Impact of Free Route Airspace Implementation on Safety Performance

Ex-post Analysis of Northern Europe Free Route Airspace (NEFRA)

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***Abstract*—The modernization of the ATM system in Europe is coordinated by the Single European Sky ATM Research (SESAR) programme established in 2004. With the SESAR deployment phase already progressing in Europe, there is a growing need to assess its real impact on ATM performance. Free Route Airspace (FRA) is one of the most widely implemented SESAR solutions in Europe. This paper aims at analyzing the actual effects of cross-border FRA implementation on safety performance, measured by the number of potential safety-related events and exposure to risk. One of the largest FRA in Europe - the Northern Europe Free Route Airspace (NEFRA) - has been selected as a showcase of the performance methodology proposed. It has been shown that FRA implementation had a positive impact on safety performance in NEFRA airspace, leading to a significant reduction in the number of potential separation losses (35%). Moreover, changed traffic characteristics have led to a decrease of risk exposure index by almost 70%.**

Keywords: free route airspace, ATM performance, safety, risk, post-ops analysis

I. INTRODUCTION

By facilitating mobility of people and goods across the globe, air transport serves as a catalyst for economic growth. Air Traffic Management (ATM) is a system component that plays an essential role in keeping air transport operations safe, orderly and expeditious. The modernization of the ATM system in Europe is coordinated by the Single European Sky ATM Research (SESAR) programme established in 2004. With the SESAR deployment phase already progressing in Europe, there is a growing need to assess its real impact on ATM performance. This was also highlighted in a recently published special report of European Court of Auditors (ECA) [1], where the "*appropriate monitoring of performance benefits delivered by ATM modernization*" appears as one of its key recommendations.

Free Route Airspace (FRA) is a specified airspace within which users can freely plan a route between a defined entry point and a defined exit point, with the possibility of routing via intermediate (published or unpublished) waypoints, without reference to the Air Traffic Services (ATS) route network, subject to availability. Within such airspace, flights remain subject to Air Traffic Control (ATC) for the separation provision and flight level change authorizations [2].

FRA is one of the most widely implemented SESAR solutions in Europe. Full 24h FRA implementation has taken place in 21 European states so far [3]. Partial implementation during night, week-end or based on permission to plan direct/DCT between a defined set of points has already been provided in a large number of European states. For example, by end of 2018 more than 40 Area Control Centres (ACCs) in Europe have already progressed with partial FRA implementation.

The major benefits of free route operations are distance and flight time savings, resulting in less fuel consumption and a notable reduction of jet engine emissions which benefits the environment [4]. These benefits are also important to meet societal goals. Moreover, for the airspace users, these benefits show a huge potential yielding a cost reduction of up to 3.8% if applied to whole Europe [5].

Notable efforts so far have been devoted to investigate potential benefits of various ATM solutions by employing simulation and optimization tools (e.g. [6], [7], [8]). Due to their nature and goal, this kind of assessments usually rely on fairly simplistic assumptions (e.g. the aircraft will follow the shortest route after FRA implementation), which is why the implementation benefits are often overestimated and rather represent the theoretical maximum that could potentially be achieved in the post-implementation period.

However, there have been very little attempts so far to estimate the actual effects on performance after the implementation has taken place. One of the reasons is that many SESAR solutions are still in the early phase of deployment or

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they have been implemented only recently and not enough performance data has been collected since the implementation date. The other reason can be attributed to difficulties of isolating the effect of one single factor (solution implementation) on real-world ATM performance, which is usually the outcome of many different factors and their combined influence (e.g. weather, fuel price, airline business models etc.).

Despite environment and cost-efficiency being the key performance areas where benefits are expected from FRA implementation, it is of utmost importance to ensure that safety always remains uncompromised. In one of the recent publications [9], dealing with the effects of FRA implementation in Hungarian Airspace, it is briefly stated that "*HungaroControl's safety performance has not only been maintained, but even improved, despite the continuous traffic growth*". Although very interesting, it is difficult to say if this finding can be solely attributed to FRA implementation, as it comes from a standardized post-ops report on classified safety occurrences.

In response to previously discussed issues and given the scarcity of relevant post-implementation studies, this paper aims at analyzing the actual effects of cross-border FRA implementation on safety performance, measured by the number of potential safety-related events and exposure to risk. The paper suggests a move from conventional performance measurement of the airspace safety by introducing proxies, such as the assessment of potential separation losses found in tactical trajectories, as well as risk exposure index. It should be noted that potential separation losses are not the actual conflicts that occurred in a given airspace, but these events are used as a proxy of safety performance or a measure of air traffic controllers' (ATCO) taskload.

The remainder of the paper is structured as follows: Section II briefly describes the scope of the study and methodology applied; results of the analysis are presented in Section III, while Section IV summarizes the paper and gives proposals for further research.

II. Scope and Methodology

One of the largest FRA in Europe - the Northern Europe Free Route Airspace (NEFRA), covering airspaces of six states (Estonia, Latvia, Finland, Sweden, Denmark, and Norway), has been selected as a showcase of the performance methodology proposed in this paper (Fig. 1 shows NEFRA airspace as defined in December 2018).

The NEFRA programme was established on 11th March 2013 when six states committed to undertake necessary actions to ensure implementation of the FRA concept above FL 285 in the joined airspace, named as NEFRA. Before the programme started, each of the Air Navigation Service Providers (ANSPs) participating in NEFRA already had plans to implement the FRA concept, following different approaches. The diversity of the lower limits established for each FRA ranged from FL95 of the former joint FRA between Finland, Estonia and Latvia, to FL285 of the FRA in Denmark-Sweden (DK/SE) FAB. In between, Norway defined two FRAs - one over the continental airspace with the lower limit at FL135, and a second one in the oceanic airspace above FL195 [10].

Figure 1. Geographical scope of the study

Analysis of the impact of cross-border FRA implementation on safety performance was done through assessment of the changes in **Situations of Interest (SoIs)**, i.e. changes in the number of potential safety-related events (separation minima infringements) and their characteristics. SoIs represent the events of potential safety concern where two aircraft come closer to each other than a specified minimum distance both in the horizontal and the vertical plane. The minimum separation criteria was set at 5NM for lateral separation and 1000ft for vertical separation. By excluding traffic below FL285, the effect of different separation minima within TMA was avoided.

Traffic data used in the analysis is based on 28-day Aeronautical Information Regulation and Control (AIRAC) cycle datasets, pre and post cross-border implementation, available via EUROCONTROL Demand Data Repository (DDR2) service. Analysis of performance during cross-border FRA implementation was done using the Current Tactical Flight Model (CTFM) (M3 in NEST terminology) flight trajectories. These are trajectories constructed by the Enhanced Tactical Flow Management System (ETFMS) of EUROCONTROL Network Manager to tactically represent a flight being flown. This actual trajectory refines the last filled flight plan trajectory (M1 in NEST terminology) when Correlated Position Reports (CPRs) show a significant deviation (1 min in time, more than 400 feet in en-route phase, more than 1000 feet in climb/descent phase or more than 10 NM laterally) and/or upon message updates from ATC (DCT, level requests, FPL update) [11].

The identification of separation violations was done using Conflict module built in Network Strategic Tool (NEST). Every second the module is searching for a loss of separation between all pairs of aircraft. Nevertheless, conflict detection in this module should be considered only as a guess, since aircraft never follow exactly their 4D trajectory flight plan, and M3 trajectory is an approximation of the actual trajectory, hence this occurrence is only a potential safety-related event.

Therefore, these events, identified using modules available in NEST via static trajectory analysis, do not necessary pose a safety threat. For example, there are many circumstances in which separation minima breach could have been justified or, on the other hand, undetected. Therefore, these should only be considered as an estimate of what could have gone wrong and they should not be taken negatively.

As mentioned before, the main challenge in estimating real effects in post-implementation period is the lack of controlled environment (compared to simulation approach), resulting in the influence of many different factors on the chosen output indicator, some of which may not be easily perceivable (e.g. difficulties in modelling airspace users' route choice behavior and associated influencing factors).

Our approach is based on intervention analysis of the time series data [12] - a common statistical method used for analyzing the impact of an intervention or external shock (in this case - FRA implementation) on the evolution of a given (performance) indicator over time. The first step is to identify if there were any immediate and obvious effects of FRA implementation on the target indicator (Number of SoIs) by searching for significant structural breaks[2] in the time series and assessing their connection with FRA implementation [13]. Breakpoints and their associated confidence intervals are estimated in Ordinary least squares (OLS) regression employing dynamic programming. Since the number of breakpoints m is not known in advance, it is necessary to compute the optimal breakpoints for m = 0, 1…n breaks and choose the model that minimizes some information criterion such as Bayesian Information Criterion (BIC) [14].

Once the structural breaks have been identified, the next step is to quantify the impact of FRA implementation. Since in this case a randomized experiment is not available, there is a need to estimate how the response variable (Number of SoIs) would have evolved after FRA implementation if the implementation had never occurred. For that purpose, a Bayesian structural time-series model is constructed, supported by an additional regressor (daily traffic demand) that is strongly correlated with the response variable, but was itself not affected by the implementation. Specifically, the model is trained on pre-implementation data in order to determine the relationship between the response variable and a selected regressor. The model is then used to predict the values in the post-implementation period (counterfactual), assuming that the intervention (FRA implementation) had never occurred.

The predicted values in the post-implementation period are later compared with the actual (observed) values of the response variable in order to assess the impact of FRA implementation. This methodology is commonly referred to as a Causal Impact analysis [15].

Finally, a year-on-year comparison of the relevant safety indicators for a selected month is presented in order to observe their evolution over a longer period and account for the effect of additional NEFRA programme milestones achieved after the initial implementation in November 2015.

III. Analysis and Results

A major milestone in NEFRA implementation was achieved on 12 November 2015 when FRA was implemented in North European Functional Airspace Block (NEFAB) states - Finland, Estonia and Latvia above FL95, and Norway above FL135.

In order to determine the point in time when the implementation of NEFRA started affecting safety performance and for a proper selection of the reference month for year-on-year comparisons, an identification of the structural breaks was performed on a time series of SoI rate (Number of SoIs per 1000 flights) from 1 January 2015 to 20 July 2016. The optimal number of level breakpoints identified is 3 and they occur on the following dates: 29 March 2015, 29 October 2015 and 06 April 2016 (see Fig. 2).

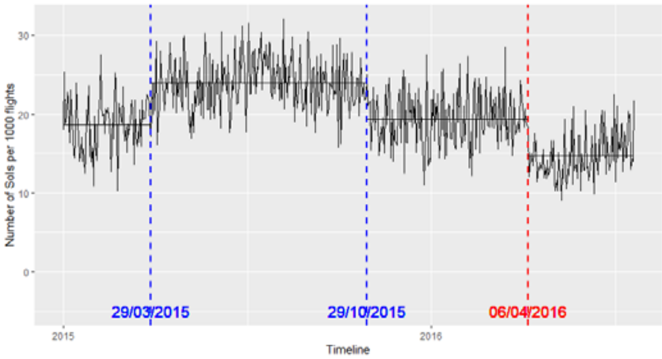

Figure 2. Significant structural breaks in SoI rate time series

The first two breakpoints (colored in blue in Fig. 2) correspond approximately with the summer airline scheduling season (spanning from 29 March to 24 October 2015), characterized by higher traffic demand levels. This is fully expected behavior, since the correlation between SoIs and traffic is fairly strong (PCC[3]≈0.75).

However, the third breakpoint (colored in red) occurring on 06 April 2016 is followed by notable decrease in SoI rate, despite the regular increase in traffic demand associated with the start of the next summer scheduling season. The reason for

[2] A structural break represents an abrupt change in the mean or other time series' parameter at a certain point in time. They can be of several types: level, trend, polynomial etc. In this study, we identify only level structural breaks.

[3] Pearson correlation coefficient.

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this could be that FRA implementation brings more safety benefits during the periods of higher traffic demand.

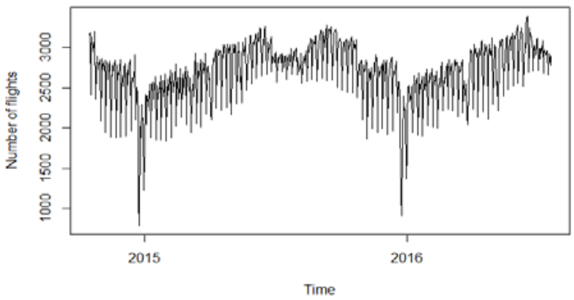

Figure 3. Daily traffic demand in the period under study

In order to quantify the immediate effect of the FRA implementation on NEFRA safety performance, a Causal Impact analysis was performed. As mentioned before, the main goal of this methodology is to estimate how the target indicator would have evolved after the implementation if the implementation had never occurred.

Daily traffic demand values were appended to the target indicator (Number of SoIs), to serve as a relevant predictor not itself affected by FRA implementation (see Fig. 3; notable dips in traffic are caused by Christmas and New Year).

The Bayesian structural time-series model, used for estimating the baseline in the post-implementation period, was trained on data of one year preceding the structural breakpoint on 06 April 2016.

A preliminary analysis of the time series characteristics (trend, seasonality, autocorrelation etc.) has been conducted in order to set appropriate parameters for the model. The best fit (R^2=0.86) is obtained with frequency parameter set at 364 days. Namely, the indicator values on every single day are similar to those observed exactly 364 days later, indicating a seasonality at yearly level. Furthermore, this number is divisible by 28 and 7, to account for AIRAC cycles and day-of-the-week effect.

The results of the analysis are shown in Fig. 4. The top chart shows the original time series of the target indicator (black line), together with predicted values in the post-implementation period (blue dashed line). Pointwise differences between actual and predicted values are shown in the middle chart, while the cumulative effect in the post-implementation period is shown in the bottom one.

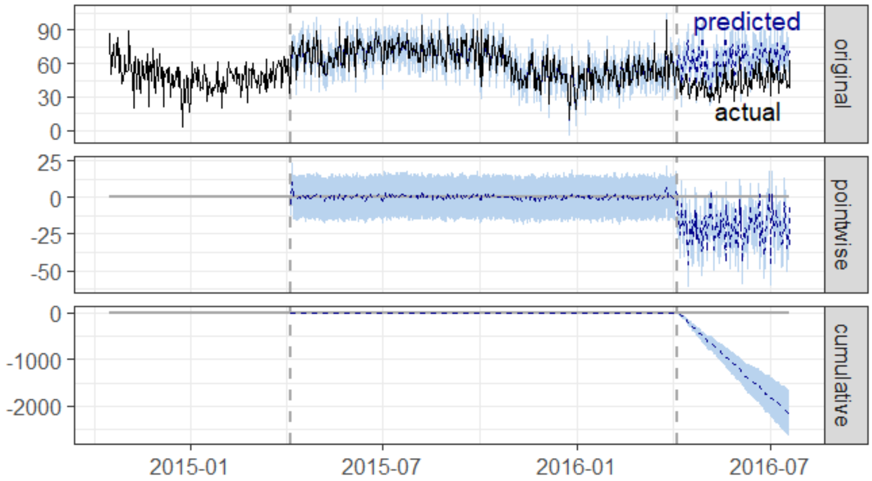

Figure 4. Results of the Causal Impact analysis of the target indicator (Number of SoIs)

The results shown in Fig. 4 are summarized in Table 1:

TABLE 1. SUMMARY OF THE CAUSAL IMPACT ANALYSIS

	Average	Cumulative
Actual	43	4592
Prediction (s.d.)	64 (2.5)	6766 (261.9)
95% CI	[59, 68]	[6250, 7259]
Absolute effect	-21 (2,5)	-2174 (261.9)
95% CI	[-25, -16]	[-2667, -1658]
Relative effect	-32% (3.9%)	
95% CI	[-39%, -25%]	

During the post-implementation period (in particular, after 06 April 2016), the target indicator had an average value of approx. 43.32. On the contrary, in the absence of FRA implementation we would have expected an average response of 63.83, which gives a difference of -20.51. In relative terms, this corresponds to a reduction in the Number of SoIs by 32% in the period shortly after implementation. The effect can be considered statistically significant (Bayesian one-sided tail-area probability p = 0.001).

Given the longitudinal nature of data and the purpose of the model, it was not possible/reasonable to use common validation techniques (e.g. k-fold cross validation) to validate the model. Instead, the predictive accuracy of the model was tested by conducting additional Causal Impact analysis entirely in the pre-implementation period. As expected, rather small differences between predicted and actual values were obtained, indicating a good quality of the model.

To assess the evolution of safety performance in the NEFRA airspace during FRA cross-border implementation, several time periods were chosen to show the gradual effect of this implementation.

Since NEFRA implementation was a phased process, starting with FRA implementation in NEFAB states on 12 November 2015, continuing with the seamless connection with Denmark/Sweden (DK/SE) on 23 June 2016 and reaching the final milestone of full cross-border FRA with Norway on 25 May 2017, as well as due to extensive amounts of data, it was decided to choose the time periods that will cover the pre-implementation stage, implementation, and post-implementation period, by analyzing the same month of data for each year between 2015 and 2018.

Taking into account the findings of a preliminary impact analysis, a busy summer month of July was chosen as a reference for the year-on-year comparisons.

The evolution of SoIs and traffic demand in NEFRA airspace for the selected month in the period from 2015 to 2018 is summarized in Table 2.

While the number of flights and flight hours within NEFRA airspace has been constantly increasing after cross-border FRA implementation (by approximately 13.5% and 13.8% respectively in the period from 2015 to 2018), the total number of potential losses of separation has decreased by 26%. The number of SoIs per 1000 flights has decreased from 26.3 in 2015 to 17.2 in 2018, which represents a decrease of almost 35% (more or less in line with the results of the Causal Impact analysis). This clearly indicates that FRA implementation has brought safety benefits in NEFRA airspace, as the probability of safety related events (i.e. separation losses) has reduced regardless of the traffic increase.

TABLE 2. TRAFFIC VS SOIS (2015-2018)

Indicator	**Year (*July only)**			
	2015	**2016**	**2017**	**2018**
Mean No of aircraft per day	2851	2928	3095	3235
Mean Flight Hours per day	1604	1638	1747	1823
Mean flight hours per flight	0,563	0,560	0,564	0,564
Total no of SoIs	2098	1351	1511	1556
No of SoIs per 1000 flights	26,28	16,48	17,43	17,18

As seen in Table 2, the greatest reduction in the number of SoIs happened immediately after cross-border implementation in 2016, while in 2017 and 2018, regardless of the significant increase in traffic, the number of potential separation losses on average stayed almost at the same level. Bottom line is that after the cross-border FRA implementation the safety performance was not impacted by the traffic increase.

To get a better insight into the evolution of hotspots, Fig. 5 shows the SoIs density in NEFRA airspace in the period from 2015 to 2018. The impact of the traditional ATS route structure is clearly visible in 2015. In subsequent years, it is indicative that SoIs are becoming more spread over time and “hotspots” are becoming less dense.

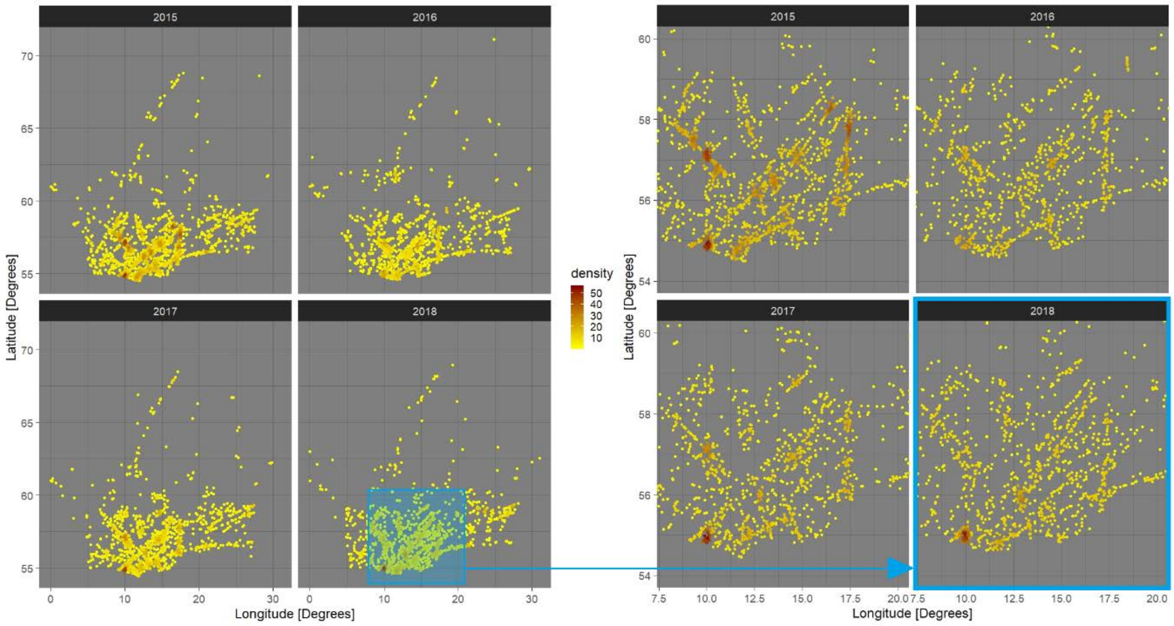

Figure 5. Density of SoIs in NEFRA airspace (July, 2015-2018)

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Another indicator analysed in this study is the risk exposure index, which combines safety and operational/trajectory information by taking into account potential separation losses and their characteristics (severity) based on historical trajectory information. The severity of potential separation losses is defined by their duration, magnitude of separation minima breach and type of separation loss in terms of geometry.

The risk exposure index was calculated according to the following formula:

$$risk\ exposure\ index = \frac{SV\ severity * SV\ duration}{flhrs} \quad (1)$$

where:

$$SV\ severity = Sc * (70 * SVc + 20 * SVo + 10 * SVp) \quad (2)$$

$$Sc = \frac{minsep - actsep}{minsep} \quad (3)$$

$$SV\ duration = time_e - time_b \quad (4)$$

Detailed information on parameters used in (1-4) to calculate risk exposure index can be found in Table 3.

TABLE 3. RISK EXPOSURE PARAMETERS

Variable	Definition	Variable	Definition
Sc	Separation breach index	SV	Number of potential Separation Violations (SV)
minsep	Minimum separation parameter	SVc	SV when aircraft are converging
actsep	Actual separation distance	SVo	SV when aircraft are opposite
$time_e$	Time when contact ends	SVp	SV when aircraft are parallel
$time_b$	Time when contact begins	flhrs	Flight seconds (flight hours*3600)

Weights (70, 20, 10) in formula (2) are used to indicate the impact of separation violation type (geometry) on controller's task of de-conflicting.

Analysis (Fig. 6) shows that the risk exposure index has dropped by almost 78% in 2016, following the cross-border FRA implementation. However, in 2017 and 2018 it increased by approximately 31% and 7%, respectively. Overall, the risk exposure index decreased by almost 70% (-68.5%) between 2015 and 2018. This indicates that not only the number of potential separation losses has decreased after FRA implementation, but their severity as well.

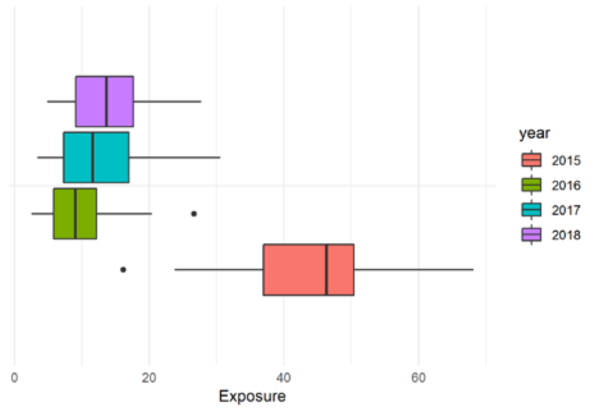

Figure 6. Risk exposure index (July, 2015-2018)

Besides the fact that risk exposure is decreasing due to a decrease in the number of potential separation losses, other two reasons for this change could be the change in the severity of encounters (reduction of separation breach) and the change in the share of different types of potential encounters (depending on their geometry), taking into account that their criticality is not the same.

IV. CONCLUSIONS AND FURTHER RESEARCH

The goal of this paper was to analyze the effects of FRA implementation on ATM performance, with a special focus on safety key performance area. The analysis presented has been conducted in response to scarcity of similar post-ops assessments of the real effects of novel ATM solutions in European airspace. The case study of NEFRA airspace also sets a new methodology and a benchmark for future monitoring of safety performance after FRA implementation.

It has been shown that FRA implementation had a positive impact on safety performance in NEFRA airspace, leading to a significant reduction in the number of potential separation losses (35%). Moreover, changed traffic characteristics have led to a decrease of risk exposure index by almost 70%. Although the number of flight hours has increased as well as the mean number of flight hours per flight, this did not compromise the safety of the airspace as the number of potential encounters has reduced substantially. Overall, despite the increase in traffic density, safety performance of NEFRA has improved, both in terms of the number of potential separation losses and in terms of their severity.

The Causal Impact methodology used in this paper has demonstrated a potential to be applied to other key performance areas and indicators. However, a notable effort has to be devoted to a proper identification and analysis of the predictor variables. In order to properly model the baseline situation (how the response indicator would have evolved if the implementation had never occurred), it has to be ensured that these variables were themselves not affected by implementation. In certain cases, this requirement greatly complicates the application of such methodology to other performance areas and indicators.

Further research on this topic could go in many directions. It would be interesting to include other performance areas and indicators as well as to extend the geographical scope of the analysis. With FRA concept expected to be implemented Europe-wide by end of 2021, there will be a need to assess the overall benefits it has brought at European level, covering different key performance areas and interdependencies between them. Moreover, other trajectory data sources, such as Automatic Dependent Surveillance - Broadcast (ADS–B), could be used in order to estimate achieved safety performance more accurately. Finally, validation of results could be performed using operational feedback from ATCOs and flight crews, if these become available.

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