, emissions and noise; airlines are mainly concerned on costs, i.e. fuel consumption and schedule adherence. It is important to bring these two agents' viewpoints together in new Key Performance Indicators (KPIs) in order to capture airspace users' needs without leaving out the inefficiencies of the entire net.

The current implementation of efficiency measurement (as defined in the SES Performance Scheme) affects the ANSPs view on efficiency since the ANSPs have to report on specific KPIs to evaluate their performance and management of the air traffic. This implementation takes into consideration only the horizontal portion of the flight, measuring the excess horizontal en-route distance compared to the orthodromic. This approach lacks of important information for airspace users' objectives since it leaves out the vertical component of the flight or wind conditions.

In order to introduce the airspace users' objectives into the global net efficiency measurement, it is key to develop advanced metrics that consider fuel consumption, schedule adherence and cost of flights. These new efficiency metrics require the design of user-preferred trajectories as the main references for performance comparison purposes. Additionally, airspace users are claiming for equity metrics showing how these inefficiencies are distributed between them in certain areas such as FIRs or city-pairs.

This paper presents the methodology followed for the design of advanced user-centric cost-based efficiency and equity indicators as well as a flight efficiency and equity assessment of the European traffic flow in two particular days in February 2017 taking into consideration the airspace users' perspective.

This research was conducted under the AURORA project (Grant 699340) supported by SESAR Joint Undertaking under European Union's Horizon 2020 research and innovation programme. AURORA aims to propose new metrics to assess the operational efficiency of the ATM system and to measure how fairly the inefficiencies in the system are distributed among the different airlines.

The AURORA consortium is formed by Centro de Referencia I+D+i ATM (CRIDA), Boeing Research and Technology Europe (BR&TE), Centre for Applied Data Analytics Research (CeADAR) and Flight Radar 24 (FR24) with the support of Iberia, Air Europa, KLM and Turkish Airlines as members of the AURORA's Airspace Users Group.

Keywords—component; Airlines; ANSP; Flight Efficiency; KPI; Air Traffic Management; SESAR; ADS-B.

I. INTRODUCTION

The Single European Sky (SES) Performance Scheme [1, 2] is designed to drive and steer the continuous improvement of European Air Traffic Management (ATM) performance. This Performance Scheme establishes EU-wide targets for four Key Performance Areas (KPIs): Safety, Cost-Efficiency, Capacity and Environment. These overall targets, which are reviewed and updated periodically, are transposed into binding national/FAB (Functional Airspace Block) targets that are incorporated into national/FAB performance plans. The Performance Scheme, established by the Performance Review Unit (PRU), defines a set of Key Performance Indicators (KPIs) for each of the KPIs. These metrics, which are obtained through air traffic-related data [5] [15] [16] [17], allow evaluating the aggregated performance of the European ATM services and their impact on airspace users without explicitly taking into account their requirements [20].

This set of KPIs is not thought out to be static. New indicators and techniques are being continuously researched as means to improve the understanding of the ATM system. Following this trend, EUROCONTROL, on behalf of the European Union (EU), invests on researches that will allow further improvement on the system measurement [3, 4]. In addition to the research made in this area, the EU publishes reports with analysis and recommendations for the ATM system on a particular year [5]. Joint reports with the Federal Aviation Administration (FAA) are also published to compare both systems and to identify best practices for the optimization of the ATM performance [6]. Being able to better understand

how these new practices are really addressing the real airlines' interests is essential.

AURORA (Advanced User-centric efficiency metRics for air traffic perFORMance Analytics – www.aurora-er.eu) project is addressing the need to explore promising new performance indicators for operational efficiency, based on aircraft operators' needs. Its scope is to investigate new indicators for flight efficiency, equity and fairness as well as to explore innovative methodologies to calculate them, not only by using historical data but also using real-time data for the on-line monitoring of efficiency. This paper presents those metrics that quantify costs of the flights together with the methodology used for their calculation based on historical ADS-B surveillance and flight plan data. Additionally, a case study is analysed, showing the potential of using ADS-B data as a mean to assess the global (origin to destination) efficiency of a flight.

II. BACKGROUND

Flight efficiency indicators are currently monitored and reported by the SES Performance Scheme [8, 9] as part of the Environmental KPA defined by ICAO [1, 2]. This monitoring is done both in the U.S. and Europe [5-7] as well as in other countries such as Australia.

Flight efficiency is a generic term that can refer to different concepts and definitions. Nevertheless, flight efficiency is always considered as a relevant area under study due to the direct economic and environmental impacts it has according to well-known studies [3, 4, 10-14]. As a consequence, efficiency indicators' monitoring is continuously growing to allow for a better understanding of the drivers of ATM flight efficiency.

Today's mandatory KPI used by the SES Performance Scheme is the "Horizontal Flight Efficiency". This KPI limits the calculation of flight efficiency to the horizontal component of the flight, and considers the geodesic route as the most efficient reference.

The method to calculate this indicator is named "the Achieved Distance Methodology" [15]. This methodology calculates the average En-Route additional distance with respect to the Achieved Distance, which is an apportionment of the most direct route between two airports (between the ASMA exit point of the departure airport and the ASMA entry point of the arrival airport), named the Great Circle Distance.

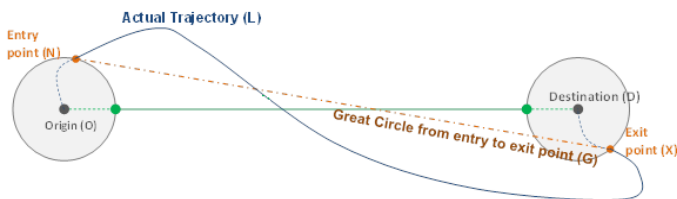


Figure 1. Flight length compared with Great Circle Distance

Some studies performed by EUROCONTROL [16, 17] have shown that this approach for the calculation of flight efficiency, based only on the horizontal component of the flight, doesn't capture the "optimum" trajectory when

considering meteorological factors or the airspace users' operational objectives. FAA's researchers have studied the possibility of introducing the wind as a parameter for the optimum trajectory calculation [18]. On the other hand, European ANSPs are also trying to improve the representativeness of flight efficiency indicators. As an example, NATS has developed the 3Di metric that may provide a good measure of the ATM influence on fuel efficiency [19]. BR&TE and CRIDA began exploring an innovative direction in a collaborative study using real operation data; as a result, a new methodology was explored to construct an Enhanced Flight Efficiency indicator that better captures the fuel consumption [20]. All previous studies showed that the existing Horizontal Flight Efficiency methodology based on the Great Circle Distance trajectory does not fully capture the optimum or more efficient trajectories, which are the cornerstone for the calculations.

These findings open a new way for investigation on optimum trajectories, considering factors such as fuel consumption, flight time costs or schedule adherence. AURORA's study takes as starting point the previous research to overcome the gaps of the today's most common flight efficiency indicator.

III. METHODOLOGY

The evaluation of flight efficiency indicators requires the definition of several types of trajectories, each of them accounting for a loss of efficiency due to different factors. The definitions below follow the nomenclature and framework used in [20, 27] and are a subset of the reference trajectories used in AURORA:

- **Optimal Distance Trajectory (ODT).** This is the shortest distance trajectory, the one that follows the Great Circle from origin to destination. The ODT does not consider the impact from other traffic or from any airspace structure restrictions. This trajectory is aligned with how efficiency is currently measured by SES Performance Scheme through the Achieved Distance methodology, as explained in [15] [17] [20].
- **Optimal Cost Trajectory 1 (OCT1).** This trajectory goes from origin to destination in free flight conditions and minimising costs of fuel and flight time. It does not take into consideration any airspace or ATC restrictions. Although air navigation fees are not considered in the calculation of this trajectory, they will be considered in the cost-based indicators.
- **Optimal Cost Trajectory 2 (OCT2).** The OCT2 differs from the OCT1 in the fact that it takes into consideration the airspace structure since it follows the horizontal path given in the flight plan. The flight plan provided by the airlines is thought to be the optimal horizontal path taking into consideration the airspace structure and air navigation fees since it comes from powerful flight planning tools used by the airlines to plan their route according to their business strategy, although, in some specific cases, airlines

may file a flight plan knowing that it will not be flown beforehand and a new one could be filed once airborne.

- **Flight Plan Trajectory (also Procedure-Optimal Trajectory) (FPT).** This trajectory corresponds to the filed flight plan and contains all procedural constraints. This trajectory would be flown by the aircraft if no ATC tactical interventions took place.
- **Actual Flown Trajectory (AFT).** This trajectory corresponds to the true trajectory flown obeying objectives specified in the filed flight plan, but also considering ground delays, tactical ATC interventions and weather diversions. All these factors contribute to the actual flown trajectory being different to what was planned (the FPT).

The methodology and process followed in the calculation of AURORA's efficiency indicators presented in this paper is summarized in Fig. 2.

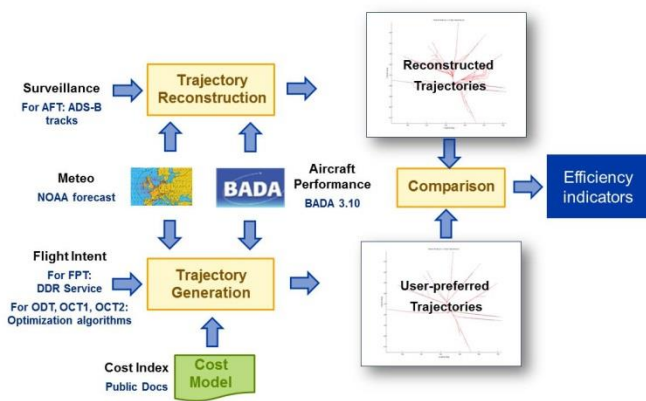


Figure 2. Process followed for the calculation of new efficiency indicators

AFT is calculated from surveillance information (ADS-B track data). National Oceanic and Atmospheric Administration (NOAA) weather forecasts is used as the weather model and Base of Aircraft Data (BADA) 3.10 is used as aircraft performance model [24]. This process, which is named Trajectory Reconstruction, enables the acquisition of the full state vector of the aircraft, including variables that are not explicitly included in the surveillance data and are needed to analyse the efficiency of the flight, such as fuel burnt.

ODT, OCT1, OCT2 and FPT are also calculated for each flight through the Trajectory Generation process. These are trajectories never flown by the aircraft, but used as references for comparison purposes. Each indicator is then obtained by selecting and comparing the proper variables of Actual Flown Trajectory with those of the User-preferred trajectories.

In the study presented here, both processes were carried out using PERCEPT (Predictive assessment of the impact of new air traffic concepts on current operations), which is a flexible air traffic modelling tool proprietary of BR&TE [20, 21]. In PERCEPT, Trajectory Reconstruction and Generation processes rely on a common Trajectory Computation Infrastructure (TCI) that produces a trajectory using as input the initial conditions (latitude, longitude, altitude, mass, time

and speed) of the flight and an aircraft intent¹ expressed using the Aircraft Intent Description Language (AIDL). Details on the AIDL and the TCI used can be found in [21, 22, 23, 25, 26]. The main idea behind the concept of Trajectory Reconstruction using PERCEPT is to find an instance of AIDL that fits the ADS-B track and then feed the resulting aircraft intent to the TCI that integrates the full trajectory. In the Trajectory Generation process, the AIDL instance that is fed into the TCI to obtain the aircraft trajectory is created depending on the trajectory that is sought after. The AIDL instance comes from flight intent information and initial conditions. Flight intent² information condenses all the restrictions and objectives that affect a particular flight that have a direct impact on the resulting trajectory. For the same origin and destination, depending if the final trajectory needs to comply with the operational flight plan or should follow an optimal profile, different instance of AIDL will be created. The complete explanation of the processes of Trajectory Reconstruction and Generation, including the optimization process used for the creation of the optimal profiles, are explained in detail in [31].

A. Definition of Efficiency Indicators

The following list presents a subset of all the indicators defined [32] and evaluated [33] in AURORA. The first indicator (KEA), which is equivalent to the one currently used by the PRU in their efficiency analysis and reports, is calculated for comparison purposes. The new indicators³ were identified through workshops and questionnaires completed by the airlines participating in the project. It is important to highlight that, by definition, positive higher values of all indicators imply higher inefficiencies.

- **KEA** quantifies the horizontal deviations of the Actual Flown Trajectory (AFT) in comparison with the Optimal Distance Trajectory (ODT), i.e. the geodesic trajectory.

$$KEA = \left(\frac{L_{AFT}}{H} - 1 \right) \% \quad (1)$$

Where L_{AFT} is the horizontal distance flown by the aircraft, i.e. AFT horizontal distance, and H is the Great Circle Distance between origin and destination, i.e. ODT horizontal distance.

¹ Aircraft intent is the information that describes how the aircraft is to be operated within a certain time interval. An instance of aircraft intent defines the aircraft behavior that has an impact on the aircraft trajectory.

² Flight intent can be seen as a generalization of the concept of flight plan. Details on the flight intent can be found in [25].

³ A nomenclature was developed for a better understanding of these indicators. This nomenclature is composed of five letters, the first letter is for the variables being compared (K for distance, F for fuel, C for cost); the second letter (E) is used to indicate that these are efficiency or environment indicators; the third and fourth, separated by underscore, identify the trajectories being compared (A for actual, P for planned and D for geodesic, F for minimum fuel and C for minimum cost); the last letter is used to indicate if a weather model is considered (e.g. CEA_CW means Cost Efficiency indicator of the Actual Flown Trajectory versus the Optimum Cost Trajectory considering Weather).

- **CEA_CW1** quantifies the extra-costs of the Actual Flown Trajectory (AFT) in comparison with the Optimal Cost Trajectory (OCT1), which optimizes flight time and fuel costs in free route conditions.

$$CEA_CW1 = \left(\frac{C_{AFT}}{C_{OCT1}} - 1 \right) \% \quad (2)$$

$$C = p_{FUEL} \cdot (\Delta m + CI \cdot \Delta t) + RC \quad (3)$$

Where C_{AFT} and C_{OCT1} are the total costs⁴ of the AFT and OCT1 respectively, both given by (3). With $CI = \text{cost index}$, $\Delta t = \text{flight time}$, p_{FUEL} is the average fuel price as given in [28], Δm is the fuel consumption and RC are the route charges, calculated using the formula given by EUROCONTROL in [29][30].

- **CEA_CW2** quantifies the extra-costs of the Actual Flown Trajectory (AFT) in comparison with the Optimal Cost Trajectory (OCT2), which optimizes flight time and fuel costs following horizontally the flight plan.

$$CEA_CW2 = \left(\frac{C_{AFT}}{C_{OCT2}} - 1 \right) \% \quad (4)$$

Where C_{OCT2} is the cost of the OCT2 given by (3).

It is important to clarify that, in the study presented in this paper, all the indicators are calculated from origin-destination. This implies that the calculation of KEA differs from the current implementation indicated by the PRU to ANSPs, where the portion of the flight in an area of 40NM around the airports (ASMA) is excluded from the evaluation of the indicators [15] [17] [20]. The airlines involved in the study mentioned their interest to understand the efficiency of their flights by considering the whole trajectory, including the ASMA.

It also relevant to remark that the calculation of route charges for the different trajectories is not based on the route charges associated to the flight plan (current way to calculate navigation fees) but the route charges associated to the actual trajectory (calculated using the geodesic distance between the entry and exit point to each airspace which is crossed by the trajectory), which will be the future way to pay charges.

B. Equity indicators

Equity metrics tend to capture how the inefficiencies of the system would be distributed between all airspace users within a certain context (e.g. ECAC region, airport, airline type or airspace crossed). In the context of AURORA five equity metrics were defined [32] and evaluated [33] and the one focused on costs is presented in this paper:

⁴ The costs considered in this paper are those corresponding to fuel, time and air navigation fees, not considering explicitly the true cost of delay. The cost of time is only considered through the cost index, which is extracted from publicly available documents [34], [35] and [36].

- **EQ-4** indicates the standard deviation of the mean ratio between the actual costs and the planned costs of all flights belonging to each airline. Below is the expression for calculation of the EQ-4 indicator:

$$EQ - 4 = \sqrt{\sum_{j=1}^N \frac{(x_{AUj} - \bar{x}_C)^2}{n - 1}} \quad (5)$$

$$\text{With } x_{AUj} = \frac{\sum_{\text{flights} \in AU_j} C_{AT}/C_{PT}}{\text{number of flights} \in AU_j} \% \quad (6)$$

$$\bar{x}_C = \sum_{j=1}^N \frac{x_{AUj}}{N} \quad (7)$$

Where C_{AT} and C_{PT} are the cost of the AT (actual trajectory) and PT (planned trajectory) respectively, as expressed in (3), n is the total number of flights in the context under study and N is the total number of airspace users in the context.

C. Scenario Description

This study analyses actual ADS-B equipped flights whose whole track remains inside the European Civil Aviation Conference (ECAC) area. ADS-B data to apply the proposed methodology were needed in time intervals of less than 5 seconds. Traffic samples with the required granularity were generated starting at the beginning of 2017. Two days without major disruptions, i.e. without abnormal ATC regulations or delays, were selected: 2017 February 20th and February 24th. February 24th had higher magnitude and different predominant wind direction than February 20th.

Constraints in time processing of the reference trajectories made necessary to focus the data sets. The study considered flights departing from 12:00 to 14:00 as these are the main peak hours of the selected days. Additionally, all flights operating several city pairs along the 24 hours of the two days were also included in the data sets. These city pairs, which were identified by the members of the AURORA's Airspace Users Group, are: London Gatwick – Madrid Barajas, London Gatwick – Barcelona, Frankfurt – Madrid Barajas, Paris Orly – Toulouse, Paris Orly – Lisbon, Istanbul – Amsterdam, Roma Fiumicino – Amsterdam and Barcelona – Brussels.

This adds up to 1,583 trajectories for the 20th and 1,692 trajectories for the 24th. Fig. 3 depicts a sample of the trajectories analysed for February 20th. The analysis of flight efficiency indicators was performed with both data sets. The analysis of equity indicators was performed with February 20th set exclusively.

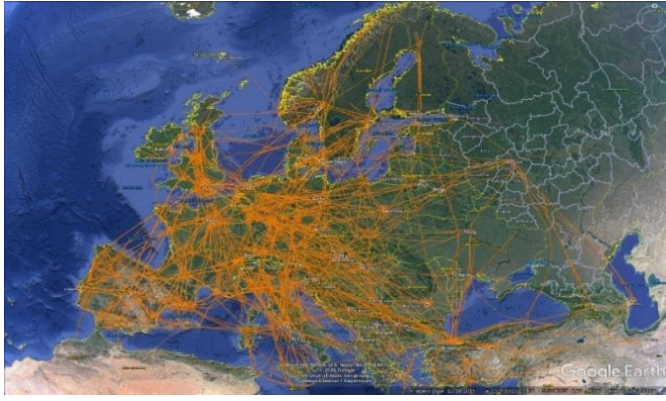


Figure 3. Sample of flights analysed for February 20th

IV. RESULTS

A. FLIGHT EFFICIENCY

Table I summarizes the mean values, the standard deviation and the coefficient of correlation between the assessed indicators for the two ECAC traffic samples. Linear correlation is obtained as an indication of up to which point the behaviour of two indicators is similar. High correlation values between the new cost-based indicators with current efficiency indicator, i.e. KEA, imply that this easy-to-obtain indicator could be representative enough to estimate how cost-efficient a flight is and there is no need of defining more complex indicators.

TABLE I. Statistical values and relationships between indicators

Days	Ind.	Mean value	Standard Dev.	Linear Correl. with KEA
20/02/2017 24/02/2017	KEA	9.7%	7.6%	
		10.2%	7.0%	
	CEA_CW1	9.3%	6.4%	0.71
		10.0%	6.4%	0.70
	CEA_CW2	4.6%	5.3%	0.25
		6.2%	5.1%	0.37

KEA and CEA_CW1 mean values are similar for both days. Thus, the ECAC view of efficiency in terms of costs deviations of the actual trajectory with respect to the optimal cost-based trajectory, i.e. OCT1, is similar to the deviations in distance with respect to the geodesic trajectory, i.e. ODT.

In spite of this, KEA is not properly representing how good is the actual trajectory with respect to the optimal cost-based trajectories. Testing different relations between the indicators, a linear relationship is taken as the most representative due to the higher value of correlation in comparison with other non-linear relations. The linear correlation between KEA and CEA_CW1 is around 0.70 which is identified as a medium-strong correlation according to Pearson scale. The correlation between

KEA and CEA_CW2 is 0.25 and 0.35 which is identified as a small correlation according to Pearson scale. Fig. 4 shows KEA vs CEA_CW1. For similar values of KEA, CEA_CW1 scatter can be observed in the figure.

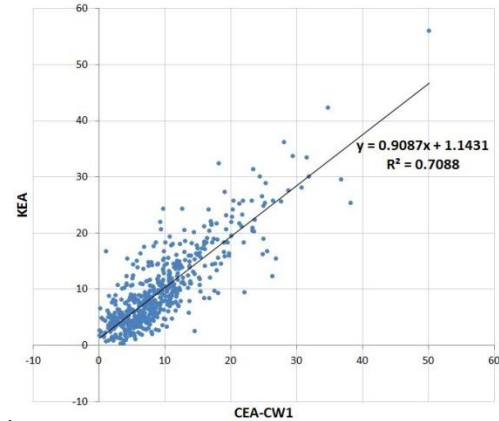


Figure 4. Scatter of CEA_CW1 values for February 20th

On the other hand, actual trajectories in the ECAC are more efficient than expected when comparing with the best possible cost-efficient trajectory following the flight plan, i.e. OCT2, as it can be seen in the difference between CEA_CW2 and KEA mean values. In fact, KEA and CEA_CW1 mean values are around 50% higher than CEA_CW2 in the two traffic samples. This indicates that half of the ECAC inefficiencies in terms of costs are due to the constraints of the route design.

Weather (wind, pressure and temperature) is not causing major horizontal deviations of the optimal cost-based trajectories in free route with respect to the geodesic for short and medium-haul flights. Fig. 5 shows a representative example of the horizontal path of OCT1 and OCT2 trajectories versus the AFT and ODT trajectories for flight IBE31RG from MAD to DUS. In this case the horizontal profile of the ODT and OCT1 trajectories are the same, and therefore they cannot be differentiated in the figure. This is also the main reason for the higher correlation between KEA and CEA_CW1 than between KEA and CEA_CW2 as horizontally ODT and OCT1 are very similar for short and medium-haul flights.

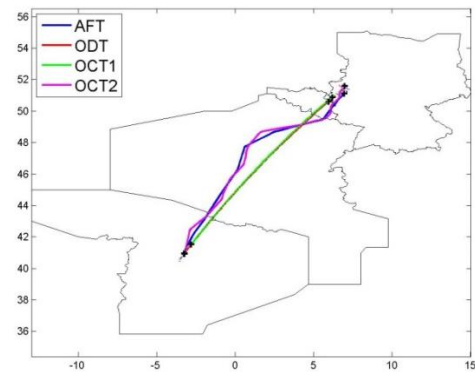


Figure 5. Horizontal differences of OCT1, OCT2, AFT and ODT

Wind is identified as a factor causing changes in the vertical profile, flight time and speed of the Optimal Cost Trajectories, both OCT1 and OCT2, with the subsequent impact on total flight. This effect, which is not captured by the current efficiency indicator, has a clear impact on CEA_CW1 and CEA_CW2 values. Fig. 6 shows an example of two flights, IBE481 and IBE04VM, operating the same aircraft type (A319). IBE481 is flying with tail wind from Oviedo to Madrid in the afternoon (8:00 PM). IBE04VM flies from Madrid to Oviedo in the morning (7:00 AM) with head wind. Both AFTs have the same flight duration because IBE481 AFT increases the speed to cover more distance, and consequently consumes more fuel. On the contrary, IBE481 OCT1 benefits from the tail wind, reducing flight time and maintaining the fuel consumption in comparison with IBE04VM OCT1. In conclusion, IBE481 is less efficient in terms of costs than IBE04VM as it is seen in the difference in CEA_CW1 values.

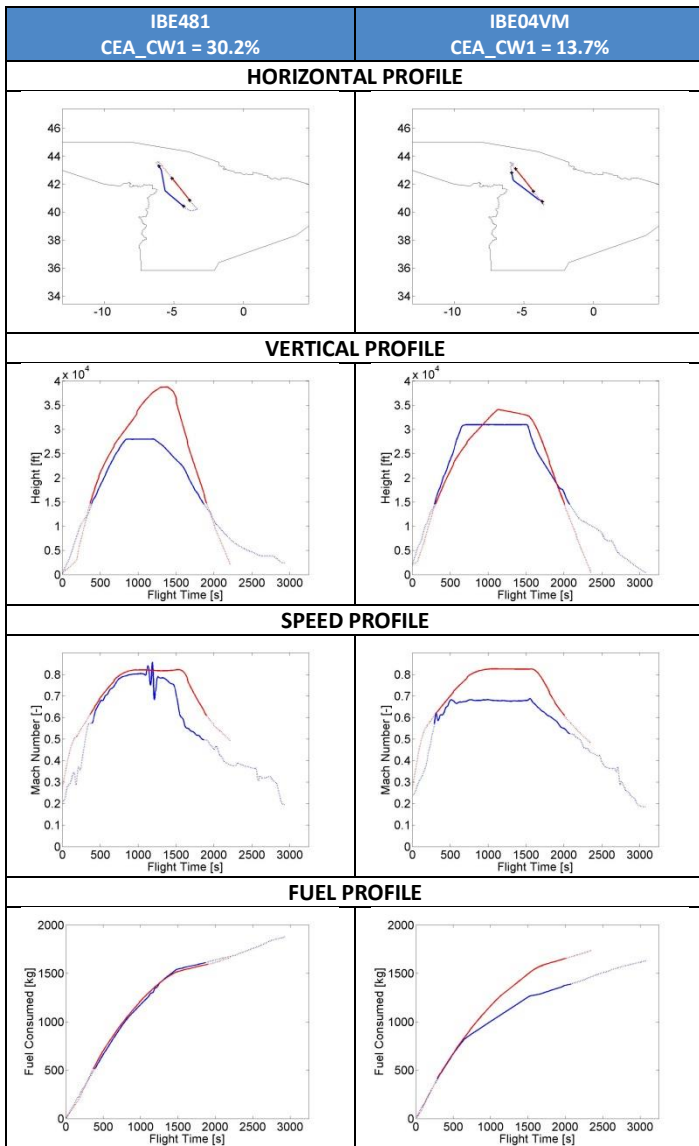


Figure 6. Impact of wind in cost-based flight efficiency indicators (AFT in blue, OCT1 in red)

CEA_CW1 and CEA_CW2 can also change the global picture of local inefficiencies. Fig. 7 represents the inefficiencies in the southwest area of the ECAC for February 24th. For example, flights crossing Romania and Bulgaria from Istanbul have values of CEA_CW1 from 15% to 30%, while KEA values are in the range of 5% to 15%.

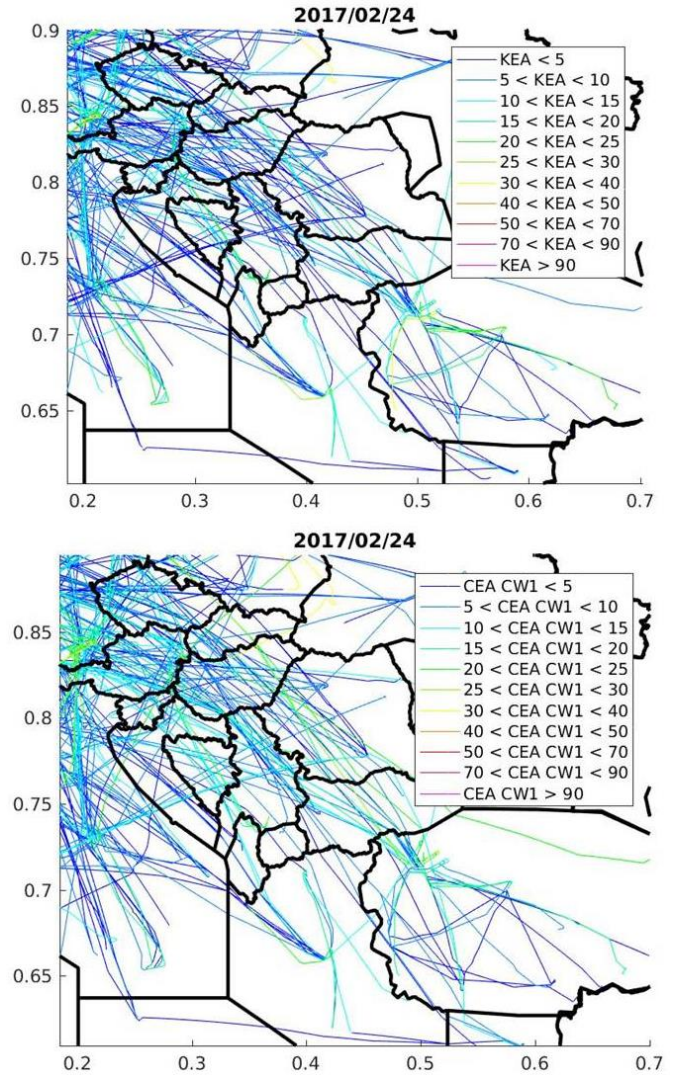


Figure 7. Cost-based and Distance indicators comparison

B. EQUITY

This subsection presents equity values calculated using EQ-4 indicator for the traffic sample of the 20th of February. The following figures provide the value for the equity indicator according to (5), and also the associated mean of the set to provide statistical background to the equity indicator. Depending on the context chosen (ECAC level, FIR level or route level), different conclusions can be extracted from the analysis.

Fig. 8 shows the EQ-4 calculation at ECAC level. It can be observed that EQ-4 is 4.05% while there is a mean of 3.65% of ratio between costs of the AFT and the FPT for all the flights

considered in the analysis. These values serve as baseline to compare the results per region or city pair.

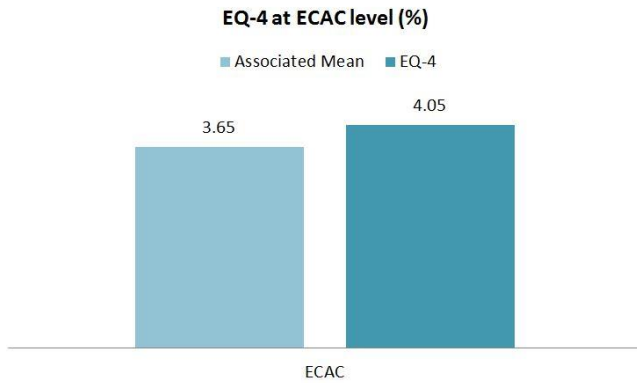


Figure 8. EQ-4 distribution (%) at the ECAC level

Fig. 9 shows the EQ-4 calculation for those flights with tracks inside four different ECAC regions: France (LF), Spain (LE), Germany (ED) and Italy (LI). According with these values and for this day, it seems that Germany represents the airspace in which the distribution among the airlines is less equitable. France is on the other extreme, with the lowest values for EQ-4. It can be also observed that its mean value of the cost ratio is not the lowest among the selected ECAC regions. Thus other regions are penalizing less the costs of flights but these other regions are less equitable between airlines.

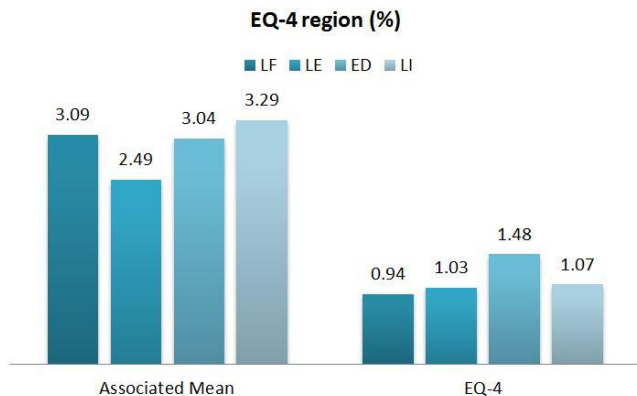


Figure 9. EQ-4 distribution (%) in different regions in the ECAC

Fig. 10 shows the equity calculations for eight city pairs, selected by the airlines collaborating on AURORA. As it can be seen, some city pairs have an average mean value of over 5%. However, when comparing IST-AMS and FCO-AMS, it can be observed that equity values are lower for the first city pair (IST-AMS). This means that the deviation in cost are less equitable distributed among the airlines flying FCO-AMS than IST-AMS. Observing the other city pairs, low equity values mean that the differences in cost between planned and actual are distributed equally among the airlines flying those city pairs. When compared with the ECAC level values, these city

pairs performance better in terms of equity than the average at the ECAC level.

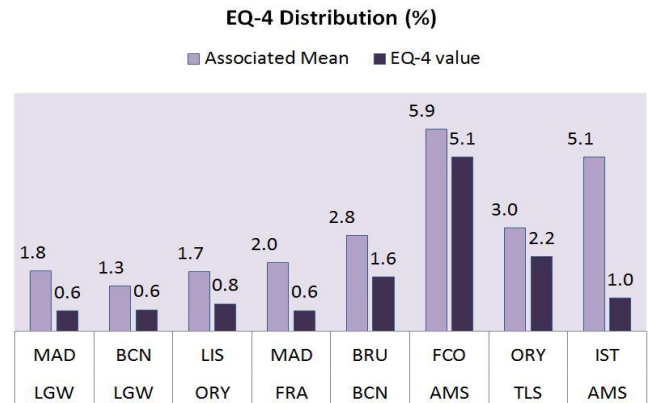


Figure 10. EQ-4 distribution (%) per city-pair

V. CONCLUSIONS

Due to the methodology proposed in this paper, ADS-B data could serve as a reliable source for the performance monitoring at the ECAC level, providing a new paradigm where ANSP's performance is not only evaluated locally, i.e., at the level of an ANSP area of responsibility, but also globally, i.e., how the actions of an ANSP impact the overall efficiency of a flight and the actions of other ANSPs responsible of that flight. In terms of the value of the KPIs analysed, the following conclusions were extracted:

- CEA_CW1 and CEA_CW2 represent how cost-efficient are the flights with respect to a future free routing environment and using today's route design respectively. Results show that half of the inefficiencies in terms of costs are due to the constraints in the route design.
- Flight inefficiency in terms of costs is not necessary aligned with inefficiency in terms of horizontal difference with respect to the geodesic trajectory i.e. CEA_CW1 and CEA_CW2 values differ from KEA values.
- Vertical and speed profiles together with the impact of weather conditions (wind, temperature and pressure) are relevant factors to be taken on board in order to quantify how cost-efficient a flight is, and this is not considered in today's indicator, i.e. KEA.
- Equity indicators provide an insight on how inefficiencies are distributed among airlines, allowing the detection of regions or routes that present abnormal values comparing with some average ones.

VI. FUTURE WORK

Based on the results and conclusions obtained from the analysis some research areas are defined:

- (1) Perform sensitivity analysis on how the assumed parameters, e.g. initial mass, affect the results.
- (2) Perform a systematic analysis to test if the different values of the indicators account for different inefficiency sources (i.e. if an indicator value, or combinations between different indicators, can pinpoint the source of the inefficiency to a specific event, such as holding patterns, inefficient speed profiles, etc.).
- (3) Calculate the indicators per phase, considering the need of introducing the approach and ascent procedures in all generated and reconstructed trajectories to isolate the effects of TMA. It should be also considered the need of defining some overlapping between phases due to the differences in flight time per phase between the generated and reconstructed trajectories. It is recommended to analyse the applicability of machine learning techniques.
- (4) Test how to measure the efficiency of flights which are also crossing the ECAC, and not only departing and arriving since this traffic also affects the efficiency of the ECAC traffic.
- (5) Analyse cause and effect relationships to quantify the impact of Airspace Users' operation modes on AURORA indicators.
- (6) Analyse how to include delay costs in AURORA indicators as an additional cost which is considered relevant for the airlines.

REFERENCES

- [1] ICAO, "EUR Region Performance Framework Document (ICAO EUR Doc 030)", 2013.
- [2] ICAO, "Manual on Global Performance of the Air Navigation System (ICAO doc. 9883)", 2009.
- [3] EUROCONTROL Performance Review Commission and University of Westminster, "Evaluation the True Cost to Airlines of One Minute of Airborne or Ground Delay", 2004.
- [4] IATA, EUROCONTROL and CANSO, "Flight Efficiency Plan. Fuel and Emissions Savings", 2008.
- [5] EUROCONTROL, "Performance Review Report 2015. An Assessment of Air Traffic Management in Europe during the Calendar Year 2015", 2016.
- [6] EUROCONTROL and FAA-ATO, "Comparison of Air Traffic Management-Related Operational Performance: US/Europe, 2016.
- [7] CANSO, "Global Air Navigation Services Performance Report 2015", 2015.
- [8] Commission Regulation (EC) No 390/2013, 3rd May 2013.
- [9] Commission Decision (EU) No 2015/348, 2nd March 2015.
- [10] University of Westminster, "European Airline Delay Cost Reference Values", 2011.
- [11] IATA, "Fuel Action Plan - Guidance Material and Best Practises for Fuel and Environmental Management", 2004.
- [12] S. Chesneau, I. Fuller and J.C. Hustache, "ATM Flight Efficiency and its Impact on the Environment", Eurocontrol Experimental Centre Note EEC/ENV/2003/001, 2003.
- [13] D. Howell, M. Bennet, J. Bonn, D. Knorr, "Estimating the enroute efficiency benefits pool", ATM Seminar, 2003.
- [14] I. Fuller, J.C. Hustache and T. Kettunen, "Enhanced Flight Efficiency Indicators", Eurocontrol Experimental Centre report EEC/ENV/2004/011, 2004.
- [15] EUROCONTROL, "Performance Indicator – Horizontal Flight Efficiency Edition 01-00", 2014.
- [16] PRU, "Vertical Flight Efficiency During Climb and Descent", April 2016.
- [17] EUROCONTROL Performance Review Commission, "Vertical Flight Efficiency", 2008.
- [18] T. Kettunen, J.C. Hustache, I. Fuller, D. Howell, J. Bonn and D. Knorr, "Flight Efficiency Studies in Europe and the United States", 6th USA/Europe ATM R&D Seminar, June 2005, Baltimore.
- [19] C. Nutt "NATS Fuel efficiency metric". NATS. January, 2012.
- [20] E. Calvo, J.M. Cordero, L. D'Alto, J. López-Leonés, M. Vilaplana, "A New Method to Validate the Route Extension Metric against Fuel Efficiency", 2015 ATM Seminar.
- [21] J. A. Besada, G. Frontera, J. Crespo, E. Casado and J. López-Leonés, "Automated Aircraft Trajectory Prediction Based on Formal Intent-Related Language Processing", IEEE Transactions on Intelligent Transportation Systems, Vol. 14, No. 3, September 2013.
- [22] Javier López Leonés, Definition of an aircraft intent description language for air traffic management applications. PhD Thesis, University of Glasgow, 2008.
- [23] J. López-Leonés, M. Vilaplana, E. Gallo, F. Navarro and C. Querejeta, "The Aircraft Intent Description Language: A Key Enabler for Air-Ground Synchronization in Trajectory-Based Operations", 26th Digital Avionics System Conference, 2007.
- [24] EUROCONTROL, "User Manual for the Base of Aircraft Data (BADA) Revision 3.10", EEC Technical/Scientific Report No. 12/04/10-45, 2012.
- [25] J. López M. A. Vilaplana I. Bayraktutar J. K. Klooster J. M. Asensio G. McDonald P. Kappertz "Towards an open test bed for the study of trajectory synchronization in the future ATM system: The ASIS initiative", Proc. ICNS, pp. 1-14 2009-May.
- [26] G. Frontera J. A. Besada A. M. Bernardos E. Casado J. Lopez-Leones "Formal intent-based trajectory description languages", IEEE Transactions on Intelligent Transportation Systems, vol. 15 no. 4 pp. 1550-1566 Aug. 2014.
- [27] Jesper Bronsvort, Paul Zissermann, Steven Barry, Greg McDonaldE. "A Framework for Assessing and Managing the Impact of ANSP Actions on Flight Efficiency", 2015 ATM Seminar.
- [28] IATA "Fuel Price Analysis" <http://www.iata.org/publications/economics/fuel-monitor/Pages/price-analysis.aspx>. 2017.
- [29] EUROCONTROL, "Conditions of Application of the Route Charges System and Conditions of Payment", 2011.
- [30] EUROCONTROL, "EUROCONTROL Route Charges System", 2016.
- [31] J. Lopez Leones, M. Polaina Morales, P. Sánchez Escalonilla, D.Ferrer Herrer, M. Sanz Bravo, F. Celorrio Camara. "ADS-B based Air Traffic Performance Assessment: Develop New Metrics for Measuring ANSPs and airlines Flight Efficiency". 7th EASN Conference, September, 2017
- [32] P. Sánchez-Escalonilla, F.Celorrio, J. López-Leones, D. Ferrer, M. Polaina. "Definition of user-centric air traffic efficiency indicators". Madrid, February 2017.
- [33] D. Ferrer, P. Sánchez-Escalonilla, L. Meler, M. Sanz, F.Celorrio, A. Martínez, J. López Leones, M. Polaina. "Report on testing of user-centric air traffic efficiency indicators and local targets". Madrid, July 2017.
- [34] W. Roberson, "Fuel Conservation Strategies: Cost Index Explained". AERO_Q207_article5, 2007.
- [35] W. Roberson, R. Root and D. Adams, "Fuel Conservation Strategies: Cruise Flight". AERO_Q407_article5, 2007.
- [36] Airbus Flight Operations Support & Line Assistance, "Getting to grips with the cost index". STL 945.2369/98. Issue II, 1998.