Chapter

Relationship between Air Traffic Demand, Safety and Complexity in High-Density Airspace in Europe

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Abstract

Air traffic performance of the European air traffic system depends not only on traffic demand but also on airspace structure and its traffic distribution. These structural (airspace structure) and flow characteristics (factors such as traffic volume, climbing/descending traffic, mix of aircraft type, military area activity) influence airspace complexity, which can affect controller workload and influence the probability of safety occurrence. In other words, all these dynamic and static complexity components can potentially have an impact upon the safety of the air traffic management (ATM) system. Having in mind fluctuation in traffic on daily, seasonal or annual level in certain airspace, a few questions arise: How changes in traffic demand influence complexity and conflict risk? Is there any correlation between traffic demand, conflict risk and complexity? and Are there any differences between seasons? For that purpose, an investigation is performed on FAB Europe Central (FABEC) airspace, based on 2 weeks of operated traffic during the summer and fall of 2017. Air traffic complexity is estimated using the EUROCONTROL complexity metrics, while conflict risk is assessed using the conflict risk assessment simulation tool. Results show that certain positive relationship exists between traffic demand, conflict risk and complexity.

Keywords: air traffic complexity, conflict risk assessment, air traffic management, safety performance

1. Introduction

In 2018, instrument flight rule (IFR) movements within the European airspace continued to grow strongly (4.65% versus 2017), making last year a new record year in terms of traffic volumes: the number of flights controlled reached an all-time record of more than 11 million [1]. The forecast growth indicates that by 2021, the European sky will handle over 12.3 million operations.

This is an incredible challenge for the safety, the en route sector capacity and impact on the environment. The implementation of two operational concepts, the free route airspace (FRA) and functional airspace block (FAB), is seen as crucial 'tools' for solving those issues.

By definition, FRA is a specified airspace wherein 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 service (ATS) route network, subject of course to availability. Within such airspace, flights remain subject to air traffic control (ATC) for the separation provision and flight level (FL) change authorizations.

The overall benefits of free route operations are distance and flight timesaving, resulting in less fuel consumption and a notable reduction of engine emissions, which benefits the environment [2]. FRA is seen as a cornerstone to improve FAB Europe Central (FABEC) structure and utilisation.

From the other side, an implementation of FABs should bring further efficiency of airspace operations because FABs are 'based on operational requirements and established regardless of State boundaries, in which the provision of air navigation services and related ancillary functions are optimized and/or integrated' [3]. Currently, there are nine FABs established to cover almost the whole European airspace [3]:

- Baltic FAB (Lithuania, Poland)
- BLUE MED FAB (Cyprus, Greece, Italy and Malta)
- Danish-Swedish FAB
- Danube FAB (Bulgaria, Romania)
- FAB CE (Austria, Bosnia and Herzegovina, Croatia, Czech Republic, Hungary, Slovak Republic, Slovenia)
- FABEC (Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland)
- North European FAB (Estonia, Finland, Latvia, and Norway)
- South West FAB (Portugal, Spain)
- UK-Ireland FAB

However, their implementation is still too slow (according to the European Commission [3]) causing inefficiency in the European ATM system.

1.1 Complexity of air traffic

Complexity of air traffic can be defined as the level of either perceived or actual spatial and time-related interactions between aircrafts operating in a given airspace during a given period. Specifically, complexity of air traffic in a given airspace can be very high solely because of the traffic intensity and its pattern in terms of mutual interactions between different traffic flows, as well as between individual aircrafts. Such presumably high complexity could be used for both planning and operational purposes mainly aimed at reducing it. Consequently, it may be reduced at the strategic, tactical and pre-tactical level. At each of these levels, it can have a spatial-based nature (such as airspace and airfield system design and/or assignment such as air routes, sectors, terminals, runway systems, etc.) and also time-based solutions (such as schedules, slot allocations, flow management, etc.). In that context, according to Netjasov et al. [4], complexity is understood as a demand characteristic of air traffic that is to be served by an appropriate supply system.

Gianazza [5] claimed that no single universal complexity measure exists but rather a set of complexity metrics, shown to be useful and relevant in a particular context and for a particular purpose.

Over the last 25 years, concern about measuring how difficult a traffic situation is, i.e. measuring complexity, has risen. Mogford et al. [6, 7] were some of the first to deal with complexity and its influence on air traffic controllers (ATCo) workload. They identified two basic elements of ATC complexity: sector complexity and traffic complexity. Dealing with the influence of a 'free flight' on physical and mental workload of the ATCos, Pawlak et al. [8] developed a model of air traffic complexity with the hypothesis that complexity causes a great change in the ATC cognitive workload.

In order to measure the ATCo workload, Laudeman et al. introduced a concept called 'Dynamic Density' (DD), which 'includes both traffic density (a count of aircraft in a volume of airspace) and traffic complexity (a measure of the complexity of the air traffic in a volume of airspace)' [9]. DD was also applied in the studies of Sridhar et al. [10] with the aim of determining whether a DD could be predicted in the future. DD concept was further elaborated and its applicability further broadened in the studies of Smith et al. [11], Kopardekar and Magyarits [12], Masalonis et al. [13], Rantanen et al. [14] and Kopardekar et al. [15, 16].

Schaefer [17] defines complexity as a measure of difficulty that a particular traffic situation will present to an ATCo. This measure is limited to the characteristics of the traffic situation itself and may thus be considered as a factor that contributes to the workload. Schaefer used complexity as a key concept for solving the problem of the ATCo workload and sector capacity. Similarly, Chaboud et al. [18] have studied the influence of complexity on workload and air traffic service costs and Flynn et al. [19] on sector categorisation and comparison between the US and European sectors based on traffic complexity characteristics. de Oliveira et al. [20] are dealing with workload balancing using complexity. Even in the last decade, investigation of relationship between complexity and workload remained actual [21–23].

Delahaye and Puechmorel [24], Histon et al. [25] and Delahaye et al. [26] dealt with the problem of measuring complexity of air traffic. They assumed that airspace complexity is related to the traffic structure and airspace geometry. According to this assumption, they concluded that a measure of complexity would find wide application in balancing the sector load, distribution of traffic in the sense of congestion, new airway network design, dynamic sectorisation, slot allocation, traffic flow management, comparison of different airspace structure effectiveness, etc. Following previous study, Gianazza [5, 27] applied complexity metrics to airspace configuration. In its study, Hilburn [28] provides a comprehensive literature survey of different theoretical views concerning complexity, different complexity factors and data collection methods. He identified more than 100 complexity factors and almost 30 methods for elicitation, refinement and validation of complexity factors.

Other approaches to define, measure, manage or even reduce air traffic or airspace complexity have recently appeared, opening a new field for further application of the complexity metric [29–32]. The above-mentioned overview also shows that great attention was given to modelling and measuring complexity in the en route environment related to the ATCo workload.

In recent years new approaches to study air traffic complexity emerged. Hong and Kim [33] dealing with the reduction of air traffic complexity have introduced a concept of complexity map. Wang et al. [34, 35] investigated the structure of air traffic situations based on aircraft clusterisation and using complex network theory. Further on searching for objective air traffic situation measurement, they have used a dynamic weighted network [36]. Some authors have used machine learning methods (ensemble learning models) [37, 38] while others human-in-the-loop simulations [39].

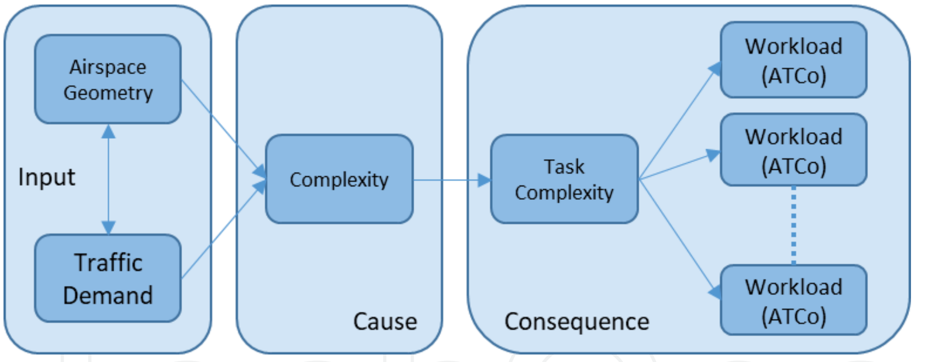

Figure 1.
Scheme of the relationship between complexity, task complexity and workload (based on [4]).

Traffic complexity affects control task complexity (**Figure 1**), where the control is performed by human operator. It is expected that a more complex task will produce a higher workload. However, the workload differs between ATCos (**Figure 1**) due to differences in their working environment, perception of the traffic situation, personal experience, etc. Therefore, complexity represents a contributing factor of task complexity and ATCo workload (more on ATCo workload modelling may be found in the studies of Loft et al. [40] and Majumdar and Ochieng [41]).

The approach presented in this chapter is based on EUROCONTROL [42] methodology, with exclusion of ATCo workload issue from the explicit consideration. Approach is taking a macroscopic view, and it is considering four complexity components: adjusted density, potential vertical interactions, potential horizontal interactions and potential speed interactions. A single metric, 'complexity score', which incorporates these four separate parameters, was considered as the simplest for benchmarking purposes. Recently, Pejovic and Lazarovski [43] have studied the performance of the North European Free Route Airspace using EUROCONTROL approach.

1.2 Conflict risk

The International Civil Aviation Organisation (ICAO) has developed the Collision Risk Model (CRM) as a mathematical tool used in predicting the risk of mid-air collision [44]. Although aircraft collisions have actually been very rare events, contributing to a very small proportion of the total fatalities, they have always caused relatively strong impact mainly due to relatively large number of fatalities per single event and occasionally the complete destruction of the aircraft involved.

From other side, one of the principal matters of concern in the daily operation of civil aviation is the prevention of conflicts, i.e. loss of separation between aircraft either while airborne or on the ground, which might escalate to collisions. A loss of separation is a situation when two aircrafts come closer to each other than a specified minimum distance both in the horizontal and the vertical planes. One can imagine that losses of separation are more frequent event than collisions, so assessment of conflict risk is becoming important.

In order to determine whether or not loss of separation situation exists and to calculate a conflict risk value, a cylinder-shaped 'forbidden volume' is defined around the aircraft [45]. A loss of separation exists between two aircrafts if one of them enters the other's forbidden volume. Losses of separation could be of a crossing or an overtaking type, depending on the aircraft trajectory relations both in horizontal and vertical planes [46].

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Dealing with a conflict risk (see Section 2.2.2) instead of a collision risk (a concept established by ICAO) is enabling a proactive safety approach, which is much closer to everyday ATCo activities.

2. Study approach

To analyse how future changes in airspace structure and traffic flow could influence complexity and safety performance, this paper proposes a showcase methodology on the analysis of FABEC.

FABEC, which includes airspaces of six countries, Belgium, France, Germany, Luxembourg, the Netherlands and Switzerland (**Figure 2**), is one of the biggest FABs and is handling more than half of the European annual traffic. According to EUROCONTROL [48] this 'airspace is one of the busiest and most complex in the world' with 'most major European airports, major civil airways and military training areas located in this area'.

In addition, Air Navigation Service Providers (ANSPs) within FABEC airspace (7 ANSPs with 14 area control centres (ACCs)) handle 55% of the annual European air traffic.

FABEC would surely benefit a lot from FAB and FRA implementation; however, their implementation would cause airspace structural as well traffic flow changes which could further influence complexity and safety performance, and also indirectly ATCos workload.

Prior to assessing those potential future influences, it was necessary to create a benchmark. For that purpose, an analysis of traffic situation in terms of safety and complexity in FABEC airspace in 2017 was made, before full FAB airspace integration and full FRA implementation.

Figure 2.
FABEC airspace (source: [47]).

Figure 3.
FABEC FRA implementation status [49].

The latest information about FRA implementation status from the ATM Master Plan Portal and Local Single Sky Implementation (LSSIP) reports show that FRA implementation at the end of 2018 in some states is ongoing (green) while in some states late (yellow). The current FRA implementation of FABEC is shown in **Figure 3**. At the moment final implementation dates vary from end of 2021 for Germany and Switzerland to the end of 2024 for France.

2.1 FAB and FRA concepts in FABEC airspace

The FABEC airspace is situated in the core area of the European Air Navigation Service network. It is among the busiest (handles about 6 million flights per year—55% of the European air traffic) and most complex airspaces in the world. Most of the large European airports are also located in this area. Since June 2013, FABEC is officially in operation.

FABEC defined a stepped and gradual FRA implementation approach, whereby FABEC area control centres (including Maastricht Upper Area Control (MUAC)), in cooperation with airlines and computerised flight planning service providers, develop and implement cross-border free route airspace based on a single common FABEC concept of operations, which complies with standards defined by the Network Manager.

FABEC FRA initiative includes joint efforts of the seven service providers, and the project was launched in 2011. FABEC ANSPs agreed on one common concept of operations to ensure a harmonised process. First implementations took place in December 2017 in the MUAC airspace. By 2018, ANSPs of Germany, France and Switzerland have also implemented several direct routes.

2.2 Traffic data and scenarios

Traffic demand data used for simulation and analysis were available via EUROCONTROL Data Demand Repository (DDR2). The analysis of complexity and safety was done using the current tactical flight model (CTFM) flight

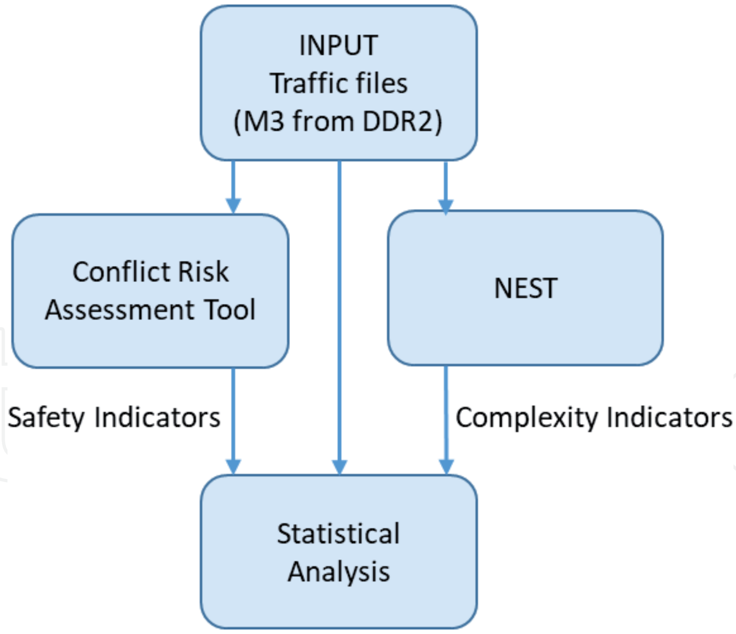

Figure 4.
Structure of the methodology.

trajectories (M3 in Network Strategy Tool (NEST [50]) terminology). 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 filed 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 (direct, level requests, flight plan update) [51].

In other words, an initial flight trajectory is updated with available radar information whenever the flight deviates from its last filed flight plan by more than any of the predetermined thresholds. Therefore, used trajectory represents the closest estimate available for the flight trajectories handled by controllers on the day of operations.

To allow the analysis of different airspaces of FABEC of seven ANSPs in a similar manner (in terms of static and dynamic parameters), the airspace and traffic only above FL195 were chosen for analysis (as the lowest level at which lower airspace starts in FABEC airspace = Class C airspace). The selection of traffic above FL195 excluded terminal manoeuvring area (TMA) traffic, which could have had additional implications during analysis of safety performance (different separation minima levels could be applicable at TMAs).

Two traffic scenarios covered 1 week of summer (July 3–9, 2017, with 131.268 flights) and winter (November 13–17, 2017, with 94.947 flights). For each traffic scenario, calculation of complexity parameters (calculated using the NEST tool) and safety indicators (calculated using the Conflict Risk Assessment Tool [44]) was done using the same input—summer and winter traffic (**Figure 4**).

2.2.1 Assessment of complexity indicators

The assessment of complexity was done using the EUROCONTROL complexity score [42] as airspace complexity indicator. The two main metrics that define the complexity score are the adjusted density and the structural index. The latter is derived from three parameters describing potential number of interactions in specific situations classified as vertical, horizontal and the mix of aircraft performances. These potential interactions can have additional complexity if they involve aircraft in evolution (vertical interaction) and in horizontal flights for headings of more than 30° of difference (horizontal interactions) and/or combining aircraft with different performances (speed interactions). Formulas used for the calculation of complexity score are explained in [42].

The adjusted density assesses the potential interactions resulting from density, including uncertainty in the trajectories and time, while the structural index balances the density metrics according to the interaction geometry and aircraft performance differences. The parameters used indicate the difficulty to manage the presence of several aircraft in the same area at the same time, particularly if those aircraft are in different flight phases, have different performances and/or have different headings [43].

The horizontal interactions assess pairs of aircraft depending on their relative headings, and only pairs of aircrafts with a difference greater than 30° heading are considered. The vertical interactions measure the interactions when aircraft in a climb/descend phase has vertical speeds with more than 500 feet per min difference (also when one of the aircrafts was in cruise). Finally, the speed interactions provide a value of the mix of aircraft types (it considers pairs of aircraft only if their different speed performances are greater than 35 knots in nominal cruise) [43].

Complexity is calculated for the en route traffic in FABEC airspace above FL195. The calculations are done in airspace volume in 3D cells of 20 × 20 NM × 3000 ft. The complexity is computed separately for each grid cell and for discretised 60 min periods, and finally averaged [42].

2.2.2 Assessment of safety indicators

The assessment of safety indicators was done using Conflict Risk Assessment Tool [46]. This tool is intended for the simulation of planned or analysis of realised air traffic, consisting of flight trajectories (4D trajectories) crossing a given airspace, with the aim of assessing safety performance. Conflict Risk Assessment Tool has been developed as a network based simulation model consisting of three modules, each being used for the calculation of certain safety indicators [46]:

- Separation violation detection module (dynamic 3D conflict detection model based on known flight intensions and distance-based separation minima) used for the calculation of duration and severity of potential loss of separation (PLoS) as well as determination of number of PLoS

- Traffic collision avoidance system (TCAS) activation module (stochastically and dynamically coloured Petri net model) used for the determination of number of traffic alerts (TAs), resolution advisories (RAs) and near mid-air collisions (NMACs)

- Conflict risk assessment module used for the calculation of conflict risk

The separation violation detection module simulates flights (following discrete simulation logic with constant time steps) and compares the actual separation of aircraft following certain predefined flight trajectories (both in horizontal and vertical planes) with a given separation minima in order to detect PLoS [46]. Once PLoS are detected, this module counts them and for each of them calculates its severity and duration under given circumstances. Finally, a list of PLoS is created.

Each PLoS discovered by the separation violation detection module is then considered by TCAS activation module. Namely, not every PLoS will activate TCAS. If the situation worsens, then TCAS activation module will uncover which event could occur. It counts TAs and RAs and based on vertical separation between aircraft at closest point of approach (CPA) counts possible number of NMACs [46].

Finally, the conflict risk assessment module is based on the calculation of 'elementary risk' for each specific conflicting pair of aircraft, considering both duration and severity of PLoS. Summing up elementary risks for all possible conflicting pairs of aircraft and dividing it with the observed period of time (e.g. 24 hours), a conflict risk in a given airspace can be estimated [46].

2.3 Objectives and assumptions of the study

Having in mind changes in the European airspace (such as introduction of FRA and FABs) and constantly growing traffic demand, the following research questions emerged:

- How did those changes influence air traffic complexity and safety?
- Is there any relationship between traffic demand, air traffic complexity and safety?
- Are there any differences between seasons?

The main objective of the research presented in this chapter is to find answers on above questions by analysing air traffic within FABEC airspace (a discrete simulation with fixed time step).

The main assumptions were as follows:

- A time increment of 10 sec is chosen as a result of the balance between run time and quality of loss of separation detection (smaller values could be better from the quality point of view but would last much longer).
- Consequently, all events lasting only 10 sec were excluded from further analysis in order to deal with potential trajectory inaccuracies.
- The safety minima separations used were horizontal separation (5 NM) and vertical separation (1000 ft); however, those values are relaxed for 10% (4,5 NM and 900 ft) in order to deal with potential position and altitude inaccuracies.
- The tactical actions by the pilots and ATCos as well as their behaviour in traffic separation are not analysed as their interventions were already partially included in M3 trajectory.
- Complexity in horizontal and vertical plane is homogeneous within FABEC airspace.

3. Results

Analysis of complexity and safety performance is performed in five stages:

1. Analysis of daily variations of complexity and safety indicators described above

2. Analysis of correlation between traffic, complexity and safety indicators (overall and seasonal comparison)

3. Analysis of PLoS severity and duration as well as horizontal and vertical separation at closest point of approach

4. Analysis of complexity and safety indicator values per flight levels

5. Analysis of geometrical characteristic of PLoS

3.1 Complexity and safety indicators overall analysis

Daily fluctuations of both complexity and safety indicators follow similar pattern throughout the week in both summer and winter. Traffic values indicate that traffic demand during winter is lower than during summer in a range from 22 to 37%. Similarly, the complexity score values fluctuate in a similar manner, and summer values are higher in a range between 17 and 29%. Overall, changes of daily complexity values are following the changes of daily traffic demand.

Contrary, the changes in daily number of PLoS and conflict risk do not follow strictly the changes in daily traffic demand. However, variations in the number of PLoS are following the changes in conflict risk. The number of PLoS during winter is lower in a range from 33 to 63%. Similarly, the conflict risk shows lower values in winter in a range from 28 to 65%.

Complexity analysis shows that total hours of interactions (bars, **Figure 5**) increase during winter mainly due to increase in speed interactions (yellow bars, **Figure 5**) which could indicate the greater changes in the mix of aircraft used. However, overall complexity score reduces during winter by 15–20% depending on the day of the week. This indicates that overall complexity score (black line, **Figure 5**) is mainly influenced by changes in adjusted density (green line, **Figure 5**). Adjusted density assesses aircraft interactions resulting from density, including uncertainty in the trajectories and time. Adjusted density shows that interactions are not only related with the traffic volume, however also with how this traffic is dispersed in airspace.

The analysis of number of interactions and number of PLoS per hour of flight (**Figure 6**) show that the total number of interactions per hour of flight reduces

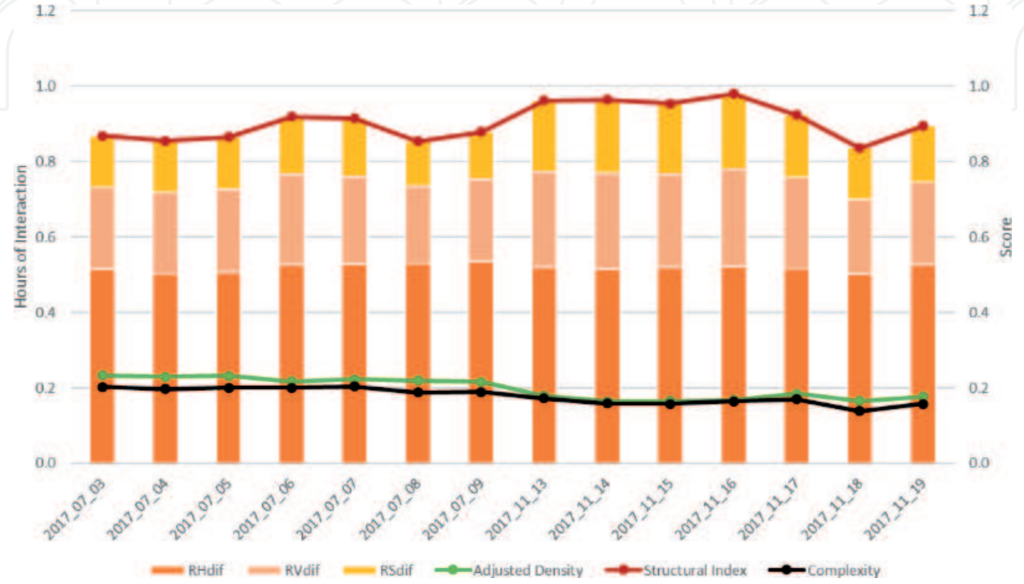

Figure 5.
Complexity parameters.

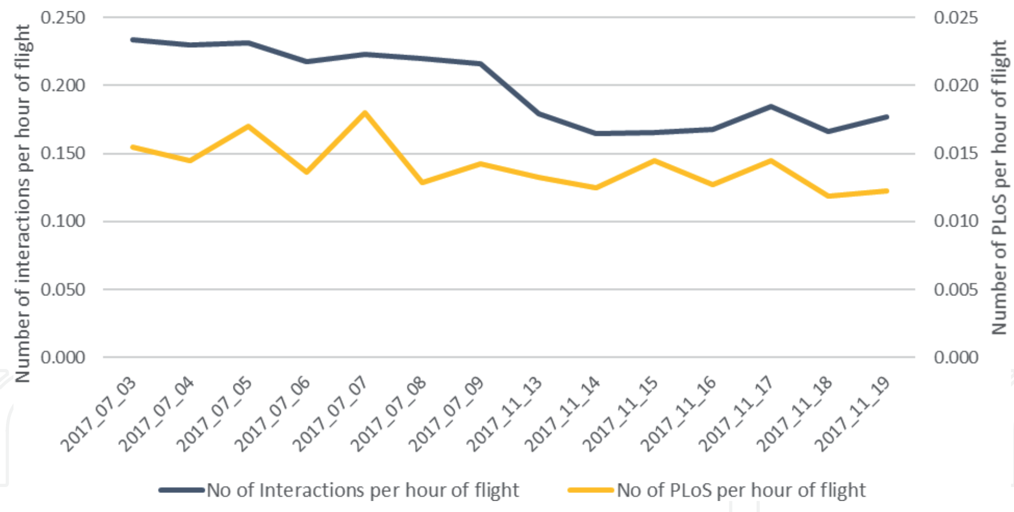

Figure 6.
Number of aircraft interactions and PLoS per hour of flight.

Both seasons	Complexity	PLoS	Conflict risk
Number of flights	+0.9807	+0.8819	+0.8008
Complexity	—	+0.9138	+0.8296

Table 1.
Linear correlation coefficients for both seasons combined.

during winter by over 23% (0.224 in summer vs. 0.172 in winter). The number of PLoS per hour of flight is somewhat more stable and does not change much with decrease in traffic. Overall change is approximately 13% (0.015 in summer vs. 0.013 in winter).

3.2 Correlation between traffic, complexity and safety indicators

A very strong correlation (R^2 = 0.9807) was found between the daily number of flights and complexity (**Table 1**). Strong correlations were also found between safety indicators (slightly better correlation with the number of PLoS) and the total number of flights. Similarly, strong correlations exist between safety indicators and complexity.

These findings could lead to a conclusion that with increase in traffic, one can expect the higher complexity, which is mostly influenced by the number of PLoS and conflict risk. In other words, this means that ATCo task load will increase, leading to a higher ATCo workload.

3.2.1 Seasonal comparison

The results of correlation analysis between traffic demand, complexity and safety indicators (conflict risk) show the positive correlation between the number of flights and complexity score (as dependent variable) that is stronger in winter (summer R^2 = 0.7163 (**Table 2**) vs. winter R^2 = 0.9022 (**Table 3**)). This is expected as daily complexity scores follow the daily number of flights (see Section 3.1). Moreover this could be explained by the fact that during the winter traffic is more uniform, while during summer there are more charter and business flights (unscheduled flights) that could change traffic flows and locations of potential conflict points, which in turn is decreasing predictability and increasing complexity score. Operationally, this could also potentially increase ATCo's workload during summer.

Summer season	Complexity	PLoS	Conflict risk
Number of flights	+0.7163	+0.3716	+0.3114
Complexity	—	+0.6980	+0.5144

Table 2.
Linear correlation coefficients for summer season.

Winter season	Complexity	PLoS	Conflict risk
Number of flights	+0.9022	+0.5005	+0.2207
Complexity	—	+0.5640	+0.2843

Table 3.
Linear correlation coefficients for winter season.

Moreover, the positive correlation between the number of flights and conflict risk (as dependent variable) is not significant (in both seasons, although in summer is somewhat stronger). Similarly, the positive correlation between complexity score and conflict risk is not significant (R^2 is higher in summer than in winter).

Correlation between the number of flights and number of PLoSs is not significant (although somewhat higher in winter). Contrary, correlation between complexity scores and the number of PLoS shows a significant positive correlation (stronger in summer).

Overall, it can be concluded that correlation between complexity and the number of PLoSs is stronger than between complexity and conflict risk (**Tables 2** and **3**). Similar behaviour can be observed in the case of correlation between the number of flights and the number of PLoS. However, it has to be noted that the conflict risk as an indicator contains more information about the loss of separation than just the total number.

3.3 Analysis of potential losses of separation

3.3.1 PLoS duration and severity

Each PLoS is characterised by the combination of severity (related to the breach of separation) and duration. The severity of the PLoS depends on the minimum distance (spacing) between the pair of aircraft (S_{min}) and the applied separation minima (Sep_{min})). The severity presents the level of aircraft proximity and is defined either for the violation of separation in the horizontal or the vertical plane, or both [45]:

$$Severity = \frac{(Sep_{min} - S_{min})}{Sep_{min}}$$

where $0 <= Severity <= 1$.

Severity could be 1 in the case when both aircrafts are at the same point in the horizontal plane (although they could be properly separated vertically) or in the case when both aircrafts are at the same altitude (however they could be properly separated horizontally).

Results of PLoS duration analysis show that majority of PLoSs are short, up to 30 sec (roughly two-thirds, i.e. 372 cases), while almost 90% do not last more than 1 min (**Figure 7**). Results of severity analysis (**Figure 8**) show that in 80% of cases severity is 1, which means that both aircrafts were at either the same flight level or at the same point in the horizontal plane.

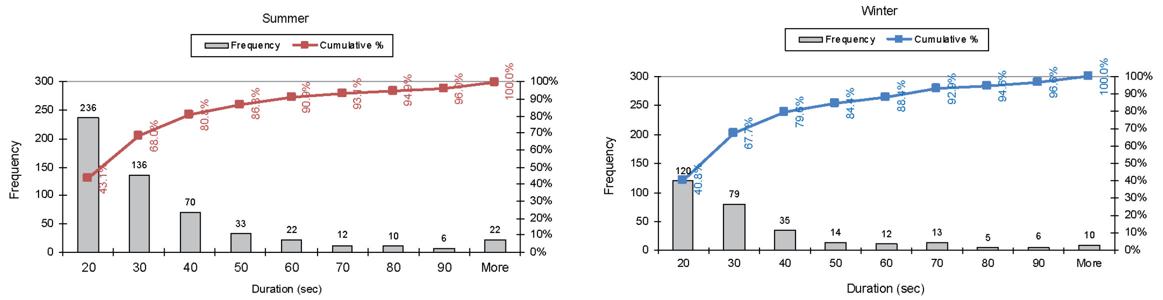

Figure 7.
Distribution and cumulative distribution of PLoS duration.

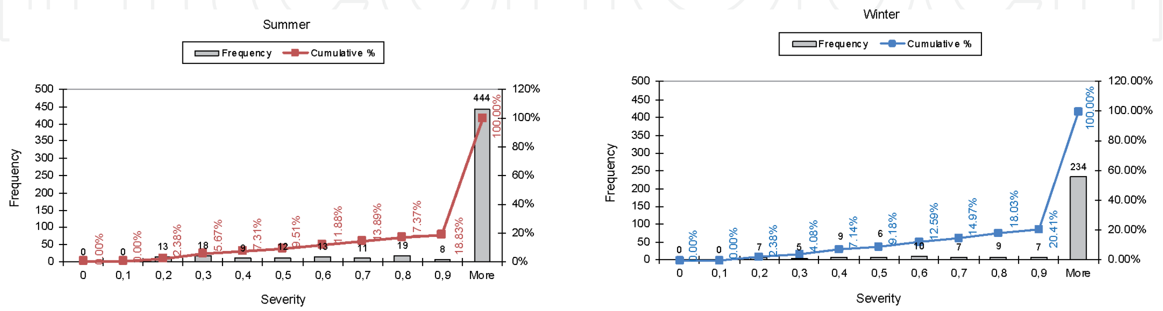

Figure 8.
Distribution and cumulative distribution of PLoS severity.

3.3.2 Horizontal and vertical separation at CPA

The results of the distribution of minimum vertical separation at the CPA show that almost 80% of PLoSs are at the same flight level or are separated vertically up to 100 ft. (top **Figure 9**). The results of horizontal distribution show that roughly 50% of PLoSs have breach of less than 3 NM (bottom **Figure 9**).

3.4 Complexity and safety per flight level

Both complexity and conflict risk can change with flight level. The distribution of an average daily complexity and average daily number of PLoS per FLs (grey lines show a standard deviation) is shown on **Figure 10**.

The highest average values of complexity are on higher altitudes (FL350 to FL380) which correspond to the level used for en route cruise. Somewhat increased values of complexity could be also seen between FL220 and FL240 (corresponds to situations in which flights are entering or leaving lower airspace), however, the number of PLoSs is not increased at this level band.

Distributions of average daily complexity and average daily number of PLoS per FL are similar, with lower values during winter days (**Figure 10**). Additionally, it can be concluded that traffic demand is influencing higher complexity values; moreover, the number of PLoSs evidently contributes to higher complexity values (**Figure 11**).

Figure 11 shows that in the summer period increase in the number of PLoS at high complexity altitudes is of higher magnitude than in winter months. This could be related to the fact that summer traffic is less predictable (due to the existence of increased number of charter flights and summer destinations traffic).

3.5 Geometrical characteristics of PLoS

To better understand the influence of PLoSs on complexity scores, it is necessary to investigate geometry between aircraft in PLoS encounters. Three types of PLoS,

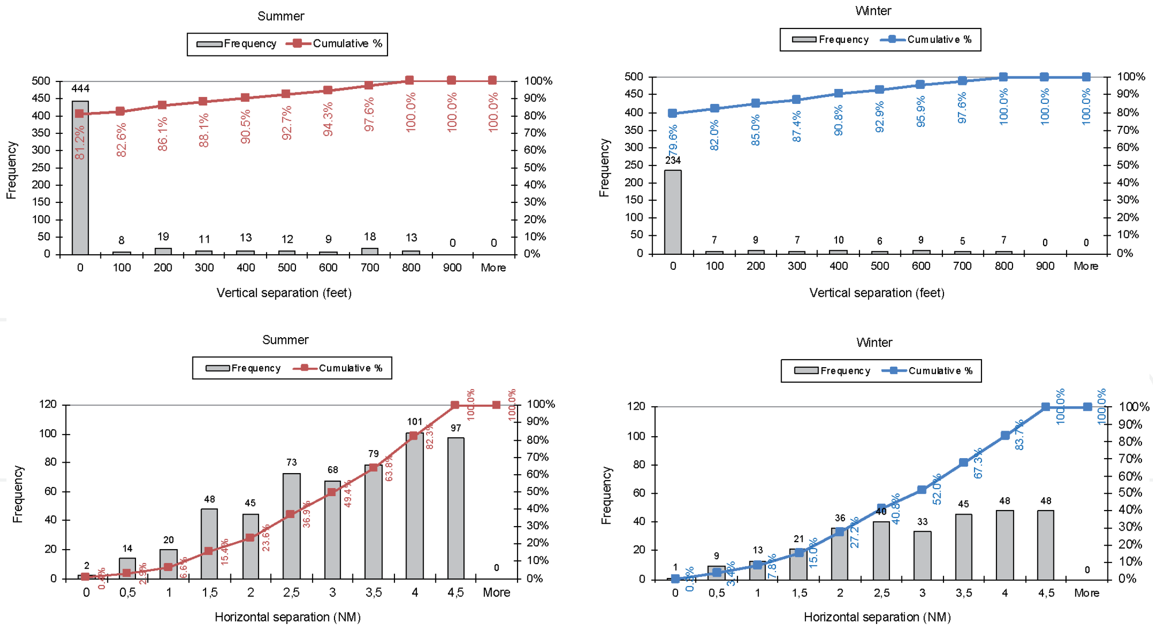

Figure 9.
Distribution and cumulative distribution of vertical and horizontal separation at CPA.

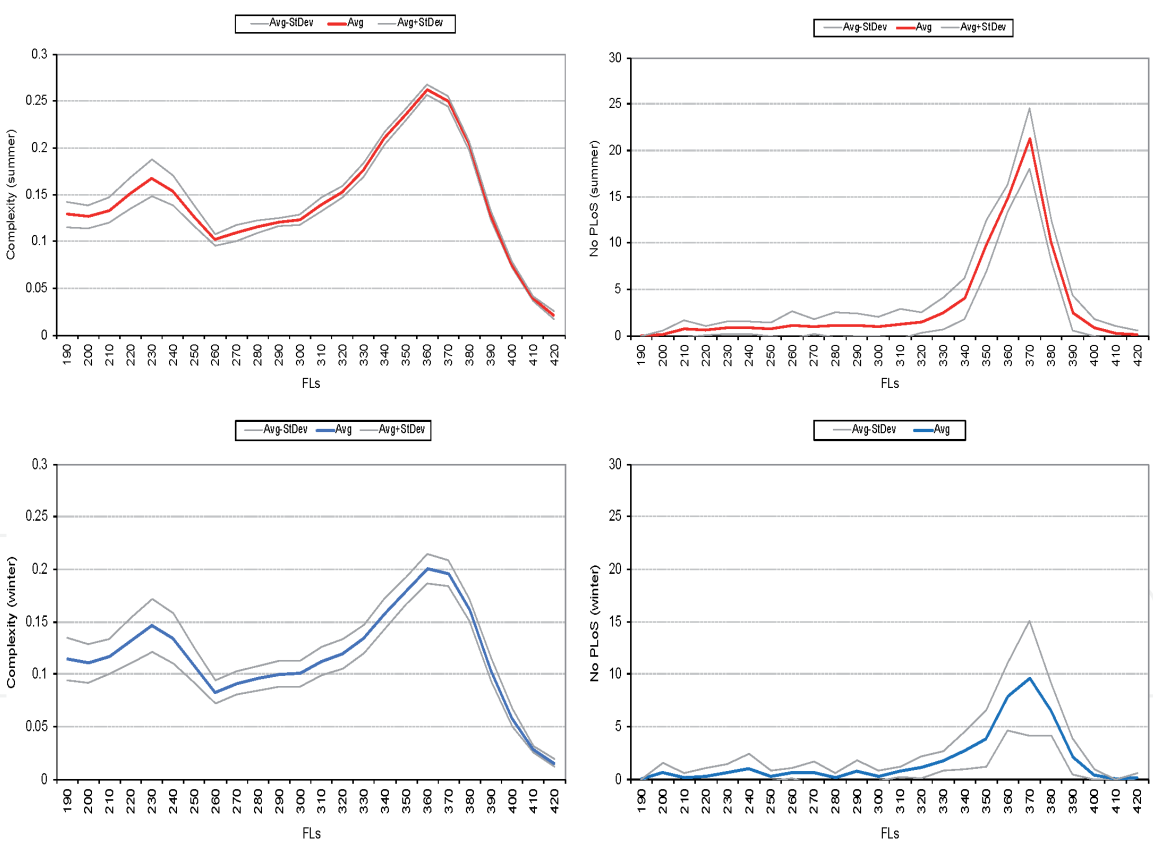

Figure 10.
Complexity and the number of PLoS per FL.

based on special position of two aircraft in PLoS, are used: overtaking (difference between headings is ±70^0), crossing (difference between headings is in a range between ±70 and ±160^0) and head-on encounters (difference between headings is in a range between ±160 and 180^0).

Figure 12 (top) shows the share of each encounter type. In summer sample percentage of overtaking and crossing PLoSs is almost similar (51 vs. 46%) while in winter there are more overtaking PLoSs (71%). Daily values (**Figure 12** bottom)

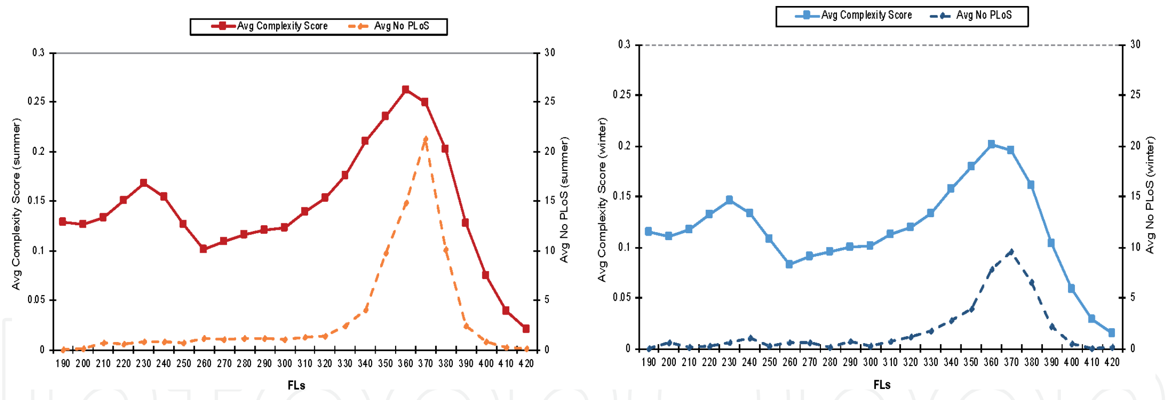

Figure 11.
Distribution of complexity and the number of PLoS per FL.

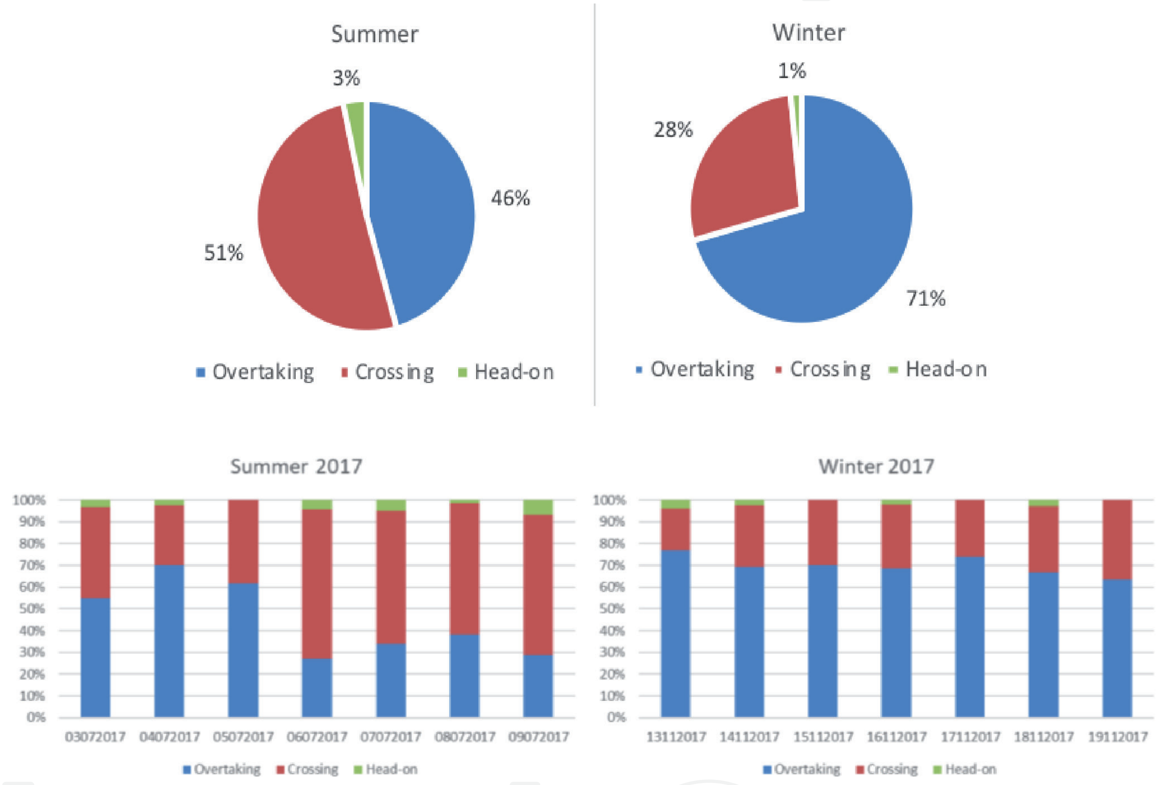

Figure 12.
Shares of encounter types.

show that daily share of encounter types are more stable during the winter which could be related to more uniform traffic flows during winter months (e.g. no seasonal and charter flights).

4. Conclusion

Air traffic performance of the European air traffic system depends on traffic demand but also on airspace structure and its traffic distribution. These structural and flow characteristics influence airspace complexity, which can affect controller workload and influence the probability of safety occurrence.

An investigation is performed on FABEC airspace in Europe, based on 2 weeks of realised traffic during summer and fall of 2017, with aim to answer several questions: How changes in traffic demand influence complexity and conflict risk? Is there any correlation between traffic demand, conflict risk and complexity? Are there any differences between seasons?

Daily fluctuations of both complexity and safety indicators follow a similar pattern throughout the week in both summer and winter. Analysis of complexity parameters shows that overall complexity score is mainly influenced by changes in adjusted density which show that interactions are not only related with the traffic volume but also with how this traffic is dispersed in airspace.

The changes in the number of PLoS and conflict risk do not follow strictly the changes in daily traffic demand, and the numbers of PLoS and the conflict risk are lower in winter. This could be related to the fact that traffic demand is lower in winter months and that traffic is more predictable.

Strong correlations were found between traffic demand, safety and complexity indicators. These findings could lead to conclusion that with increase in traffic, one can expect the higher complexity, which in turn influences the number of PLoS and conflict risk. In other words, this means that ATCo task load will increase, leading to a higher ATCo workload.

Both complexity and conflict risk can change with flight level. The highest average values of complexity and number of PLoS are on higher altitudes (FL350 to FL380) which correspond to the level used for en route cruising. Increase in number of PLoS at these altitudes is higher, in relation to increase in complexity, during summer. This could be related to the fact that summer traffic is less predictable (due to existence of increased number of charter flights and summer destinations traffic).

In a conclusion, this small-scale analysis showed that changes in traffic demand do influence complexity and safety performance (both in terms of the number of PLoS and conflict risk). Moreover, this analysis set a benchmark for future monitoring of safety and operational performance after FRA implementation at FABEC airspace. Further analysis should investigate whether dispersion of traffic after FRA implementation is enough to create complexity decrease and whether change in complexity have not compromised safety and ATCo workload. Moreover, analysis could increase credibility by considering traffic flows, sectors, types of flights (charter, low cost, business, etc.) and vertical profiles of flight.

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