Cooperative Network Design

The Aerospace Performance Factor (APF)
Developing the EUROCONTROL ESARR 2 APF

EUROCONTROL

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Document Approval

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Introduction

To ensure that safety levels are maintained or improved, systematic safety monitoring processes should evaluate, as a matter of routine, achieved safety performance in all safety-related operational activities.

Aviation has increasingly sought to measure the performance of its various elements by means of metrics and indicators, a trend that will be further accelerated by SESAR. For certain elements, some metrics are relatively straightforward, e.g. capacity and delays. However in the domain of safety, appropriate metrics are far from straightforward. For instance an obvious safety metric is the number of accidents, but accidents are rare and this metric alone fails to convey the full extent of safety for a system as complex as the aviation one.

The SAFREP Task Force was tasked[1] with developing a set of ATM Safety lagging indicators. Focus has been placed upon occurrences or incidents, i.e. events that can be considered as breaches of specified safety thresholds, which, apart from being more numerous than accidents, are considered to be early warning signals of a potential degradation of safety. However, problems also lie with the use of incidents as indicators, ranging from their definition to their reporting and the associated reporting culture. Furthermore, the focus on individual incident categories makes the assessment of safety at systemic level complex. It is the belief of the SAFREP TF that, to do this, what is needed is a coherent assessment of the relative importance of multiple incident data. Such an assessment only has credibility if this is undertaken by subject matter experts (SMEs) with considerable experience in the field.

Given that safety incidents are increasingly collected in a reliable manner, and that the quality of the data has improved over the years, the SAFREP TF feels that it may be possible to develop a safety indicator that incorporates both such multiple sources of incident data and a coherent judgement about the relative importance of the data. This would then allow for safety performance of a given system to be subsequently measured over a considerable time horizon and allow for enhanced risk assessment of the aviation system.

[1] EUROCONTROL 2nd SAFREP Report to Provisional Council 'Roadmap for the Development of the Safety Key Performance Indicators in ATM'

Current EUROCONTROL Data Collection

The SAFREP TF first reviewed and then concluded that the indicators used by the Safety Regulation Commission (SRC) were sufficiently robust to be used as meaningful indicators. Moreover, the Task Force recognised that all relevant safety reports should be integrated into a single unified measurement. By including all reports (including SME's assessments) all data could be included in the measurement. By following this approach, where all data is placed 'on the table' for all to see, a comprehensive multi-factor indicator could be developed which might identify current performance, long-term trends, and ultimately allow for the better management of the overall system.

Recognising there would be numerous issues associated with creating new reporting criteria, and knowing the importance of historical data to support trending, the Task Force **concluded that a means was needed that would utilise all of the traditional safety reports**. The spectrum of traditional data collected by EUROCONTROL, should include the following: **Separation Minima Infringements (SMI),Inadequate Separations (IS), Near Control Flight Into Terrain (NCFIT), Runway Incursions (RI), Un-authorised Penetration of Airspace (UPA)/ Airspace Infringements (AI), Aircraft Deviation from ATC Clearance, Level Busts, etc**.

- **A** - Serious Incident
- **B** - Major Incident
- **C** - Significant Incident
- **E** - No significant safety effect
- **D** - Not determined
- Not classified

Figure 1: Severity Classification for ATM-related incidents

The classification of ATM-related incidents in ESARR 2 AST is further based on the severity of their effect on the safe operations of aircraft and occupants i.e. A, B, C, E or D (see Figure 1) where A is the most severe category and through their ATM contribution (Direct, Indirect, No Involvement, Not mentioned or Not Assessed).

Annually, incident analysis is based on the Annual Summary Template (AST) reports of an average 28 – 30 States.

In addition, EUROCONTROL tracks, through the same AST, the category of ATM Specific Occurrences. These occurrences are technical failures in general associated with the capability of the ANSP to provide safe ATM services. EUROCONTROL has been tracking these since 2002, when reporting of ATM Specific Occurrences became mandatory.

Whilst in this category there is still much room for improvement, since 2002, EUROCONTROL has been tracking ATM Specific Occurrences such as: **Communication Function Failures, Navigation Function Failures, Data Processing Function Failures, Surveillance Function Failures, etc**. These are further classified by severity (AA, A, B, C, E and D) (see Figure 2) and whether they have ATM direct contribution.

- **AA** - Total inability to provide safe ATM service
- **A** - Serious inability to provide safe ATM service
- **B** - Partial inability to provide safe ATM service
- **C** - Ability to provide safe but degraded ATM service
- **E** - No effect on ATM service
- **D** - Not determined

Figure 2: Severity Classification for ATM-related incidents

By capitalising on existing safety reports spanning various areas of ATC operations, the SAFREP TF believed that the total impact each of these indicators had on the total performance of the system could be established.

What was less clear, however, was how these specific reports would be included in a comprehensive measure. For example, what was the effect over ATM of a Separation Minima Infringement (SMI) and/or a Level Bust and/or Failure of Surveillance Function for example? Similarly, what was the relative contribution of a Runway Incursion with a severity rating of B to the overall performance of the ATM system? What impact do Airspace Infringements with a severity rating of C have on the overall assessment of the performance and safety of the European airspace system? And so on.

Indeed, the aggregation of various information data and performance indicators was progressing slowly and with great difficulty until the arrival of the Aerospace Performance Factor (APF) and its principle of aggregating various data from different sources.

APF Origins

The Aerospace Performance Factor (APF) represents a new methodology that moves away from performance measurement that relies on a single or limited number of measures. Instead, the APF aims to aggregate multiple operational safety risks, expressed as the sum of reported incidents, in a weighted manner, into one value that can vary over time. Although this unique value gives the overall risk, the methodology allows it to be broken down into its component parts for the analysis of specific causal factors and lessons learnt. APF displays the resultant value with a system-wide view in a graphical format and can show macro changes in performance trends, based on actual data.

Originally developed by the United States Federal Aviation Administration (FAA) Air Traffic Organization (ATO) and US Navy as a safety metric, the methodology has been adopted by the SAFREP TF following a period where EUROCONTROL worked jointly with several air navigation service providers (ANSPs) within Europe and FAA to achieve a European APF based on ESARR 2 and its Annual Summary Template data flow. It is an integral part of the SAFREP TF's development of lagging indicators by aggregating safety occurrences (that are not accidents) with the support of subject matter experts. Accidents with direct and indirect ATM contribution are also represented in an aggregated manner but represented separately from other safety occurrences.

APF Design

The SAFREP TF concluded that for an aviation organisation to operate efficiently with the lowest level of risk, accurate data reporting using multiple sources of information is necessary. This data must reflect quantified information, allowing for repeatable and consistent risk weighting assessment from the experience and judgement of SMEs. This judgement needs to offer a balanced perspective of performance to develop an indicator from which long term trends can be identified for better risk management of the aviation system.

The design goal of the APF is to do this in a coherent, robust manner and it aims to provide a graphical representation of a system's overall performance over a long time horizon compared to a specific baseline. It should be noted that the **APF should not be used as a sole indicator of a system's performance**, rather that it should be one part of a larger set of system safety management system (SMS) measures.

Put simply, the APF is the aggregation of all system safety elements, as determined by the individual organisation, multiplied by the SME weighing value (see next section on the Analytical Hierarchy Process (AHP)), and then balanced by a denominator of the organisation's successful outcomes such as the number of flight hours flown.

Since November 2008, the SAFREP TF has, in conjunction with the FAA, investigated the APF process and formulated a EUROCONTROL APF based around the requirements of ESARR 2 and associated AST data. Experts in the APF methodology from Imperial College, London have also been engaged in the development process and have applied academic rigour to the methodology, findings and outcomes.

APF and Analytical Hierarchy Processing (AHP)

APF is therefore, an approach for measuring of safety performance using multiple localised safety measures, e.g. reported incidents, causal factors, or other operational factors or constraints etc., weighted by SME judgment, and normalised against system operations. The weighting is achieved by the use of elements of Analytical Hierarchy Processing (AHP), a methodology used in multi-objective decision making analysis.

The simplicity and power of the AHP has lead to its rapid and widespread use across multiple domains beyond the process of making complex decisions. AHP enables a decision maker to portray the relationships between many facets of a complex problem, and incorporates both quantitative and qualitative information including experience and intuition. Hence, the APF methodology can be applied to any organisation that needs to assess risk, or performance, based on a complex set of metrics.

It finds its best application in decision-making, although it functions as well making comparisons of variables without necessarily having to make a decision between alternatives. Given its simplicity and ease of use, and relying on the three primary functions of AHP (structuring complexity, measurement, and synthesis), SMEs' thoughts and experience can be organized in a manner that is simple to follow and analyze. These characteristics make AHP an effective methodology to a wide range of applications and allow any complex situation that requires structuring, measurement, and synthesis to be better understood.

Building the Hierarchy

All factors were obtained through the use of historical incident reports of events and incidents within the system. The elements chosen by the SAFREP TF for the EUROCONTROL APF were extracted from the occurrences that are reported through the Annual Summary Template and were grouped into 4 categories:

- **Airborne Events/Air Incidents (AI);**
- **Ground Incidents (GI);**
- **Potential/Near Collision in the Air;**
- **ATM Specific Occurrences.**

The elements are then placed in a hierarchy, using a 'mindmap' that represents the logical relationships of the elements to each other. The completed structures of the elements are displayed in Figure 3.

Initially, all ESARR 2 – Annual Summary Template potential safety data to be reported, was mapped. However, it was found to be too complicated and unbalanced. After various iterations, the definition of the terms to be weighted and the questions asked to the expert were improved and a robust mindmap was developed (see Figures 3 and 4 below).

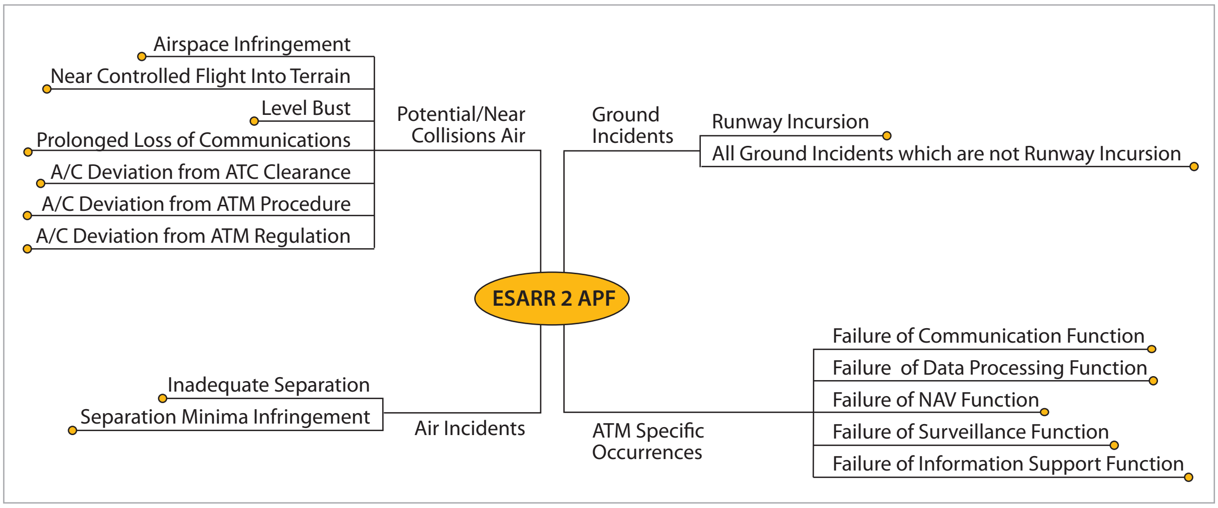

Figure 3: **The EUROCONTROL APF hierarchy structure – simplified version**

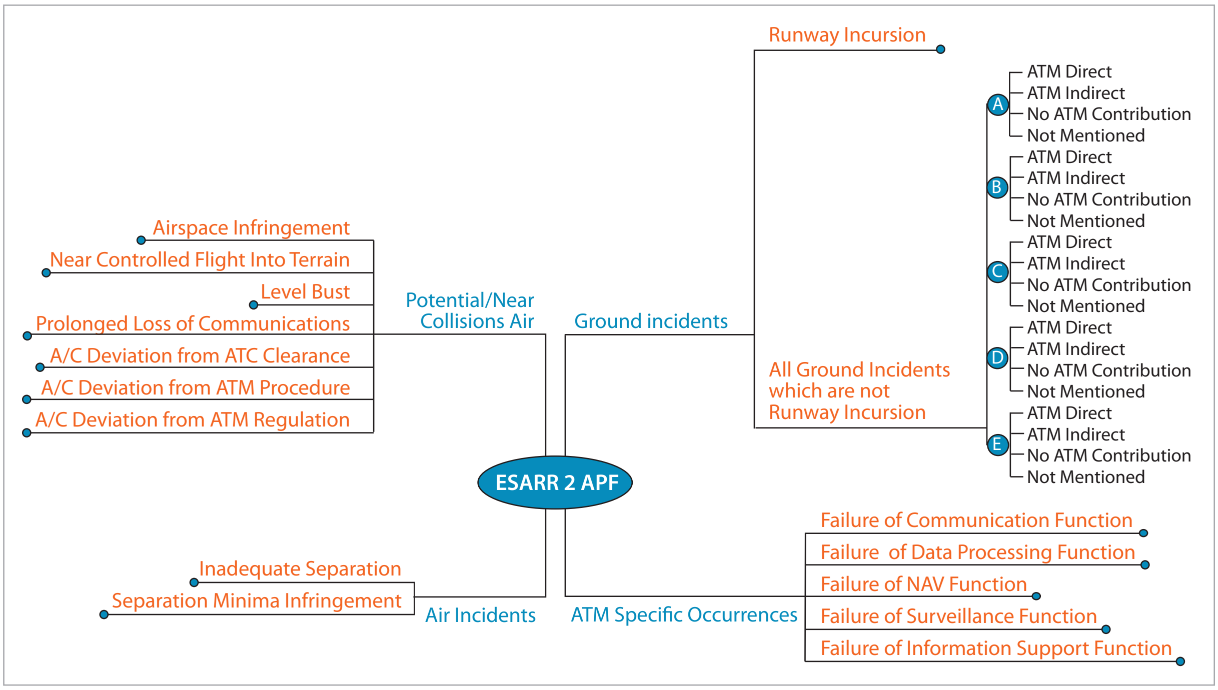

Figure 4: **The EUROCONTROL APF hierarchy structure – expanded version**

APF/AHP Weighting

Once the hierarchy was built, subject matter experts of the SAFREP Ad-Hoc Safety KPI group systematically evaluated the various elements by comparing them to one another, two at a time. The SMEs, who between them had a combined ATM/aviation experience/knowledge of approximately 350 years, were presented with the paired comparison and a rating scale and asked "*Which of these 2 choices represents a greater risk to the safety of the ATM system?*" By making the comparison of the various elements the experts used their judgement about the elements' relative significance and a ratio scale was created. The 'pairwise' evaluations created by the SMEs were then converted into weights for each element of the APF hierarchy structure depicted in the mindmaps in Figures 3 and 4 above.

The same calculations were then performed on each element of the hierarchy to calculate each element's relative contribution to the overall model. By calculating each element of the branches comprising a collection of the hierarchy and summing up of the score, the relative contribution of the element and branch to the overall model could be 'rolled-up' and overall scores could be determined. In so doing, all safety elements are 'rolled up' to create a cumulative value on the overall system.

The final weights for the EUROCONTROL ESARR 2 APF finalised by SAFREP Ad-Hoc Safety KPI group are as presented in Figure 5.

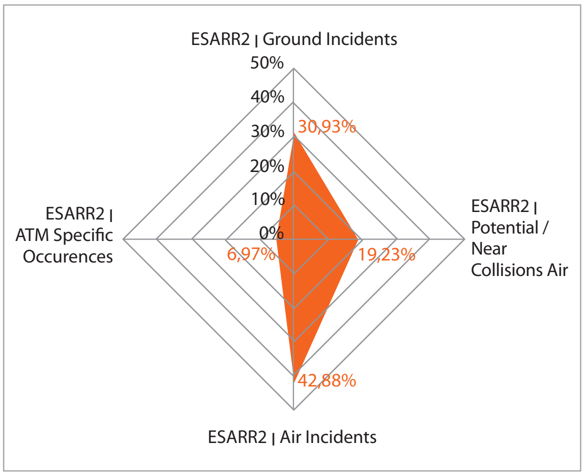

Figure 5: The ESARR 2 APF – weights

The weighting exercise of the ESARR2 APF led to similar results in respect of what the risks are in ATM and what the priorities are at European level. The initial worry that experts with different backgrounds would score very differently and would average themselves, proved to be only a theoretical one. The experts weighted consistently when an accurate definition and explanation of what was to be weighted was provided before the scoring. Several iterations were required to fine tune a balanced 'mindmap' and a final weighting. The overall inconsistency rating was less then 0.15 which compares favourably with similar results from FAA weightings and is an important element in the validation process of the APF.

The use of the weighting system within the APF is as much art as science. It is designed to incorporate various elements into the APF equation, assess relative importance of those elements by the SMEs, and display the data in a format that is usable by both high level organisational management as well as detailed analysts.

The APF methodology is an entirely new way of looking at data and should not be compared to other legacy systems. For example, the Fahrenheit scale should not be compared with the Celsius scale other than to say they both measure temperature (especially without a translation formula). So too with the APF. It is not possible to compare one method of assessing importance, or risk, with the APF's method of using an AHP-type of SMEs' opinion. There is nothing wrong with how risk is assessed using the Safety Management System (SMS) risk methodology. Nor is the APF methodology of assessing importance, or risk, wrong. They are just two separate methods that must be accepted as they are with the full understanding of the methodology, benefits, and limitations of each.

Applying the model to real data

The goal of the EUROCONTROL ESARR 2 APF was to create a visual representation of the performance of the European ATM/airspace system. To achieve this, the final step in the process was to apply real data based on the existing historical safety indicators. Therefore the SAFREP Safety KPI Ad Hoc Group agreed to populate the APF with ESARR 2 AST data for the period January 2006 - December 2008 to demonstrate and validate the model/methodology. A comparison of the model for a specified period of time would reveal the relative contribution of each of the elements and branches of the model.

Performance over time

The relative contribution of the elements (and branches) of the model to the performance of the European ATM/airspace can also be applied to time-series data collected over other time periods. By examining the performance of the system over time, a view of the historical performance might also lead to an expectation of the future direction (Figure 6).

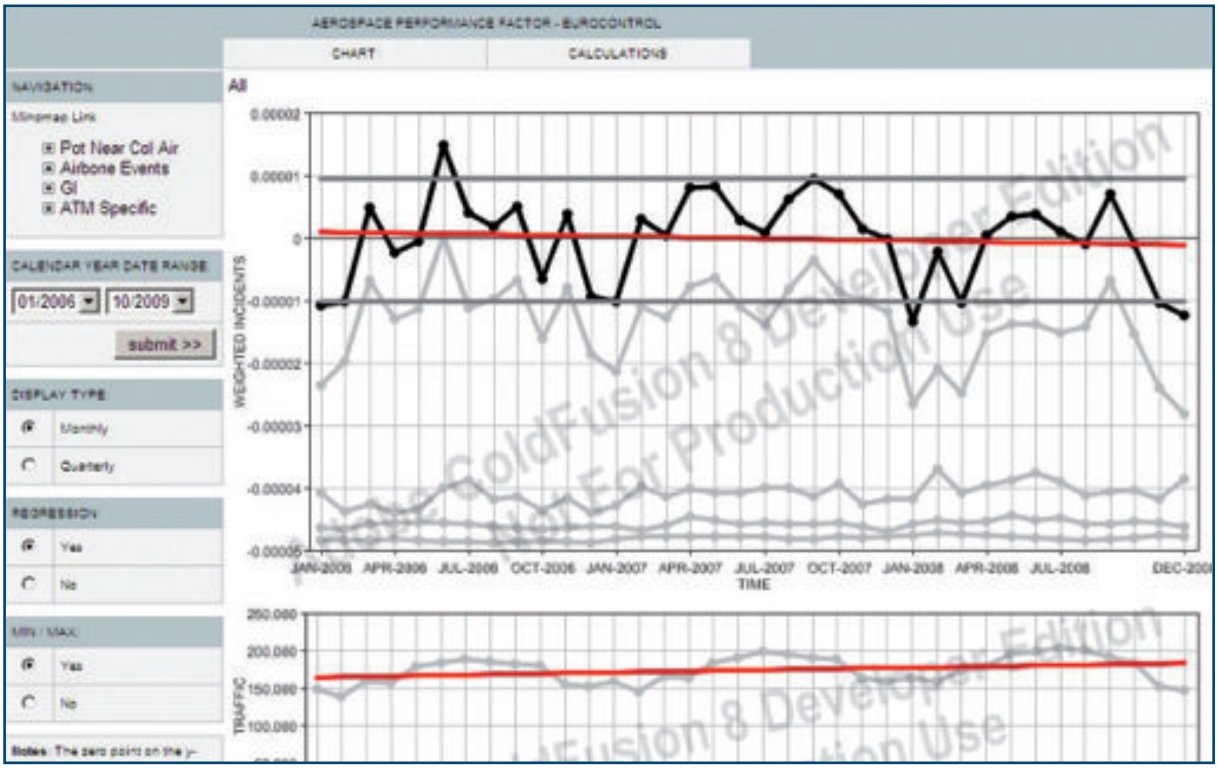

Figure 6: The EUROCONTROL ESARR 2 APF – overview

An interactive APF

One strength of the APF application (hardware/software) is its ability to allow the user to become interactive with the safety data at a variety of levels. Figure 6 shows, as an example, the ATM performance within ECAC for the period January 2006 – December 2008. The black line represents the total performance of the European ATM/airspace, while the red line represents the regression line. In order for the APF to be interactive, the figures allow the user to click on the sub-category lines of the figure and display the underlying data associated with this sub-category. For example, in Figure 7 the sub-categories that comprise the black line (i.e., performance of the system) are displayed in light grey and are grouped as following: Potential Near Collisions (Air), Airborne Incidents, Ground Incidents, and ATM Specific Occurrences. All categories of incidents were normalised to the traffic values amounted for the number of States submitting an AST to EUROCONTROL. By clicking on the sub-category lines (in this example the Airborne Incidents line followed by the Separation Minima Incidents SMIs) a new figure is displayed with the details for this sub-category (Figure 8: Diagnostic level within EUROCONTROL ESARR 2 APF). When the user navigates to a new figure all the functionalities of the figure remain the same but are calculated for the chosen category. In addition to displaying a baseline particular to the user-chosen category, the APF application also displays the sub-categories that comprised that category. In the same manner that the other lines on the figures allow the user to 'drill-down' the lines in Figure 6 also allow the user to make a selection and view the details of the sub-categories that comprise the category (Figures 7 and 8).

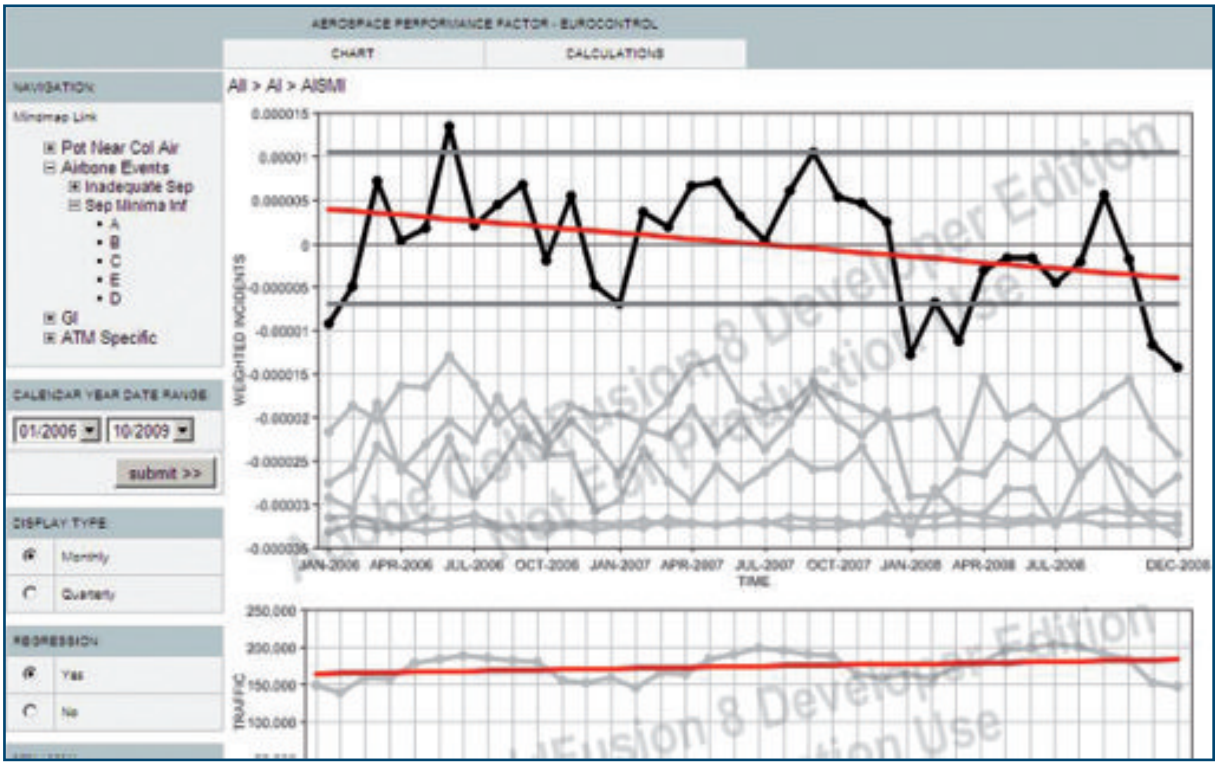

Figure 7: Drilling on Separation Minima Infringements using the EUROCONTROL ESARR 2 APF

As the "drill down" process moves into more specific data, the APF enters the diagnostic section. Within this section, the raw data is presented based on the categorisations and classifications of the organisation. Figure 8 shows sub-grouping of factors, or elements, associated with Separation Minima Infringements.

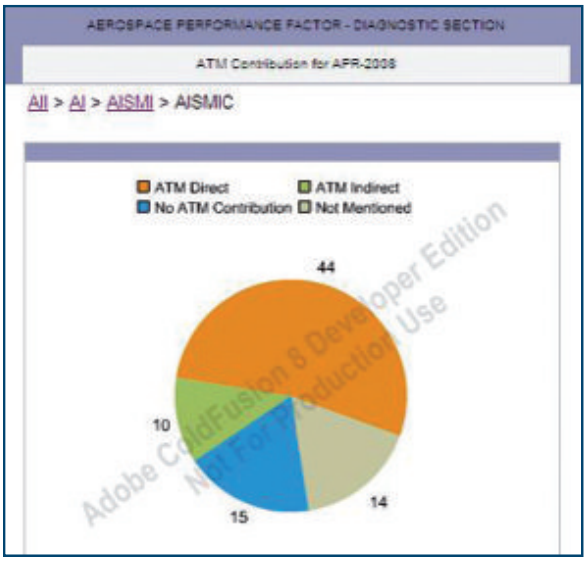

Figure 8: Diagnostic level within EUROCONTROL ESARR 2 APF

EUROCONTROL Accidents APF

Following a thorough analysis of ATM accidents, the SAFREP TF also decided to include in the accident related KPI not only the accidents involving Commercial aircraft with direct ATM contribution, but also accidents with indirect ATM contribution, as this would also reveal valuable lessons to be learned for ATM and trigger safety improvements.

The Task Force also decided to limit the accidents included in the KPI to those involving aircraft with a MTOW above 2250, so as to be in line with ICAO Annex 13 and the AST requirements.

Consequently, the measurement will start from 2005, the year when the AST started to apply the MTOW>2250 kg criterion. The SAFREP TF decided also not to weight the accidents but to still represent the accidents in an APF-lik manner.

Figures 9 and 10 depict the number of accidents involving aircraft with MTOW>2250 with Direct and Indirect ATM Contribution, as reported through the AST.

1. Involving CA and/or GA

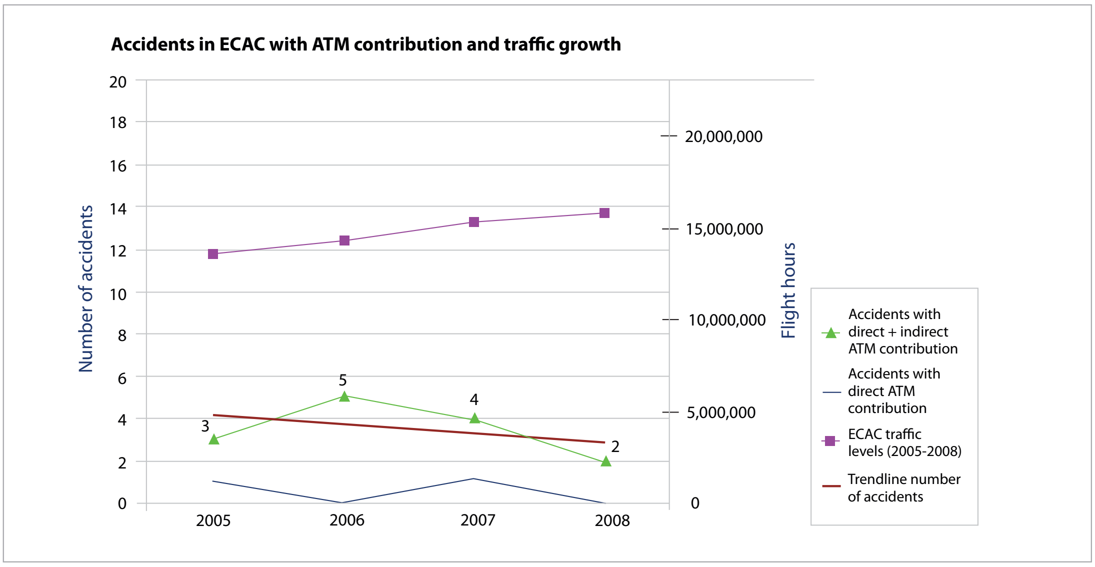

Figure 9: **Number of accidents involving aircraft with MTOW>2250 with ATM Direct and Indirect contribution –** ***Involving Commercial and General aircraft***

2. Involving at least one CA

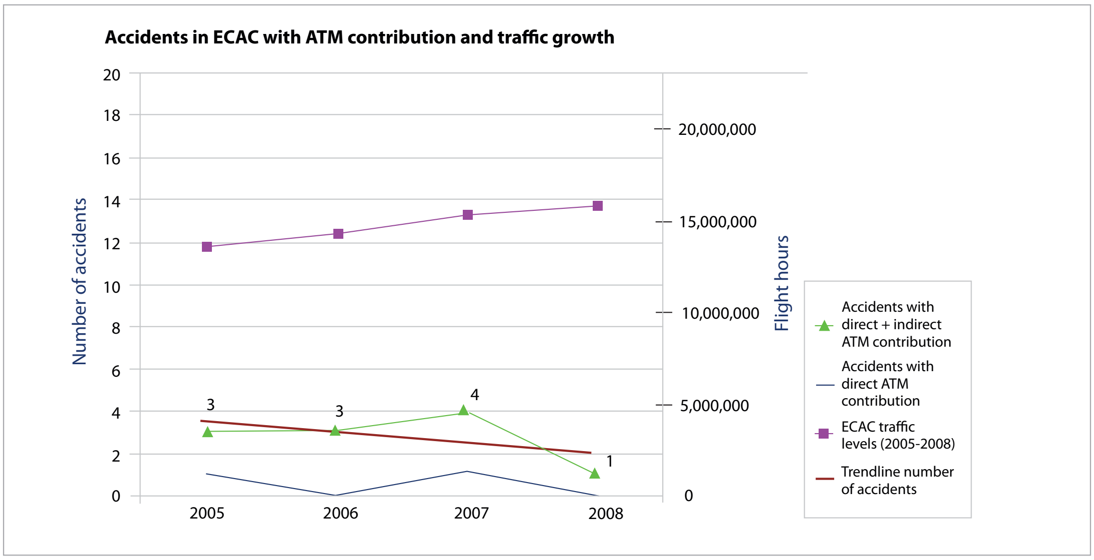

Figure 10: **Number of accidents involving aircraft with MTOW>2250 with ATM Direct and Indirect contribution –** ***Involving at least one Commercial aircraft***

As may be expected, the number of accidents varies from year to year, but the overall trend is not increasing against a background of increasing traffic levels. It must be stressed that the above calculations are based on a number of critical assumptions, including the rates of forecast traffic growth and the percentage contribution of ATM within the overall number of accidents.

These assumptions are being further validated and improved, supported by increased levels of safety data reporting by states and the work carried out by the SAFREP TF in developing KPIs for safety.

This work needs to continue to reap the full benefits of the APF.

Meeting the ECAC objective[2] will demand an increasingly stringent safety performance over time with enhanced commitment by States, not only to provide comprehensive data but also to adopt, with an element of urgency, the outstanding action plans published by EUROCONTROL. SAFREP believes that the APF approach provides a valid methodology for analysing and presenting progress against this key performance objective.

[2] To improve safety levels by ensuring that the numbers of ATM induced accidents and serious, or risk bearing, incidents do not increase and, where possible, decrease.

Other APF Developments

The FAA is currently enhancing its APF to provide improved graphical representation of the data as well as refining performance parameters. Improved granularity of the data now allows the FAA to set specific yearly safety targets based on the indices within their APF. These principles will also be applied to the EUROCONTROL APF but would need further work to refine the processes and results.

Moreover, in Europe, SAFREP TF member ANSPs from Germany, Ireland, Poland, Spain, France, and The Netherlands are either developing operational APFs or exploring implementation of the methodology. Furthermore, a number of ANSPs involved in the SAFREP TF agreed to have their individual state data applied to the EUROCONTROL ESARR 2 APF model. Evaluation of the results is ongoing; initial indications are that, suitably adapted to meet local needs and demands, the EUROCONTROL ESARR 2 APF is also a possible measure of aggregating 'lagging' indicators at national level as well as at the European level.

Finally, the European-based commercial airline easyJet supported by the Imperial College of London created an APF based on their industry-specific categorisation structure and data. Whilst in North America, in addition to the FAA, the United States Naval Safety Centre and Southwest Airlines are both operationally applying or respectively exploring the possibilities of exploiting the APF methodology.

APF Summary

To ensure that safety levels are maintained or improved, systematic safety monitoring processes should evaluate, as a matter of routine, achieved safety performance in all safety-related operational activities.

The SAFREP Task Force feels that it is possible to develop a safety indicator that incorporates multiple sources of incident data and a coherent judgement about the relative importance of the data. This would then allow for safety performance of a given system to be subsequently measured over a considerable time horizon and allow for enhanced risk assessment of the aviation system. The SAFREP TF adopted the APF methodology as a means to achieve this objective.

The goal of the EUROCONTROL ESARR 2 APF was, therefore, to use aggregated ESARR 2 AST data to create a visual representation of the performance of the European ATM/airspace system. The SAFREP TF believes that the proposed EUROCONTROL ESARR 2-based APF can be used by the ATM decision makers at European and national levels, to analyse trends, detect unwanted degradation of safety levels and support the development of effective improvement plans. Moreover, the SAFREP TF feels that through the APF, the lagging safety KPIs can finally start to be de-mystified and a stock index of safety to be followed over time can be established. Using the APF graphs for incidents and accidents, for the first time, ECAC safety objectives for both accidents and incidents can be monitored globally to check that they are being met. The APF can also be used to assess the extent to which political, strategic, regulatory and industry safety targets are being met, again at European and national levels.

Collaboration with the FAA (since November 2008), the US Navy and the participating ANSPs, as well as academic support (from Imperial College London), has been key in the development of a robust APF that enables an holistic overview of the safety performance of the European ATM system and how it is performing against, inter alia, the ECAC safety objective. Over 350 years of subject matter expert opinion, knowledge and experience has been used to create a valid EUROCONTROL ESARR 2-based APF.

It should be noted, though, that the APF methodology is an entirely new way of looking at data and should not be compared to other legacy systems. Unlike engineering solutions, any system whereby humans are involved, either as designers, operators, or users, needs to include the human assessment of intangible aspects of the system. There is nothing wrong with how risk is assessed using the Safety Management System (SMS) risk methodology. Nor is the APF methodology of assessing importance, or risk, wrong. They are just two separate methods that must be accepted as they are with the full understanding of the methodology, benefits, and limitations of each.

Finally, in line with ongoing developments in the APF, the SAFREP TF recommends that further work should be undertaken to allow further evaluation of existing data and to develop and set safety targets based on the indices within the EUROCONTROL ESARR 2 APF.

Acknowledgements

EUROCONTROL would like to express their thanks to the following people for their participation in developing the EUROCONTROL ESARR2 APF.

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Hans Jürgen MORSCHECK	DFS, Germany
Hervé FORESTIER	DSNA, France
Sylvian RICQ	DSNA France
Alexis CLINET	DSNA France
Janne ENARVI	FINAVIA, Finland
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Garrett MACNAMARA	IAA, Ireland
Leif SANDBERG	LFV, Sweden
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