Traffic Forecasts and their Influence on the Environment

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ABSTRACT

Air navigation service providers ensure safe and efficient flight operations by managing the separation of aircraft. Following a sharp downturn due to the COVID pandemic, air traffic demand is currently recovering. It may be expected that the increasing number of flights directly affects the environment. Based on the STATFOR traffic forecasts from autumn 2021, we use regression analyses to predict delays, emissions, and environmental costs for the years 2021 to 2027. We will show that the uncertainty of traffic demand has significant consequences for environmental performance indicators.

KEYWORDS: Air Traffic Management, Forecast, Efficiency, Delay

1. Introduction

Prior the turn of the Millennium, air transport was characterized by relatively steady growth. The experience of the last two decades has also shown that civil aviation on balance recovers quickly from external shocks. Even if, the most positive traffic estimates are not realized, and traffic does not reach pre-pandemic levels for another four to five years, demand can be expected to increase in the long run.

In the early 1990s, EUROCONTROL started to assess the European air navigation service providers (ANSPs). In the currently valid benchmarking scheme, four Key Performance Areas (KPAs) are defined: safety, capacity, cost efficiency, and environment. The latter is expressed by the indicator "horizontal flight efficiency" (HFE) and is mainly a metric expressing detours.

During the COVID pandemic, performance benchmarking mainly focused on cost efficiency, supplemented by capacity in pre-COVID times, while environmental aspects played a minor role. However, with the relaxation of the COVID measures by the governments, the industry experiencing a strong increase in traffic movements, which also raises environmental concerns. Further, social pressure (e.g., Fridays for future) caused a shift of focus towards environmental aspects of air traffic.

Although the importance of environment in performance benchmarking has increased, there have been no studies on the relationship between traffic forecasts and environmental impacts. This gap is filled by the present study. Therefore, the paper is structured as follows. Section 2 covers the first focus area. We describe the traffic scenarios which are mainly based on the forecasts provided by STATFOR in autumn 2021 (EUROCONTROL., 2021b). We also briefly look at the consequences for the ANSPs (resources and costs) as well as for the airspace users (delay). The second focus area (section 3) addresses the definition, assessment, and prediction of the Horizontal Flight efficiency. Section 4 summarizes the findings and provides an outlook on further research.

2. Forecasting European Air Traffic

2.1 Traffic Scenarios

Traffic forecasts have significant influence on the cost- and resource planning of an ANSP. To ensure service provision at minimum total costs to stakeholders, it is necessary to predict the demand as precisely as possible. The optimum competes with sufficient resources for robust and safe operations, but minimum resources for cost-effectiveness.

Nevertheless, forecasting always inheres uncertainty due to global (e.g., financial crisis) or local (e.g., the Russian attack on Ukraine) events, leading to short-term changes in traffic demand. To cover these uncertainties, STATFOR published three scenarios (low, base, and high) (EUROCONTROL., 2021b). However, it was highlighted in (Fricke, 2021a) that the forecast quality is very limited and

(FABEC., 2021, Standfuss, 2021b) showed that in the past the actual demand did not match the confidence interval (CI) in the majority of cases. As a consequence, we created two further scenarios (super high and super low): the super low scenario assumes that there is a new virus mutation in 2022 and traffic figures decrease again, followed by a growth rate below the low scenario for the years 2023-2027. The super high scenario expects that COVID was a significant, but short external shock and traffic figures recover faster as anticipated by STATFOR. The growth rates are 2%-10% higher than the ones in the high scenario.

We applied this method to all ANSPs, using the transformation procedure (state-related figures into ANSP related figures) proposed by (Standfuss, 2021b), as well as to all Functional Airspace Blocks (FABs) and the EUROCONTROL area (also further designated as "Europe"), the latter shown in Figure 1 (left). As shown in the figure, the expected demand in 2027 may increase up to 14 M flights in the most optimistic scenario. In the most pessimistic scenario, the demand will be about 9.3 M flights and thus below the number in 2019. The STATFOR scenarios inhere a CI of 1.8 M Flights, the range between super high and super low scenario represents 4.8 M flights.

2.2 Resources and Costs

It goes without saying that the implied confidence intervals lead to planning uncertainties for ANSPs. Resource planning relies on expected demand for a pre-set horizon. With Air Traffic Control Officers (ATCOs) being the most scarce and expensive resource. Using ACE data (EUROCONTROL., 2020b) and assuming a constant ATCO-productivity (the reference year 2019) (EUROCONTROL., 2020c, EUROCONTROL., 2021a), we can calculate the number of ATCOs and the corresponding employment costs for each ANSP as well as each scenario.

Unlike flights, resources and costs are clearly allocated to an ANSP. This means that the values can be aggregated and therefore the required controllers and subsequent employment costs can be calculated on the FAB level. As an example, the largest unit in meanings of demand, FABEC, employed 5,609 ATCOs in 2019. Using the forecasted traffic scenarios, the FAB will need between 4,668 and 7,167 ATCOs in the year 2027, respectively 5,865 ATCOs in the case of STATFORs baseline scenario. In other words, the uncertainty with regards to resources is 2,499 Full-Time Equivalences (FTEs) when comparing super high and super low scenarios.

The need for resources directly affects the costs to be planned for Reference Period 3 (RP3) and beyond. In 2019, employment costs in FABEC summed up to 1.07B Euros. As shown in Figure 1 (right), the expected costs for the year 2027 will be between 890M and 1.4B Euros, respectively 1.1B Euros in the most-likely scenario.

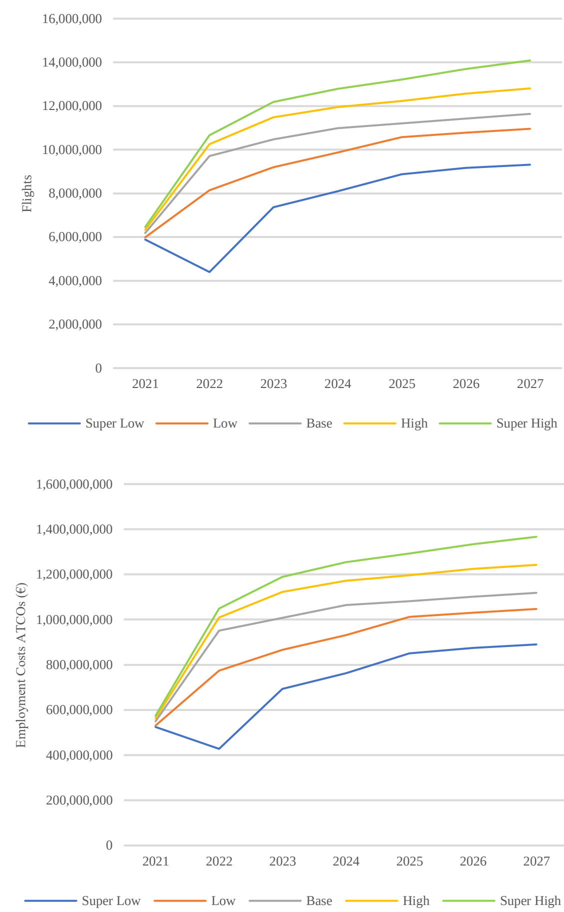

Figure 1. Expected Flights in the EUROCONTROL area (left) and expected ATCO employment costs for FABEC (right)

The conversion of demand into resources (ATCOs) inheres to some limitations. First, the assumption of a linear interdependency between resources/costs and demand might not be accurate, since scale effects are expected to have an influence. Second, the need for resources does consider ATCOs only. However, an increase in ATCOs may lead to the need for other resources as well (administrative staff, working positions, etc.), affecting costs as well. Third, the costs do not consider training costs or drop-out rates. Fourth, productivity is expected to be constant at the 2019 level. Fifth, the calculations do neither consider contractual or union aspects nor the availability of ATCOs. Last, a change of traffic flows may lead to higher or lower workload influencing the actual need of ATCOs and subsequently their productivity and costs.

2.3 Delay

An essential quality criterion of ANS service is represented by the punctuality of flights. If demand exceeds the available capacity, delays will occur, which can be due to various reasons, including weather, staffing, accidents, etc. Accordingly, in ANS provision delays are divided into total ATFM delay (all causes) and CRSTMP delay (those causes which can be assigned to ANSPs). EUROCONTROL publishes data for the number of flights as well as the delay minutes (distinguished into causes on a daily basis. We used the data from 2015 to 2019 to derive the interdependency between demand and delay. Earlier studies revealed that the function relationship should be expected to be exponential (Galarraga, 2021, Standfuss, 2021a). Thus, we imply the functional form shown in (1), where y stands for the delay, x for the flights, and a, b and c are parameters to be optimized. The parameter c represents an "offset" or "threshold" parameter, implying that delay does not occur below the corresponding demand.

$$y=a(x-c)^b \qquad (1)$$

The solver optimizes the parameters so that the quadratic distance between observations and function is minimized. This procedure was applied for both total and CRSTMP delay. Due to the high heterogeneity in European ATM and the subsequent particularities of ANSPs, the analysis was executed for each ANSP separately. For CRSTMP delay, it assumed that the offset parameter is at least as high as the one for ATFM delay. This is necessary since CRSTMP delay is a share of the total ATFM delay.

It can be observed that the relationship between demand and delay tends to be linear for smaller ANSPs (b = 1), while the exponential parameter for larger ANSPs results in a parabolic or hyperbolic function. This can be explained by the fact that those small airspaces are also non-saturated. As a result, demand is not yet in the range of exponential growth and delay occurs due to capacity constraints in no or just a minor number of cases. Some of the ANSPs have no (reported) delay or only a small number of observations, which may hamper a precise forecast.

Based on the functional shape, as well as the predicted flights, the delay can be determined for each day for the years 2021-2027. Since delay minutes are aggregatable, the values for FABs and Europe can be determined by summing up the minutes of the corresponding ANSPs. Further, it is possible to calculate the ATFM delay per flight, respectively CRSTMP-delay per flight, which might be beneficial for capacity target monitoring (FABEC., 2018) or setting (PRB., 2018). Figure 2 shows the expected total delay minutes per flight for the German ANSP DFS. Depending on the year and scenario, the share of CRSTMP-delay is about 62% to 85%.

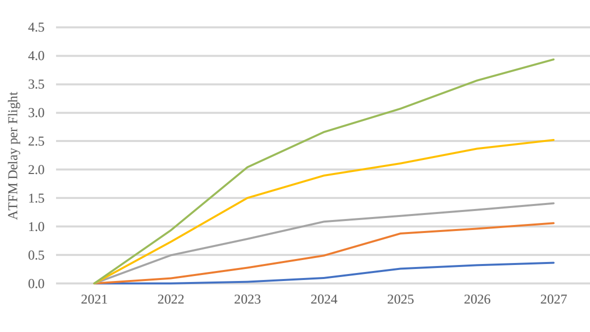

Figure 2. Expected ATFM delay per flight, 2021-2027, DFS

3. Environmental Benchmarking

3.1 Horizontal Flight Efficiency

In the EUROCONTROL benchmarking scheme, environment-related performance is assessed by the horizontal en-route flight efficiency (EUROCONTROL., 2021c). PRU publishes the achieved and flown distance for each day. The corresponding indicators may be referred to as three different trajectory data (EUROCONTROL., 2021d):

- The shortest constrained trajectory (SCR),
- The last filed flight plan trajectory (FTFM),
- The actual trajectory (CPF).

Official reports as well as the provided database use indicators to express the HFE, representing a proxy for detours. The higher the indicator, the lower the efficiency. In our study, we focus on the indicators of the planned (KEP) and actual trajectory (KEA). The indicators are calculated as shown for KEA in formula (2).

$$KEA = \frac{L}{H} - 1 \qquad (2)$$

The yearly values for KEA or KEP represent the average of the daily values; however, the ten highest and ten lowest values are excluded. In our analysis, we use all values. It should be noted that the methodology and significance of the indicator might be debatable. As an example, (Sitova, 2016) showed that the achieved distance concept leads to biases, in particular for small airspaces. The authors recommend not comparing HFE scores spatially. Further, (Fricke, 2021b) introduced a new approach of assessing horizontal flight efficiency (3DE). However, the EUROCONTROL indicator is still used in official benchmarking. We use it as a proxy for emissions and environmental costs.

3.2 Approach and Method

One aim of the study is to connect operational prediction (e.g., flights) with the environmental consequences. Thus, an HFE forecast was requested to derive inter alia climate costs. The forecast of KEA and KEP is more challenging than resources or delay, since multiple factors may affect the scores. Therefore, we ran regressions to identify and quantify influencing factors, and to predict future values.

Regression analysis allows the quantification of one or more independent variables (factors) on one or more dependent variables. In our investigation, the dependent variable is the KEA or the KEP indicator. The independent variables are represented by (potential) influencing factors on KEA or KEP, e.g., demand, delay, or weather. Due to the high level of heterogeneity in European Airspace and the particularities of each ANSP, we decided to calculate one regression model for each ANSP, each FAB, and Europe. Each regression model is based on 1825 observations (365 days x 5 years). Since panel data is available, panel regression models like Pooled, Fixed- or Random-Effect Models were applied. The method was chosen by applying Hausman Test and Breusch-Pagan Test. We maximized model quality (e.g., adjusted R^2) by variable reduction.

3.3 Influencing Factors

To predict the horizontal flight efficiency, it is necessary to examine factors influencing the score. Therefore, in the first step, a long list of factors is compiled, e.g., demand, complexity, weather, military airspaces, etc. Table 1 shows all potential factors, whether it was included (C) or not (also in test models), the expected influence (E) as well as the data source. Aggregations (FABs, Europe) partly use average data, e.g. for wealth. Expected effects are based on the consequences for airspace users. For example, if fuel becomes more expensive, airlines will avoid detours more consequently, leading to a decrease in the HFE score. The annual dummies reflect the (unobserved) development of the HFE scores. The negative sign reflects the assumption that HFE decreases over time, e.g., due to efficiency improvements by technical advances.

Table 1. Considered Factors for Regression Analysis

Factor	Acronym	E	C	Data Source
Demand	DEM	+	Y	PRU (EUROCONTROL., 2020a)
Airspace Size	SIZE	-	Y	ACE (EUROCONTROL., 2020b, EUROCONTROL., 2021a)
Density	DENS	+	Y	Calculated
Adj. Density	ADENS	+	Y	PRU
Horizontal Score	HS	+	Y	(EUROCONTROL., 2020d)
Vertical Score	VS	+	Y	
Speed Score	SS	+	Y	
Complexity Score	COMP_S	+	Y	
ATFM Delay	ATFM_DEL	+	Y	PRU (EUROCONTROL.,
CRSTMP Delay	CRSTM_DEL	+	Y	2020a)
Weather	ATMAP	-	Y	METAR
CO2 Price	CO2P	-	Y	
Fuel Price	FuelP	-	Y	
Charge	CHARGE	-	Y	CRCO (EUROCONTROL, 2016)
Wealth	WEALTH	+	Y	Worldbank (Worldbank., 2019)
Military Area	MIL	+	N	
Staff Scheduling	FLEX	-	N	
2015	Y2015	-	Y	Dummy
2016	Y2016	-	Y	Dummy
2017	Y2017	-	Y	Dummy
2018	Y2018	-	Y	Dummy
2019	Y2019	-	Y	Dummy

In a second step, it is checked which factors are quantifiable and which only have qualitative characteristics. As an example, there is a metric that is supposed to define the complexity of demand, but it has already been shown that this indicator is not applicable due to methodological weaknesses (Standfuss, 2020). Military data, while available in principle, is sensitive and therefore not usable.

Weather is one of those factors that operational experts rank as significant for HFE. Severe weather can lead to detours, which would affect particularly the KEA score. However, there are no metrics yet that quantify weather in the en-route area. For this reason, we developed an approximation based on a concept of weather evaluation for airports. Weather conditions are usually recorded at each airport using the Meteorological Aviation Routine Weather Report (METAR) and reported every 30 min. Besides this general weather information, additional measurements were available related to adverse weather situations, such as information about wind gusts, runway conditions (e.g., ice layer), thunderstorm-related cloud formations, or measurements of runway visual range. For the following analysis, METAR messages are parsed and filtered to enable the quantification of weather measurements regarding their impacts on the aviation domain.

To quantify the weather on ANSP level, we used the ATMAP algorithm. It quantifies and aggregates major weather conditions and contains five different weather classes with significant influence on aircraft and airport operations include (1) visibility and cloud ceiling; (2) wind; (3) precipitation; (4) freezing conditions; and (5) dangerous phenomena. More severe weather conditions lead to higher coefficients, (cf.(Schultz et al., 2021)). The ATMAP score was determined for a list of airports. The score for the corresponding ANSP is defined by the mean of the airport values. Although this approach is very rough, it yielded positive results: Countries with frequent severe weather conditions achieved a higher score, e.g., countries in the north.

The selection of variables is crucial for valid regression analysis. Including variables without influence on HFE, or excluding significant variables, will lead to an over-or underestimation of the effect by the considered variables (omitted variable bias). However, it is not meaningful to consider all factors in one regression model. Therefore, we carried out correlation analyses in advance. Highly correlated factors were therefore only used in different models. We further applied the VIF test to avoid multicollinearity in the regressions.

3.4 Regression Results

We ran the regression analysis individually for all ANSPs, FABs, and Europe. For this purpose, we primarily use fixed-effects models. In exceptions, however, Pooled OLS, possibly without constant, was applied, e.g., due to statistical tests or implausible prediction results. Table 2 shows the KEA results for all FABs. For illustrational reasons, we only show the model, quality, and whether a factor was included or not.

Please note that the model quality (R^2) is comparable only between models based on the same regression method and whether the "constant" was included or not. For Fixed Effects Model (e.g., FABEC), quality is expressed by the "Dummy R^2". Pooled OLS including constant uses the Adjusted R^2

(e.g., DANUBE FAB). Pooled OLS excl. the constant is determined by the non-centered R^2 (not existing on the FAB level, but on the ANSP level).

Model quality differs according to the unit considered. Table 3 shows the average model quality per indicator and regression model. Overall, regression models for KEA achieve higher quality. Thus, it might be assumed that also the prediction of HFE scores is more precise than those for KEP. Further, quality is slightly higher on the FAB level.

Table 2. Regression Models on the FAB level

FAB	Type	R^2	CONST	DEM	ATFM_DEL	ATMAP	CO2P	FuelP	CHARGE
Baltic FAB	FEM	49%	X	X	X	X	X	X	
BLUE MED FAB	POLS	13%	X	X		X	X		
DANUBE FAB	POLS	36%	X	X	X	X			
DK-SE FAB	FEM	41%	X	X	X				X
FAB CE	FEM	64%	X	X		X		X	
FABEC	FEM	54%	X	X	X	X	X	X	
NEFAB	FEM	22%	X	X		X	X		X
SW FAB	POLS	27%	X	X	X	X	X	X	X
UK-Ireland FAB	FEM	53%	X	X	X	X	X	X	

Table 3. Comparison of Model Quality

	ANSP		FAB	
	KEP	KEA	KEP	KEA
Dummy R^2	41,8%	42,7%	42,4%	47,2%
Adjusted R^2	19,4%	24,9%	19,7%	25,3%
Non-Centered R^2	89,2%	92,5%	95,0%	-

3.5 Prediction of the Environmental Impact

Regression analysis provides the strength (value of the coefficient), direction (the sign of the coefficient), and significance (p-value of the model statistic) of the influence of all factors considered. The coefficients can be used to calculate (expected) KEA and KEP values for the following years. Therefore, the model with the highest quality is used for the HFE prediction. Expected demand and delay for 2021 to 2027 are extracted from the traffic scenarios (sections 2.1 and 2.3). Other expected values are based on official documents (e.g., charges and CO_2 prices) or own assumptions. In general, the following assumption has been made (selection):

- HFE decreases slightly (expressed by yearly dummies) over time,
- Fuel Prices and CO_2 prices increase,
- Charges decrease.

The method led to useful and plausible efficiency scores. As an example, figure 3 shows the results for FABEC. The expected HFE in 2027 will be between 4.9% and 6.7% for KEP, respectively 2.3% and 3.6% for KEA. Significant deviations are only to be expected for those national airspaces controlled by multiple ANSPs, especially the Benelux countries. Since the HFE score is based on states, the ANSP-specific HFE score will be higher, which was also demonstrated in a case study for skeyes (Belgium).

Figure 3. Predicted HFE based on KEP (left) and KEA (right) for FABEC

For some ANSPs, the predicted value for 2022 was compared with the actual score. For the British NATS, for example, a KEP of 5.8% was predicted; the actual value (April 2022) was 5.6%. Since the HFE is expected to increase in the summer, this result is considered to be very close to reality.

3.6 Summary and Outlook

The paper discusses the impact of STATFOR's traffic forecast, extended by two scenarios, on the performance of ANSPs, FABs, and Europe. In the light of current social, political, and economic preferences, we focus on the environmental domain. This is reported by EUROCONTROL through the indicator Horizontal Flight Efficiency. Although this score has significant methodological weaknesses, it is still a frequently used metric, especially in the official reports. It can be assumed that the diversions factor is indirectly or directly dependent on demand. Uncertainty in actual transport demand is therefore also accompanied by uncertainty in HFE, and thus in environmental consequences and their costs.

The results reflect the perspective in Autumn 2021 (STATFOR forecast date). Later geopolitical events are not integrated and effects (e.g., due to the war in Ukraine) are not taken into account. We have shown that uncertainties in demand lead to uncertainties in resource and cost planning. As some airspaces are already operating at capacity, an increase in delay can be assumed. The expected values were determined and mapped using functional relationships. Based on traffic scenarios, delay values, and other endogenous and exogenous influences, the influence of various factors on the HFE was determined utilizing regression analysis. The pan-European approach is not practicable. However, the ANSP-specific approach led to appropriate results, both in terms of regression and prediction.

Using this method, it was possible to predict the HFE scores for the years 2021 to 2027. The comparison with the 2022 values gives confidence in the quality of the method. One limitation might be that the HFE is very sensitive to demand, but during the Corona pandemic, it was found that the HFE hardly decreased despite the absence of traffic. This can be attributed both to the fact that the calculation method of the HFE has weaknesses and that no COVID years were included in the regression. As a consequence, the values for 2021 should be interpreted accordingly.

This paper includes preliminary work for another study that will be published soon. The HFE results will be used to quantitatively determine the emissions, climate costs, and environmental costs depending on the scenarios. This is relevant for both operational users and policy decision-makers. Furthermore, the findings can be used in new, more precise measures of environmental performance.

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