Abstract: This paper presents a safety performance indicators assessment model developed for the purpose of APACHE project (funded by the SESAR Joint Undertaking within the framework SESAR 2020 Exploratory Research Programme as part of the Horizon 2020 programme). The APACHE project proposes a new framework to assess European Air Traffic Management (ATM) performance based on simulation, optimization and performance assessment tools that will be able to capture the complex interdependencies between Key Performance Areas (KPAs) at different modelling scales (micro, meso and macro). The APACHE System is the platform, build up with different software components (existing and to be developed) implementing a wide set of performance indicators across several KPAs. In this paper a part of this platform related to Safety Assessment of future ATM system is presented and illustrated.

Keywords: Risk Assessment, Aviation Safety, Air Traffic Control, Air Traffic Management

1. INTRODUCTION

Air transport demand often exceeds available capacity of the air transport system, resulting in a series of negative consequences (flight delays, flight cancelations, etc.). On the other hand, the expectations of the air traffic management (ATM) community and the whole society are much bigger and primarily related to an increase in safety, environmental protection, reduction in delays and ticket prices, etc. In such circumstances, the existing ATM system has to undergo certain changes that will allow it to meet these often-contradictory requirements in the future (APACHE, 2017a).

In the 1980s, ATM community has recognized this complex problem. A need to create a more efficient, safer and ecologically sustainable system at the global, regional and national levels was defined, which will make maximum use of numerous possibilities of modern technical and technological achievements. One of the main pillars of the future ATM system should be an efficient Performance Management System, which will enable managers to assess progress in various fields such as (in the context of air traffic) safety, capacity, accessibility, cost-efficiency, environment etc., with a significantly greater reliability (APACHE, 2017a).

In 1998, EUROCONTROL founded the "Performance Review Commission" (PRC) with the aim of establishing an independent and transparent performance management system within the European ATM system. The Commission is supported in its work by the "Performance Review Unit" (PRU), which is directly involved in collecting and analysing performance data in collaboration with airspace users, ANSPs, airports, etc. (EUROCONTROL, 2016a). Every year the PRC issues “Performance Review Reports” (PRR (EUROCONTROL, 2016b)) which provide information on the air traffic demand (expressed as a total number of IFR flights) and performance of the European ATM system in the four main KPAs (safety, capacity, environment and cost-efficiency).

The APACHE project proposes a new framework to assess European ATM performance based on simulation, optimization and performance assessment tools that will be able to capture the complex interdependencies between Key Performance Areas (KPAs) at different modelling scales (micro, meso and macro) (APACHE 2016).

The APACHE System is the platform, build up with different software components (existing and to be developed) implementing a wide set of performance indicators across several KPAs. Moreover, the APACHE System can be configured to synthesize aircraft trajectories and airspace sectorisation for future

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scenarios, in line with the SESAR 2020\(^2\) scope, where input data is not available (and also for hypothetical scenarios based in the current concept of operations) (APACHE 2017b). In this paper a part of this platform related to Safety Assessment of future ATM system is presented and illustrated.

2. SAFETY PERFORMANCE INDICATORS

Safety Performance Indicators (PIs) are part of the wider APACHE performance framework (APACHE, 2017a). Related to the scope of APACHE project, the PRU is currently assessing a range of PIs in the field of safety, e.g. number of accidents and serious incidents, number of reported unauthorised penetrations of airspace, number of reported separation minima infringements, etc., among which two are used as KPIs: Total commercial air transport accidents; and the number of accidents with air navigation service contribution. All PIs and KPIs are based on accident/incident investigation reports (post operation analysis). APACHE proposes performance indicators which are measurable in simulation and could be measurable in a real system as well, but are not dependent on accident/incident reporting (APACHE, 2017a).

Two categories of PIs are proposed in APACHE based on their values (APACHE, 2017a): absolute and relative one. Indicators with absolute values are given as counts of specific occurrences, listed in Table 1 by ascending severity Traffic Alert (TA) warnings (SAF-1), Resolution Advisories (RA) issued (SAF-2), Near Mid Air Collisions – NMACs (SAF-3). All these indicators could be also given as rates of specific occurrences, i.e. as counts normalized by the number of flights or total flight hours through the given airspace. Similarly, number (or rate) of separation violations could be used to indicate safety (SAF-4).

Apart from these indicators, and related to the latter one, it is proposed to measure separation violation for aircraft in conflict (SAF-5), in situations when either horizontal, vertical or both separation minima are violated, as well as duration of conflict situations (SAF-6). Based on these two indicators it is possible to calculate a risk of conflicts and risk of accidents (SAF-7).

Each portion of airspace can be characterized by those indicators in order to find out a “hot spots” in the airspace (portion of airspace with the highest values of most serious occurrences). Apart from finding the geographically most safety jeopardized location it is also possible to follow distribution of each absolute indicator during given period of time (time series) in order to find out the moment of time in which the highest values are expected (APACHE, 2017a).

Table 1: New Safety PIs proposed, indicators with absolute values (APACHE, 2017a)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAF-1: Number of Traffic Alerts warnings</td>
<td>No. TAs</td>
<td>Count of TAs</td>
</tr>
<tr>
<td>SAF-1.1: Traffic Alerts warnings</td>
<td>TAs/flight (hour)</td>
<td>(Number of TAs) / (Number of flights or Flight hours)</td>
</tr>
<tr>
<td>SAF-2: Number of Resolution Advisors issued</td>
<td>No. RAs</td>
<td>Count of RAs</td>
</tr>
<tr>
<td>SAF-2.1: Resolution Advisors issued</td>
<td>RAs/flight (hour)</td>
<td>(Number of RAs) / (Number of flights or Flight hours)</td>
</tr>
<tr>
<td>SAF-3: Number of Near Mid Air Collisions – NMACs</td>
<td>No. NMACs</td>
<td>Count of NMACs</td>
</tr>
<tr>
<td>SAF-3.1: Near Mid Air Collisions – NMACs</td>
<td>NMACs/flight (hour)</td>
<td>(Number of NMACs) / (Number of flights or Flight hours)</td>
</tr>
<tr>
<td>SAF-4: Number of separation violations</td>
<td>No. SVs</td>
<td>Count of separation violations</td>
</tr>
<tr>
<td>SAF-4.1: Separation violations</td>
<td>SVs/flight (hour)</td>
<td>(Number of separation violations) / (Number of flights or Flight hours)</td>
</tr>
<tr>
<td>SAF-5: Severity of separation violations</td>
<td>-</td>
<td>[(Separation minima) – (Actual separation)] / (Separation minima)</td>
</tr>
<tr>
<td>SAF-6: Duration of separation violations</td>
<td>Sec</td>
<td>Time during which separation minima is violated.</td>
</tr>
<tr>
<td>SAF-7: Risk of conflicts/accidents</td>
<td>-</td>
<td>Compound PI which depends on SAF-5 and SAF-6</td>
</tr>
</tbody>
</table>

TAs/RAs, NMACs occur very often. According to study of Gottstein and Form (2009), in average 3 TCAS-related events occur in German airspace every day. So, count of those occurrences could be a good proxy of what is really happening in the airspace. Of course, TAs/RAs, NMACs are based on anticipation of distance at closest point of approach between two aircrafts when this anticipation is time-based.

\(^2\) SESAR 2020 – Single European Sky ATM Research Programme (https://www.sesarju.eu/)
Apart from those indicators, there is also separation violation situations, i.e. conflicts, determination of which is based on actual distance between two aircrafts and depends on separation minima applied. Duration of separation violation situation is measured as a time period in which actual separation is lower than separation minima, while severity presents a measure of how close the difference between actual separation and separation minima is to zero (Figure 1). Risk of conflict represents a combination of duration and severity of separation violation (Netjasov 2010, 2012).

**Figure 1**: Representation of potential conflict duration and severity ($S_{\text{min}}$ and $H_{\text{min}}$ are horizontal and vertical separation minima respectively, $\Delta t_c$ is conflict duration (Netjasov 2010, 2012))

Normalized values of counts present how frequent mentioned occurrences are relative to the number of flights passing through a given airspace or relative to total flight time of all flights passing through the same airspace (APACHE, 2017a).

### 3. MODELLING APPROACH

In order to assess safety of future ATM system within APACHE performance framework a Risk Assessment (RA) component is proposed. RA is intended for simulation of air traffic consisting of optimal flights trajectories (output of Trajectory Planner (TP) and Traffic and Capacity Planner component (TCP)) through a given airspace sectorisation (output from Airspace Planner (ASP) component) with aim to assess safety performances and to provide outputs in form of Safety KPIs as well as safety feedback (which could be considered by TCP and ASP components in case that proposed flight trajectories and sector boundaries are not suitable from the safety point of view) (APACHE, 2017b).

The RA component is consisting of three modules (Figure 2):
- Separation violation detection module,
- TCAS activation module and
- Risk of conflict/accident assessment module.
The RA component is based on the assumption that conflict between pair of aircraft exists when either horizontal and/or vertical separation minima are violated. The Separation violation detection module compares actual separation of aircraft (both in horizontal and vertical plane) with given separation minima in order to detect potential conflict. Once conflict is detected this module counts them (SAF-4) and then for each conflict calculates severity (SAF-5) and duration (SAF-6) of conflict situation in the observed airspace under given circumstances (APACHE 2017b).

If the situation worsens the TCAS activation module is activated. It counts Traffic Alerts (SAF-1) and Resolution Advisories (SAF-2) warnings and based on them number of NMACs (SAF-3) (APACHE 2017b).

The risk of conflict/accident assessment module is based on calculation of ‘elementary risk’ which is defined as the area between the surface limited by the minimum separation line and the function representing the change of aircraft separation. The risk of conflict/accident (SAF-7) is then defined as the ratio between the 'elementary risk' and the observed period of time. Apart from the risk between specific aircraft pairs, an assessment of the total risk in a given sector is also considered (APACHE 2017b).

The conflict/accident risk between aircraft pairs and the total conflict/accident risk depends on airspace geometry, traffic demand, aircraft velocities, spatial and temporal distribution of air traffic in the airspace as well as the applied separation minima. As such, the risk value taken as a safety feedback could suggest changes in flight trajectories and/or changes in sector boundaries, i.e. sector geometry.

Based on the RA architecture (Figure 2) a specific computer programme (written in Python language) is developed containing following:

- **STEP 1**: Reduction of traffic input (triage) eliminating flights not in conflict (divergent trajectories, different FLs, different entry times, etc.);
- **STEP 2**: Determination of flights in conflicts and calculation of risks and other safety indicators (Netjasov 2010, 2012);
- **STEP 3**: Checking whether TCAS will be activated and how (TA only, or TA with RA, or RA revision, etc), and counting of TCAS events. It is based on (Netjasov 2011, 2013).

### 4. NUMERICAL EXAMPLE

In order to illustrate developed RA component, a set of 1340 planned flights passing through French airspace (July 28, 2016 between 10:00 - 12:00 local time) is chosen. For each flight a detailed 4D trajectory was available (Figure 3).

A deterministic simulation was performed with the following parameters:

- Time increment – 10 sec;
- Horizontal separation – 10 NM and 5 NM;
- Vertical separation – 1000 ft.

Analysing outputs a following results and values for PI's were obtained:

- Number of possible aircraft pairs: 897,130;
- Number of possible conflicts (SAF-4) with horizontal separation minina of 10NM: 3232;
- Number of possible conflicts (SAF-4) with horizontal separation minina of 5NM: 1715;
- Number of possible encounters in which only TA will be activated (SAF-1): 236;
- Number of possible encounters in which both TA and RA will be activated (SAF-2): 15;
- Number of possible Near Mid Air Collisions (SAF-3): 3;
- Risk of conflicts for horizontal separation minima of 10NM (SAF-7): 0.16;
- Risk of conflicts for horizontal separation minima of 5NM (SAF-7): 0.09;

For each separation violations it was possible to instantly identify aircraft in conflicts. This information presents a safety feedback which could serve for flight plans amendments in TP and TCP components of APACHE.

There is also possibility to find out “hot spots” (Figure 4), i.e. geographical locations with higher frequency of conflicts. This information also presents a safety feedback which could serve for amendment of sector boundaries in ASP component of APACHE.

**Figure 3:** Trajectories of planned flights passing through Franche airspace on July 28, 2016 between 10:00 and 12:00 local time

**Figure 4:** Dispersion of locations of conflicts (each point represents a closest point of approach for a pair of aircraft)
5. CONCLUSION

Within the APACHE project a new framework to assess future European Air Traffic Management system performance based on simulation, optimization and performance assessment tools at different modelling scales (micro, meso and macro). This paper presents a Risk Assessment component developed with aim to assess Safety Performance of future ATM system.

Risk Assessment component is consisting of three modules: separation violation detection module, TCAS activation module and risk of conflict/accident assessment module. Modelling approach followed during development of this module is containing three steps: reduction of traffic input, determination of flights in conflicts and calculation of risks and TCAS activation checking. A dedicated computer programme written in Python language is developed.

Developed model was tested on two hour planned flights through French airspace and shows capabilities to calculate certain safety performance indicators and to provide valuable safety feedback to traffic and airspace planners.

Further research will go in two directions. One direction should cover validation of developed model and other direction will aim to cover wider area (European wide) and time (full day traffic).

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