WP2 Final Report
Continuous Safety Monitoring

N. Aghdassi (Avanssa), A.L.C. Roelen (NLR), B. Dziugieł (ILOT) and R. Menzel (JRC)

The main purpose of ASCOS's Work Package 2 (WP2) "Continuous Safety Monitoring" is to develop a methodology and create supporting tools for multi-stakeholder continuous safety monitoring. This is achieved through 4 stages or sub-tasks which ultimately culminate in the development and implementation of tools in support of continuous safety monitoring. The final report provides an overview of the work and achievements within ASCOS WP2.

Coordinator	L.J.P. Speijker (NLR)
Work Package Manager	N. Aghdassi (Avanssa)

Grant Agreement No.	314299
Document Identification	D2.5
Status	Approved
Version	1.3
Date of Issue	09/12/2014
Classification	Public

This page is intentionally left blank

Document Change Log

Version	Author(s)	Date	Affected Sections	Description of Change
1.0	N. Aghdassi et al	12/09/2014	All	Version for PMT approval
1.1	N. Aghdassi et al	22/09/2014	All	PMT comments processed
1.2	L.J.P. Speijker	02/12/2014		Minor textual changes, added FDM tool recommendations
1.3	N. Aghdassi et al	09/12/2014		Further improvements, following suggestions by JRC

Review and Approval of the Document

Organisation Responsible for Review	Name of person reviewing the document	Date
Avanssa	Nuno Aghdassi	21/08/2014
NLR	Alfred Roelen	31/08/2014
CAAi	Terry Longhurst	31/08/2014
CAAi	Stephen Long	31/08/2014
Deep Blue	Simone Rozzi	31/08/2014
Deep Blue	Luca Save	31/08/2014
JRC	Wietse Post	31/08/2014
JRC	Reinhard Menzel	31/08/2014
ILOT	Andrzej Iwaniuk	31/08/2014
ILOT	Bartosz Dziugieł	31/08/2014
Thales Air Systems	Bernard Pauly	19/09/2014
Apsys	Susana Bravo Muñoz	19/09/2014
Deep Blue	Luca Save	19/09/2014
Certiflyer	Gerard Temme	19/09/2014
Organisation Responsible for Approval	Name of person approving the document	Date
Avanssa	Nuno Aghdassi	19/09/2014
NLR	Lennaert Speijker	09/12/2014

Document Distribution

Organisation	Names
European Commission	M. Kyriakopoulos
NLR	L. Speijker, A. Rutten, M.A. Piers, P. van der Geest, A. Roelen, J.J Scholte, J. Verstraeten, A.D. Balk, E. van de Sluis, M. Stuip
Thales Air Systems GmbH	G. Schichtel, J.-M. Kraus
Thales Air Systems SA	B. Pauly
Airbus Defence and Space APSYS	S. Bravo Muñoz, J.P. Heckmann, M. Feuvrier
Civil Aviation Authority UK	S. Long, A. Eaton, T. Longhurst
ISDEFE	M. Martin Sanchez, I. Etxebarria, M. Sánchez
CertiFlyer	G. Temme, M. Heiligers
Avanssa	N. Aghdassi
Ebeni	A. Simpson, J. Denness, S. Bull
Deep Blue	L. Save, S. Rozzi
JRC	W. Post, R. Menzel
JPM	J. P. Magny
TU Delft	R. Curran, H. Udluft, P.C. Roling
Institute of Aviation	K. Piwek, A. Iwaniuk, B. Dziugiel
CAO	P. Michalak, R. Zielinski
EASA	K. Engelstad
FAA	J. Lapointe, T. Tessitore
SESAR JU	P. Mana
Eurocontrol	E. Perrin
CAA Netherlands	R. van de Boom
JARUS	R. van de Leijgraaf
SRC	J. Wilbrink, J. Nollet
ESASI	K. Conradi
Rockwell Collins	O. Bleeker, B. Bidenne
Dassault Aviation	B. Stoufflet, C. Champagne
ESA	T. Sgobba, M. Trujillo
EUROCAE	A. n'Diaye
TUV NORD Cert GmbH	H. Schorcht
FAST	R. den Hertog

Acronyms

Acronym	Definition
ACARE	Advisory Council for Aviation Research
ADREP	Aviation Data Reporting Program (ICAO)
AIM	Accident Incident Model
ANSP	Air Navigation Service Provider
ARC	Abnormal Runway Contact
ASCOS	Aviation Safety and Certification of new Operations and Systems
AST	Annual Safety Template
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
ATS	Air Traffic Service
CATS	Causal model for Air Transport Safety
CFIT	Controlled Flight Into Terrain
CGAA	Collision on the ground between aircraft
CGAVPO	Collision on the ground between aircraft and vehicle/ person/obstruction
CICTT	CAST-ICAO Common Taxonomy Team
CMA	Continuous Monitoring Approach
EASA	European Aviation Safety Agency
EASAC	European Aviation Safety Advisory Committee
EASp	European Aviation Safety Plan
EC	European Commission
ECAC	European Civil Aviation Conference

ECCAIRS	European Co-ordination Centre for Aviation Incident Reporting Systems
ECR	European Central Repository
ESARR	Eurocontrol Safety Regulatory Requirements
ESIMS	ESARR Implementation Monitoring and Support
EU	European Union
FDM	Flight Data Monitoring
FOQA	Flight Operations Quality Assurance
HEMS	Helicopter Emergency Medical Services
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
LALT	Low Altitude
LOC-I	Loss of Control In-flight
MID-AIR	Mid-Air Collisions
MS	Member States
MTOM	Maximum Take-Off Mass
MTOW	Maximum Take-Off Weight
RAMP	Ground Handling events
SCF-PP	System or component failure or malfunction related to the engine
SESAR	Single European Sky ATM Research
SISG	ICAO's Safety Indicator Study Group
SMS	Safety Management System
SPI	Safety Performance Indicator
SRC	Safety Regulation Council (Eurocontrol)
SSP	State Safety Plan

TCAS	Traffic Alert and Collision Avoidance System

This page is intentionally left blank

Executive Summary

ASCOS is an innovative EU funded research project, dealing with Aviation Safety and Certification of new Operations and Systems. ASCOS contributes to the Area/Topic Operational Safety in the Activity Ensuring Customer Satisfaction and Safety of the EU's 7th Framework Programme Aeronautics and Air Transport.

The objective of ASCOS is to develop innovative certification process adaptations and supporting safety driven design methods and tools to ease the certification of safety enhancement systems and operations while, at the same time, increasing safety [5, 6, 7, 8]. ASCOS aims to better account for the human element, already from the early stages of the certification process, and thus reducing consequences of human error and increasing safety. The project follows a total system approach, dealing with all aviation system elements in an integrated way over the complete life-cycle.

ASCOS contains work packages on Certification processes (WP1), Continuous Safety Monitoring (WP2), and Safety Risk Management (WP3). Within WP4 "Certification Case Studies", four case studies will be conducted to validate the processes, methods and tools proposed. The case studies deal with the certification of aircraft failure management systems, a future ATM/CNS system for improved surveillance, aircraft systems for improved controllability in flight, and aircraft ground handling operations.

Work Package 2 of the ASCOS project is responsible for developing a methodology and supporting tools for multi-stakeholder Continuous Safety Monitoring, using a baseline risk picture for the total aviation system. This report provides an overview of WP2 and presents the key results from each of the WP2 sub-task deliverables. More detailed information is available in the associated deliverables, of which D2.1 [1] is public.

The first stage of WP2 (sub-task 2.1) consists of creating a framework for safety performance indicators and using it to propose a sample set of SPIs for key operational safety issues identified by EASA and used in its European Aviation Safety plan (EASp). This is achieved by breaking down the total aviation system into its fundamental layers (or barriers if we consider James Reason's Swiss cheese accident model), namely; technology, human, organisation and system of organisations and deriving SPIs for each layer.

Subsequently, sub-task 2.2 creates a baseline risk picture of the various parts of the total aviation system by quantifying the frequency of occurrence of the key operational issues identified in the EASp (and their accident scenarios). This is done by both analysing existing safety data and using an improved quantified Causal model for Air Transport Safety (CATS) in order to quantify the frequencies of occurrence of runway excursions, ground collisions, controlled flight into terrain, mid-air collisions and in-flight loss of control events.

The third stage of WP2, sub-task 2.3, develops an improved process for safety performance monitoring in which Safety Performance Indicators (SPIs) for each stakeholder are linked with precursors for all the main operational issues for commercial air transport operations. Specifically, sub-task 2.3 looked at how Continuous Monitoring Approach (CMA) can be used as an integral part of the life cycle processes for continued airworthiness of aircraft, and maintenance of certificates for air navigation service providers, operators, and manufacturers as well as how flight data can be used to enhance the safety benefits of a multi-stakeholder CMA in aviation.

Work package 2 culminates with the creation of a set of tools for continuous safety monitoring (sub-task 2.4). The tools created are compatible with the ECCAIRS platform and will allow the user to construct Safety Performance Indicators as proposed in sub-task 2.1 to the extent that the proposed safety performance indicators can be based on the evaluation of the frequency of occurrences reported in an ECCAIRS 5 based occurrence reporting system. The tool is designed to monitor the development of such occurrence rates permitting to compare current dates with historic ones (see sub-task 2.3) and to permit the easy comparison of a set of occurrences related to ASCOS activities with a set not related to ASCOS.

This page is intentionally left blank

Table of Contents

List of Figures

List of Tables

This page is intentionally left blank

1 Introduction

1.1 Background

According to the ASCOS description of work, the main objective of ASCOS is "to develop novel certification process adaptations and supporting safety driven design methods and tools to ease the certification of safety enhancement systems and operations, thereby increasing safety". To achieve this objective, it is deemed necessary to develop a methodology and supporting tools for multi-stakeholder continuous safety monitoring, using a baseline risk picture for all parts of the total aviation system. Such a continuous safety monitoring approach is also advocated by ICAO.

ASCOS contributes directly to the high level Flight Path 2050 and ACARE Vision 2020 safety goals. By 2020, the target is 1) reducing accident rate by 80%, and 2) reducing human error and its consequences. Figure 1 gives the worldwide fatal accident rate for commercial operations with western-built jet aircraft over the period 1980 until 2010. As can be observed, there has been little to no improvement of aviation safety worldwide from about 2004 onwards. Europe, the United States and other 'western' regions show a similar trend.

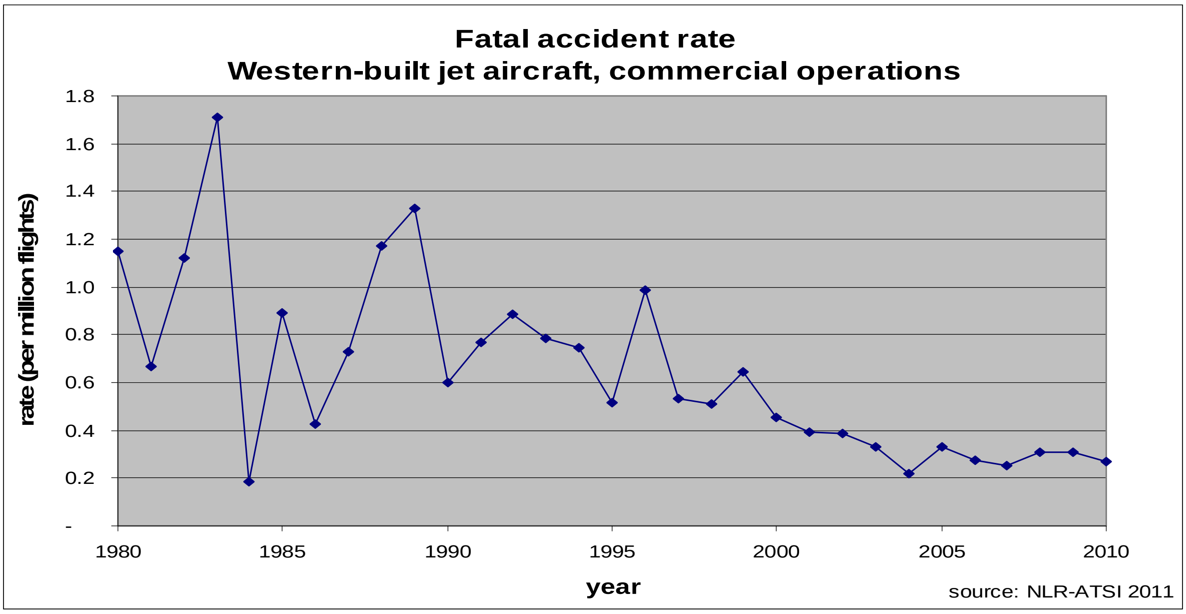


Figure 1 Worldwide fatal accident rates over the period 1980 until 2010 (Source: NLR-ATSI)

ASCOS aims to break this 'stagnation' of safety improvement through introduction of novel and innovative certification adaptations, which will ease the certification and approval process of safety enhancement systems and operations. It is clear that significant impact on the accident rate can only be realised if the priorities are focused on areas that exhibit a high risk. A specific activity during establishment of ASCOS will be the identification of such priority areas through analysis of the European Aviation Safety Programme Manual, European Aviation Safety plan, Annual Safety Reviews from EASA and Eurocontrol, and consultation with the ASCOS User Group.

1.2 Objectives

The main aim is to develop a methodology and the supporting tools for multi-stakeholder Continuous Safety Monitoring, using a baseline risk picture for all the parts of the total aviation system. This main aim is to be achieved by the following detailed objectives:

- To define a framework of Safety Performance Indicators for the total aviation system;
- To establish a baseline risk picture for the total aviation system;
- To develop an improved process for safety performance monitoring;
- To develop and implement tools in support of continuous safety monitoring.

1.3 Approach

The first stage consists of defining a framework of safety performance indicators for the total aviation system. This will be achieved by using the Reason model and analysing the following barriers in the lead-up to any given accident:

- Component
- Individual (human)
- Organisation
- System of organisations

In order to come up with a selection of safety performance indicators (SPI) for each one of the barriers, it will be necessary to determine a set of quality criteria for developing and choosing appropriate SPIs. The following criteria are deemed to be relevant for selection:

- Quantifiable and permitting statistical inferential procedures;
- Valid or representative to what is to be measured;
- Provide minimum variability when measuring the same conditions;
- Sensitive to change in environmental; or behavioural conditions;
- Cost of obtaining and using measures is consistent with the benefits;
- Comprehended by those in charge with the responsibility of using them.

The next stage will be to use industry-recognised accident scenarios to describe the logical link between barrier failures and the final outcome (the accident).

The key operational accident scenarios of the European Aviation Safety Plan (EASP) include:

- Runway excursion
- Mid-air collision
- Controlled Flight Into Terrain
- Loss of control in flight
- Ground collisions

This analysis will result in the selection of appropriate safety performance indicators for each of the barriers present for each type of accident scenario.

Sub-task 2.2 in WP2 will create a baseline risk picture for the total aviation system. This will be achieved using a two-fold process of analyzing existing data included in aviation safety reports and correlating the data with specific accidents which have occurred recently, as well as, quantifying the key operational accident scenarios of the EASp using the CATS statistical model which includes data from thousands of real accidents.

The follow-on task consists of developing an improved process for safety performance monitoring. This is an integral part of safety assurance within safety management systems and therefore in order to meet future technological and operational demands industry, organizations and, ultimately, national aviation authorities will need to seek novel ways of monitoring safety performance. That's why this task investigates if and how the Continuous Monitoring Approach (CMA) could be used as an integral part of the life cycle processes for continued airworthiness of aircraft, and maintenance of certificates for air navigation service providers, operators, and manufacturers. ASCOS investigates if, and how, flight data obtained by Flight Data Monitoring (FDM), could be used to enhance the safety benefits of a multi-stakeholder CMA in aviation.

The final task of WP2 will be to create the tools that will assist all stakeholders in the aviation industry to implement continuous safety monitoring. This is done by using the results coming from the other tasks within WP2 to create a set of tools implementing the defined approach for the main operational issues as defined in the European Aviation Safety plan (EASP) framework. Ultimately the tools provide an overview (in the form of tables, charts, visual indicators, etc.) of the past evolution of given safety performance indicators. The tools are ECCAIRS compatible which means that they can be used by the many existing ECCAIRS users around the world.

1.4 Structure of the document

The key results and conclusions from the different sub-tasks are contained in the following Sections:

- Section 2 provides a framework for safety performance indicators in the total aviation system (WP2.1)
- Section 3 deals with the baseline risk picture for the total aviation system (WP2.4)
- Section 4 focuses on processes for continuous safety monitoring (WP2.3)
- Section 5 describes the developed tool for Continuous Safety Monitoring (WP2.4)
- Section 6 contains the main conclusions and recommendations

2 Framework Safety Performance Indicators

2.1 Introduction and Objectives

A proper implementation of continuous safety monitoring requires the development of specific safety performance indicators for states, airlines, airports, ANSPs as well as for aviation products designed and manufactured.

Performance indicators of various key performance areas (including productivity, financial, environmental, quality and safety) are routinely being used throughout the aviation industry as part of the general management processes. Examples of frequently used indicators of various sorts are: passenger volume, revenue passenger kilometres, passenger load factor, aircraft dispatch rate, aircraft movements, hourly airport capacity, gate departure delay, lost work time from employee accidents and injuries, component mean time between repair, total revenue, net profit, capital expenditures, etc. For some performance areas, such as finance, identical performance indicators are being used throughout the aviation system. For other performance areas, such as productivity, dissimilar indicators are being used by the different types of stakeholders in the aviation system. This is a direct result of the diverse types of product that are being provided by these stakeholders. Performance indicators for aviation safety are relatively new. Until recently, safety was not seen as a performance area that could be actively managed. The widespread introduction of Safety Management System (SMS) throughout the aviation system has changed this and has resulted in an increasing application of indicators of aviation safety performance. But unlike other performance areas, there is no common framework for safety performance indicators in aviation. Even between stakeholders of the same type (e.g. airlines) there are differences, sometimes fundamental, in the way safety performance is being measured.

In the context of developing a methodology and the supporting tools for multi-stakeholder continuous safety monitoring, the objective of WP 2.1 is to define a framework of safety performance indicators for the total aviation system.

2.2 Terminology and Approach

At a conceptual level, an accident is often depicted as a sequence of safety barrier failures. There can be different types of safety barriers. They are often represented as separate and sequential layers, whereby barrier failures are depicted as holes in the layers. Safety performance can be measured by identifying and counting such holes. A distinction is made between safety barriers related to human, technology and organisational systems. The class ‘system of organisations’ is added to cater for those barriers that exist on the interfaces between organisations. For each of those four types of safety barriers, potential measures of safety performance were collected and compared with the following criteria:

- Quantifiable and permitting statistical inferential procedures;
- Valid or representative to what is to be measured;
- Provide minimum variability when measuring the same conditions;
- Sensitive to change in environmental; or behavioural conditions;

- Cost of obtaining and using measures is consistent with the benefits;
- Comprehensible by those in charge with the responsibility of using them;
- The accuracy of the data should be capable of quality control and verification;
- The total set of indicators should remain manageable.

2.3 Results Summary

2.3.1 Technology

The 'technology' part of safety barrier classification consists of the technical components of the air transport system. Failures of such components are regularly (in many cases even consistently) registered and these failure registrations can be used as safety performance indicators of the 'technology' class. A component failure is regarded as a failure of the 'technology' class of barriers.

Because of the industry-wide use of the ATA chapter numbers and the fact that the same codes are basically also used in ECCAIRS it seems very logical to apply the system for the definition of aircraft system related safety performance indicators. Unfortunately, a similar industry-wide classification system for other technical components of the air transport system (Airport, Air Navigation Services ANS) does not exist. Therefore the list of systems and components of ANS and Airports in the ECCAIRS 'Descriptive factors' is used.

2.3.2 Human

The 'human' part of the safety barrier classification consists of the human actors of the air transport system. Failures of such components are normally referred to as 'errors' or 'human errors'. Differently from the failures to the technical components they are quite frequent, but rarely monitored and registered. In order to overcome these limitations it appears more reasonable to detect, record and analyse those safety occurrences which are likely to be related to some kind of human error than to record the errors themselves.

2.3.3 Organisation

When it comes to establishing safety performance indicators at the level of the organisation, one must consider this within the context of a safety management system and choose those metrics which are a true measure of an organisation's performance in terms of managing safety and a reflection of the safety culture within. As a framework for safety performance indicators at the level of the organisation, the key operational safety issues stated in EASA's European Aviation Safety plan are relevant:

- Runway excursions;
- Mid-air collisions;
- Controlled flight into terrain;
- Loss of control in flight;
- Runway incursions;
- Fire, smoke or fumes.

For each of these key operational issues, several indicators were identified for which data is likely to be available within the context of a safety management system of a service provider.

2.3.4 System of Organisations

The aviation system can be considered as a system of organisations in the sense that several different organisations cooperate to achieve an overall objective that no individual organisations can reach by itself. The individual organisations constituting a system of organisations can be very different and operate semi-independently, yet their interactions are essential for the performance of the total system. To measure the correct functioning of a system of organisations, one needs to define when a system of organisations is functioning correctly. It is assumed that a correctly functioning system of organisations contributes to an overall acceptable safety performance. A system of organisations functions properly:

- When there is no performance decrease at interfaces between organisations;
- When there is proven interaction, openness and sharing of information between different stakeholders;
- When during the entire lifecycle the system functions as designed, and;
- When there is a harmonized approach to safety performance management activities across different organisations.

Therefore, safety indicators at the level of the system or organisations should represent the quality of interfaces, interaction, lifecycle and harmonisation.

2.3.5 Quantification

Simply counting the number of safety occurrences (e.g. accidents, serious incidents, occurrences etc.) is normally not a correct way to measure aviation safety. The occurrence data need to be normalised by their exposure to the risk of flying. The number of flights is considered to be the most appropriate for normalisation of occurrence data. Quantification of a particular SPI then requires counting the number of occurrences of the event described by the SPI as well as the associated number of flights. Data availability is obviously an important issue. For that reason linking the SPIs with the ECCAIRS system is important as well as linking the SPIs with a source of normalisation data such as EASA's warehouse for aviation production data.

The ECCAIRS system has become the world standard for collecting and classification of coding accident and incident data. In Europe, the ECCAIRS software is the standard for reporting system, and data is centrally stored in the European data repository. For quantification of the SPIs, access to such a large data pool is essential and for that reason it is of vital importance that the SPIs can be unambiguously linked with the ECCAIRS system.

2.4 Conclusions and Recommendations

The following safety performance indicators are proposed:

Technology

- Rate of auto-flight system failures/flight
- Rate of electrical power system failures/flight
- Rate of flight control system failures/flight
- Rate of fuel system failures/flight
- Rate of hydraulic power system failure/flight
- Rate of ice/rain protection system failures/flight
- Rate of landing gear system failures/flight
- Rate of navigation system failures/flight
- Rate of powerplant system failures/flight
- Rate of aerodrome de-icing facilities failure/flight

Human

- Rate of fire/smoke/fumes events/flight
- Rate of runway incursions/flight
- Rate of stall warnings/flight
- Rate of bank angle alerts/flight
- Rate of near CFIT/flight
- Rate of deviation from glideslope/approach
- Rate of deviation from localizer/approach
- Rate of level bust at low altitude/flight
- Rate of separation minima infringements (ROC>7)/flight
- Rate of airspace infringements/flight
- Rate of level busts/flight
- Rate of high speed rejected take-off/attempted take-off
- Rate of continued approach (go around not conducted) following unstabilised approach/approach
- Rate of long landings/landing
- Rate of excessive approach speed event/approach

Organisation

- Rate of unstable approaches/landing
- Rate of deep landings/landing
- Rate of flight crew failure to deploy ground spoilers/landing
- Rate of delayed brake application/landing

- Rate of delayed application of thrust reversers/landing
- Rate of level-busts/flight
- Rate of navigation errors which result in a loss of separation with another aircraft/flight
- Rate of incorrect flight crew response to genuine TCAS RA warnings/warning
- Rate of loss of separation events/flight
- Rate of STCA warnings/flight
- Rate of EGPWS events/flight
- Rate of incorrect flight crew response to genuine EGPWS warnings/warning
- Rate of navigational errors which result in a loss of separation with terrain/flight
- Rate of MSAW warnings/flight
- Rate of misuse of automation events/flight
- Rate of near-stall events/flight
- Rate of high bank angle events/flight
- Rate of runway incursion events/flight
- Rate of fire/smoke/fumes events/flight
- Average airport emergency response time

System of Organisations

- System combined runway incursion rate
- System combined taxiway incursion rate
- System combined airprox rate
- Operator combined erroneous weather prediction rate
- System combined bird strike rate
- Total number of formal safety related meetings involving at least to different type of organisations (e.g. an aerodrome and ANSP) per year
- Total number of formal meetings of network of analysts to discuss safety performance measurement
- The safety impact of each significant airport infrastructural change is assessed and deemed acceptable before the actual introduction of the change
- The actual safety impact of each significant airport infrastructural change is evaluated at most after 3 years of implementation of the change
- The safety impact of each significant aircraft modification is assessed and deemed acceptable before the actual introduction of the modification
- The actual safety impact of each significant aircraft modification is evaluated at most after 3 years of implementation of the modification
- The safety impact of each significant ATM provision modification is assessed and deemed acceptable before the actual introduction of the modification
- The actual safety impact of each significant ATM provision modification is evaluated at most after 3 years of implementation of the modification

- The safety impact of an aircraft flying under an outdated certification scheme is assessed after each significant change in certification rules
- A proper means to identify future risks is set-up and altered when deemed necessary
- Future risk are identified on a regular basis (at least each year new risks should be identified) using a dedicated means to do so
- A common risk classification framework is used by CAAs and industry (using the same criteria for likelihood and severity of events)
- The number of organisations that have fully implemented a Safety Management System before the final transitional dates allowed.
- The average level of regulatory compliance of states (for example using ICAO USOAP CMA or EASA audits) should be measured every three years and should increase every three years.

To facilitate quantification and semi-continuous updating of the safety performance indicators, it is recommended that each proposed safety performance indicator that is based on operational occurrences is unambiguously connected with one or more events of the ECCAIRS taxonomy and a suitable denominator from EASA's warehouse for aviation production data. Data from both sources should be assembled, and the safety performance indicator values should be (semi)-continuously calculated. It should be ensured that the monitoring of human actions cannot be misused or abused (e.g. for legal purposes), and that it is not intended to monitor the actions of one particular human operator. It is recommended to map of what is considered important to measure (as listen in this deliverable) versus the measures that are possible given current data. A gap analysis would then show what data needs to be gathered to ensure that safety can really be monitored effectively.

3 Baseline Risk Picture for Total Aviation System

3.1 Introduction and Objectives

3.1.1 Introduction

The top 5 commercial air transport accident categories that include a high number of fatal accidents are 1) loss of control in flight; 2) Aircraft system or component failure or malfunction; 3) abnormal runway contacts, usually involving long, fast or hard landings; 4) ground handling aircraft damage by vehicles or ground equipment or incorrect loading; and 5) controlled flight into terrain. The EASA Annual Safety Review 2010 also provides information on safety occurrences in the European Central Repository (ECR). The top ECR safety occurrence categories include: Air Traffic Management / Communication Navigation Surveillance (ATM/CNS); aircraft system/ component failure or malfunctions; ground handling; Airprox/TCAS alert/loss of separation/ near midair collisions/midair collision; and bird strikes.

General aircraft operation event types are the most frequent category in the ECR occurrences. Analysing this event further, gives three major events affecting the aircraft operation: flight crew interaction with air navigation services; aircraft collisions with obstacles, including bird strikes; and aircraft handling. The ATM domain has a small contribution to aviation incidents and accidents. However, according to EASA, efforts are still required to further improve ATM Safety. This may be due to the fact that – although ATM safety occurrences seldom lead to fatal accidents – they are still listed in the top ECR occurrence categories.

The creation of a Baseline Risk Picture for the Total Aviation System is a part of the activities of the ASCOS Work Package Continuous Safety Monitoring, which also includes a framework of safety performance indicators for the total aviation system (see section 2), development of an improved process for safety performance monitoring and, finally, the development and implementation of tools in support of continuous safety monitoring.

3.1.2 Objectives

The objective of this work package was to create a baseline risk picture of the various parts of the total aviation system by quantifying the frequency of occurrence of the key operational issues identified in the European Aviation Safety Plan (EASp) (and their accident scenarios).

3.1.3 Research approach and methodology

Initially, the data scope and data analysis methodology was defined, because the baseline had to be established using a representative, reliable and reproducible set of safety data. The NLR-ATSI Air Safety database was used as data source for quantification of the accident scenarios. Air safety data are all data that characterise activities of the air transport system. The NLR-ATSI Air Safety Database contains detailed information on accidents, serious incidents and incidents of fixed wing aircraft and helicopters (covering commercial operations and General Aviation) from 1960 onwards. Currently the Air Safety Database contains information on more than 200,000 accidents, serious incidents and incidents that occurred worldwide.

Furthermore, the Air Safety Database contains a large collection of worldwide non-accident related data, flight exposure data, weather data, fleet data, and more. The Air Safety Database is updated frequently using reliable sources including data from official reporting systems, insurance claims, accident investigation boards, aircraft manufacturers, and civil aviation authorities. The Air Safety Database uses the most recent version of ECCAIRS to collect, store and analyse all this safety information.

An improved quantified Causal model for Air Transport Safety (CATS) was used in order to quantify the frequencies of occurrence of the accident scenarios and the key operational issues identified in the EASp (runway excursion, ground collision, controlled flight into terrain, mid-air collision and in-flight loss of control).

A review was also carried out of EASA and Eurocontrol's Annual Safety Reports in order to gather additional data to support and supplement where needed the CATS model. In general, the amount of data was limited to what was required for the purpose of the analysis. Finally, statistical analysis was performed on the selected air safety data from the NLR-ATSI Air Safety database in order to obtain the required results, e.g. in the form of a ratio or probability for events representing all known accident scenarios in the total aviation system.

European Aviation Safety Plan (EASp)

In order to further improve the already good safety record that exists in the civil aviation industry, ICAO developed and is promoting the principles of safety management throughout the aviation industry. The concept of safety management isn't new but when ICAO issued the first edition of their Safety Management Manual, it set into motion a new, more structured and integrated approach to safety management, right across the aviation industry (please also refer to ASCOS D3.1 conclusion §6.1 [9]).

The new philosophy of safety management suggests that there needs to be a cascading effect set into motion that sets the foundations for a safety management system that is integrated throughout; at an organizational level, at national level with the regulator and, finally, at a global level.

These principles revolve around the implementation of a Safety Management System (SMS) in industry organisations which are based on the State Safety Programme (SSP) of their national regulatory authority. Therefore, as a starting point, every ICAO Contracting State must have an SSP.

The sharing of roles between the European Union and the Member States, as described in the Basic Regulation made it impossible for Member States to take full responsibility for an SSP by themselves. Although some EU States went ahead and created their own SSP, most Member States did not have the capabilities to create such a programme. This is why there was a need to create the European Aviation Safety Programme (EASp) and also to complement what is already done by the Member States which encompasses the powers transferred to the Union.

In view of this need and in order to streamline the strategic approach, a European Aviation Safety Advisory Committee (EASAC) was established in October 2009 with representation from industry, some Member States, Eurocontrol, the European Commission and the Agency. Its fruitful guidance and the collaboration mechanisms established have culminated in the development of two important elements of the EASp: a manual and a safety plan.

The European Aviation Safety Plan (EASp) details the EU's strategy and priorities areas that need to be tackled in order to improve aviation safety in Europe. Its framework consists of systemic issues, operational issues, emerging issues and human factors and performance.

The plan identifies the following 5 key operational safety issues:

- Runway Excursions;
- Mid-Air Collisions;
- Controlled Flight Into Terrain (CFIT);
- Loss of Control In Flight (LOC-I);
- Ground Collisions.

These 5 safety issues are the basis upon which the ASCOS framework for safety performance indicators is created, and are therefore also central to the baseline risk picture for the total aviation system.

Causal model for Air Transport Safety (CATS)

The Causal model for Air Transport Safety (CATS) was initially developed as a result of an initiative by the Netherlands Ministry of Transport in order to gain a thorough understanding of the causal factors underlying the risks of air transport and their relation to the different possible consequences so that efforts to improve safety can be made as effective as possible.

The causal model uses a backbone structure of generic accident scenarios which have been defined based on the ICAO definition of an accident, in order to systematically develop accident scenarios: abrupt manoeuvre, cabin environment, uncontrolled collision with ground, controlled flight into terrain, forced landing, mid-air collision, collision on ground, structural overload and fire/explosion. The accident scenarios are grouped by accident type and different flight phases. The Event Sequence Diagram (ESD) methodology is used for representing the accident scenarios.

An ESD consists of an initiating event, pivotal events and end states. A representation of a generic ESD is given in Figure 2 (please also refer to ASCOS D3.2). ESDs provide a qualitative description of series of events leading to accidents. Because pivotal events can also cause avoidance of an accident, an ESD also models scenarios which lead to incidents and reportable occurrences. An initiating event represents the start of the main accident scenario. The initiating event of course also may have causes, and they are represented in a fault tree. Each pivotal event represents a possibility for the safety occurrence to develop into an accident, or a possibility that the accident is avoided. If all pivotal events contribute towards an unwanted outcome, than the end state is an accident or serious incident. If a pivotal event causes avoidance of an accident the end state is a safe continuation of the flight. A single ESD therefore can represent more than one accident scenario, and also represents accident avoidance scenarios. In case of the generic ESD of Figure 2, there are two accident scenarios and two accident avoidance scenarios.

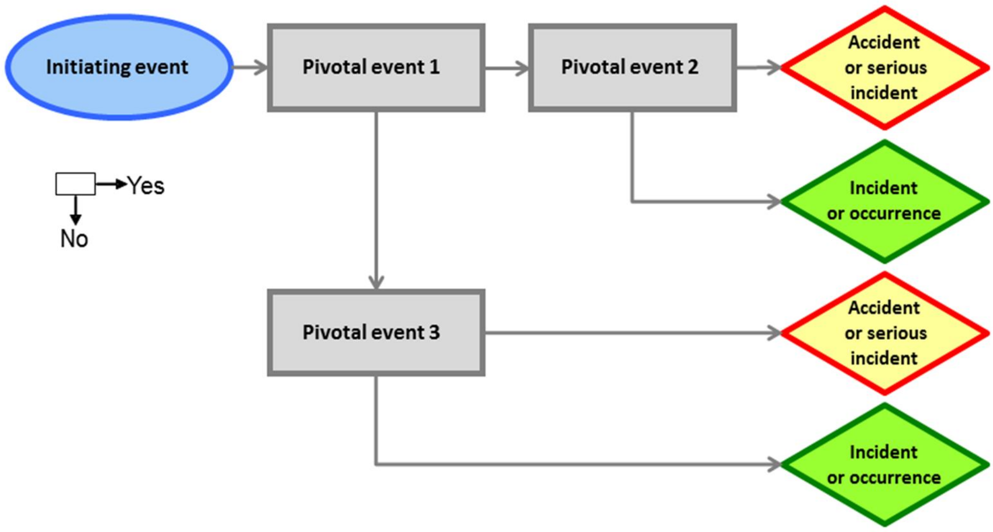


Figure 2 Generic representation of an ESD

In total 35 generic accident scenarios were developed based on a combination of retrospective and prospective analyses. These scenarios were subsequently quantified and allow the user to obtain a probability of occurrence for any given combination of an event.

Note that an improved version of the Causal model for Air Transport Safety, representing all possible accident scenarios in the current total aviation system is being developed as part of the ASCOS Project. Within the remainder of this study, this improved version is used to establish a total aviation system baseline risk picture.

3.2 Results Summary

3.2.1 Analysis of annual safety reports

Analysis of EASA and Eurocontrol annual safety reports shows a consistent enhancement of safety over the last 2 decades. This is true both in terms of the number of fatalities and also the number of accidents. Europe has consistently experienced a low rate of fatal accidents compared with many other regions of the world and there have been recent years where there have been no fatal accidents to operators of that region.

Globally, the average rate of accidents involving fatalities has stagnated at around 5 accidents per 10 million flights, suggesting that a great deal more needs to be done to further improving aviation safety in the future. The introduction of system-wide safety management systems and a greater recognition of the role of human factors (including fatigue) in accidents is expected to bring about the next step-change in safety, particularly as traffic volume increases. Helicopter operations in the European member States (MS) have also seen improvements in safety over the years although EMS (Emergency Medical Service) operations still account for most fatal accidents. Business aviation has improved similarly.

Among the accident categories for EASA MS operated aircraft, abnormal runway contact is one of the most frequent together with runway excursions, ground incidents and non-power plant system or component failures. Nevertheless, the accident categories which result in the most fatalities are loss of control in-flight, power plant system or component failures, post-impact fire/smoke and controlled flight into terrain.

About 40 % of all fatalities occur in accidents which happen during the approach and landing phases of flight. Furthermore, loss of control accidents in-flight result in higher numbers of fatalities when compared, for instance, to abnormal runway contact events (such as hard landings and runway excursions) despite being rarer occurrences. This explains the focus of the EASp on these and other events categories such as CFIT, mid-air collisions and ground collisions.

The introduction of ESARRs and the collection of ATM safety data by Eurocontrol have shown an increase in reporting by ATM agencies across Europe although there are still obstacles for the full implementation of safety standards across the entire ATM system in Europe. The main safety issues identified correspond to those which are also followed by EASA and established in the EASp as the key operational safety issues. EU Commission regulation 390/2013 which lays down a performance scheme for ATM services will hopefully remove any remaining barriers for the full implementation of safety management regulations and further enhance operational safety for the future.

3.2.2 Baseline risk level

The European Aviation Safety Plan (EASp) of the European Aviation Safety Agency (EASA) identified main risk areas of commercial air transport operations. These risk areas are classified according to the type of issues they highlight, amongst which are operational issues. Operational issues are brought to light by the reporting and analysis of safety occurrence data. Safety occurrences are events where the available safety margin towards accidents or serious incidents has been reduced. Accidents are unrecoverable and represent end states in a series of events that include safety occurrences.

The EASp lists the following operational issues as being of primary importance: runway excursions, mid-air collisions, controlled flight into terrain (CFIT), loss of control in flight (LOC-I), and ground collisions.

To calculate the probability of occurrence of the main operational issues, the total number of accidents and serious incidents related to a specific operational issue has been divided by the exposure data corresponding to the data scope. The selected time interval was between 1 January 1995 and 31 December 2011. Accidents and incidents that occurred within EASA member States were included. The exposure data of flights in EASA member States[1] with commercially operated (scheduled and non-scheduled) turbine aircraft with a maximum take-off mass of 5700kg or heavier has been calculated to be 108.866.747 flights. **Error! Reference source not found.** provides the number of occurrences and corresponding frequencies for each of the accident end states. Frequencies were calculated by dividing the number of occurrences of a particular accident type plus a rest term (consisting of occurrences that could not be assigned to a specific accident type and were distributed equally across accident types of a particular category) by the total number of flights (108.866.747).

Table 1 Number of occurrences and corresponding frequency

ESD	ESD name	Accident end state code	Accident end state name	Number of occurrences[2]	Number of occurrences not assigned to accident scenario and distributed over total number of end states[3]	Frequency per flight
1	Aircraft system failure during take-off	ASC01d1	Runway excursion	2	0.39	$2.19 \cdot 10^{-8}$
2	ATC related event during take-off	ASC02d1	Runway excursion	0	0.39	$3.57 \cdot 10^{-9}$
3	Aircraft directional control by flight crew inappropriate during take-off	ASC03d1	Runway excursion	2	0.39	$2.19 \cdot 10^{-8}$
3	Aircraft directional control by flight crew inappropriate during take-off	ASC03d3	Runway excursion	2	0.39	$2.19 \cdot 10^{-8}$
4	Aircraft directional control related system failure during take-off	ASC04d1	Runway excursion	3	0.39	$3.11 \cdot 10^{-8}$
4	Aircraft directional control related system failure during take-off	ASC04d3	Runway excursion	1	0.39	$1.28 \cdot 10^{-8}$
5	Incorrect configuration during take-off	ASC05d1	Runway excursion	1	0.39	$1.28 \cdot 10^{-8}$

[1] This includes all flights that either took off or landed in an EASA member states. Overflights are not included.

ESD	ESD name	Accident end state code	Accident end state name	Number of occurrences[2]	Number of occurrences not assigned to accident scenario and distributed over total number of end states[3]	Frequency per flight
5	Incorrect configuration during take-off	ASC05d3	Collision with ground	1	0.05	$9.64 \cdot 10^{-9}$
6	Aircraft takes off with contaminated wing	ASC06c1	Collision with ground	2	0.05	$1.88 \cdot 10^{-8}$
8	Aircraft encounters windshear after rotation	ASC08d1	Collision with ground	0	0.05	$4.59 \cdot 10^{-10}$
9	Single engine failure during take-off	ASC09d1	Runway excursion	3	0.39	$3.11 \cdot 10^{-8}$
9	Single engine failure during take-off	ASC09d3	Runway excursion	2	0.39	$2.19 \cdot 10^{-8}$
10	Pitch control problem during take-off	ASC10d1	Runway excursion	2	0.39	$2.19 \cdot 10^{-8}$
10	Pitch control problem during take-off	ASC10d3	Runway excursion	0	0.39	$3.57 \cdot 10^{-9}$
10	Pitch control problem during take-off	ASC10e1	Collision with ground	0	0.05	$4.59 \cdot 10^{-10}$
11	Fire, smoke, fumes on-board aircraft	ASC11c2	Aircraft continues flight damaged	12	0.00	$1.10 \cdot 10^{-7}$
11	Fire, smoke, fumes on-board aircraft	ASC11d1	Collision with ground	0	0.05	$4.59 \cdot 10^{-10}$
11	Fire, smoke, fumes on-board aircraft	ASC11e1	Personal injury	2	0.00	$1.84 \cdot 10^{-8}$
11	Fire, smoke, fumes on-board aircraft	ASC11e2	Aircraft damaged	78	0.00	$7.16 \cdot 10^{-7}$
12	Flight crew member spatially disoriented	ASC12c1	Collision with ground	1	0.05	$9.64 \cdot 10^{-9}$
13	Flight control system failure	ASC13c1	Collision with ground	2	0.05	$1.88 \cdot 10^{-8}$
14	Flight crew incapacitation	ASC14c1	Collision with ground	1	0.05	$9.64 \cdot 10^{-9}$

ESD	ESD name	Accident end state code	Accident end state name	Number of occurrences[2]	Number of occurrences not assigned to accident scenario and distributed over total number of end states[3]	Frequency per flight
15	Ice accretion on aircraft in flight	ASC15c1	Collision with ground	0	0.05	$4.59 \cdot 10^{-10}$
16	Airspeed, altitude or attitude display failure	ASC16c1	Collision with ground	4	0.05	$3.72 \cdot 10^{-8}$
17	Aircraft encounters thunderstorm, turbulence or wake vortex	ASC17c1	In-flight break-up	7	0.00	$6.43 \cdot 10^{-8}$
17	Aircraft encounters thunderstorm, turbulence or wake vortex	ASC17d1	Collision with ground	1	0.05	$9.64 \cdot 10^{-9}$
17	Aircraft encounters thunderstorm, turbulence or wake vortex	ASC17e1	Aircraft continues flight with injury	30	0.00	$2.76 \cdot 10^{-7}$
18	Single engine failure in flight	ASC18d1	Collision with ground	1	0.05	$9.64 \cdot 10^{-9}$
18	Single engine failure in flight	ASC18d3	Collision with ground	8	0.05	$7.39 \cdot 10^{-8}$
18	Single engine failure in flight	ASC18e1	Aircraft lands off runway	6	0.00	$5.51 \cdot 10^{-8}$
19	Unstable approach	ASC19d1	Collision with ground	11	0.05	$1.02 \cdot 10^{-7}$
19	Unstable approach	ASC19d3	Collision with ground	6	0.05	$5.56 \cdot 10^{-8}$
19	Unstable approach	ASC19f1	Runway excursion	21	0.39	$1.96 \cdot 10^{-7}$
19	Unstable approach	ASC19g2	Runway excursion	4	0.39	$4.03 \cdot 10^{-8}$
19	Unstable approach	ASC19g3	Aircraft continues landing roll damaged	11	0.00	$1.01 \cdot 10^{-7}$
21	Aircraft weight and balance outside limits during approach	ASC21c1	Collision with ground	1	0.05	$9.64 \cdot 10^{-9}$

ESD	ESD name	Accident end state code	Accident end state name	Number of occurrences[2]	Number of occurrences not assigned to accident scenario and distributed over total number of end states[3]	Frequency per flight
23	Aircraft encounters windshear during approach or landing	ASC23d1	Collision with ground	4	0.05	$3.72 \cdot 10^{-8}$
23	Aircraft encounters windshear during approach or landing	ASC23d3	Collision with ground	1	0.05	$9.64 \cdot 10^{-9}$
23	Aircraft encounters windshear during approach or landing	ASC23f1	Runway excursion	1	0.39	$1.28 \cdot 10^{-8}$
25	Aircraft handling by flight crew inappropriate during flare	ASC25d1	Runway excursion	15	0.39	$1.41 \cdot 10^{-7}$
25	Aircraft handling by flight crew inappropriate during flare	ASC25e1	Runway excursion	4	0.39	$4.03 \cdot 10^{-8}$
25	Aircraft handling by flight crew inappropriate during flare	ASC25e2	Aircraft continues landing roll damaged	49	0.00	$4.50 \cdot 10^{-7}$
26	Aircraft handling by flight crew inappropriate during landing roll	ASC26c1	Runway excursion	40	0.39	$3.71 \cdot 10^{-7}$
27	Aircraft directional control related system failure during landing roll	ASC27c1	Runway excursion	25	0.39	$2.33 \cdot 10^{-7}$
31[1]	Aircraft are positioned on collision course in flight	ASC31d1	Collision in mid-air	4	0.00	$3.67 \cdot 10^{-8}$
32[1]	Runway incursion	ASC32d1	Collision on runway	7	0.00	$6.43 \cdot 10^{-8}$
33	Cracks in aircraft pressure cabin	ASC33c1	In-flight break-up	0	0.00	0
33	Cracks in aircraft pressure cabin	ASC33c2	Aircraft damage	0	0.00	0
35	TAWS alert	ASC35d1	Collision with	4	0.05	$3.72 \cdot 10^{-8}$

ESD	ESD name	Accident end state code	Accident end state name	Number of occurrences[2]	Number of occurrences not assigned to accident scenario and distributed over total number of end states[3]	Frequency per flight
			ground			
36[1]	Conflict on taxiway or apron	ASC36d1	Collision on taxiway or apron	120	0.00	$1.10 \cdot 10^{-6}$
38	Loss of control due to poor airmanship	ASC38c1	Collision with ground	0	0.05	$4.59 \cdot 10^{-10}$

[1] *To ensure correct use of the exposure data, collisions between two aircraft are considered as two separate occurrences.*

[2] *Note that only 502 occurrences and 51 types of accident end states codes have been filed in Table 4 while 1055 occurrences corresponding to 79 types of end states codes have been identified. The reason for the difference is that only 502 occurrences actually led to 'accident end states' (the other occurrences led to 'non accident' end states). Only accident end states were used to quantify the 'risk frequencies per flight'.*

[3] *One 'collision with ground' accident that could not be assigned to an accident scenario has been equally distributed over all 'collision with ground' end states. Seven 'runway excursion' accidents that could not be assigned to an accident scenario have been equally distributed over all 'runway excursion' end states.*

Based on the results of **Error! Reference source not found.**, the frequencies of the key operational safety issues as identified by EASA can be calculated. The results are presented in Table 2.

Table 2 Frequency of key operational safety issues

Key operational safety issue	Associated ESD end state that matches the key operational safety issue	Frequency
Runway excursion	ASC01d1, ASC02d1, ASC03d1, ASC03d3, ASC04d1, ASC04d3, ASC05d1, ASC09d1, ASC09d3, ASC10d1, ASC10d3, ASC19f1, ASC19g2, ASC23f1, ASC25d1, ASC25e1, ASC26c1, ASC27c1.	$1.24 \cdot 10^{-6}$
Mid-air collision	ASC31d1	$3.67 \cdot 10^{-8}$

CFIT	ASC35d1	3.72 10^{-8}
Loss of control in flight	ASC05d3, ASC06c1, ASC08d1,ASC10e1, ASC11d1, ASC12c1, ASC13c1, ASC14c1, ASC15c1, ASC16c1, ASC17d1, ASC18d1, ASC18d3, ASC19d1, ASC19d3, ASC21c1, ASC23d1, ASC23d3, ASC38c1	$4.13 \cdot 10^{-7}$
Ground collision	ASC32d1, ASC36d1	$1.17 \cdot 10^{-6}$

3.2.3 Comparison with Eurocontrol's Integrated Risk Picture

It is interesting to compare the frequencies of the key operational issues as presented in Table 2 with the results from Eurocontrol's Integrated Risk Picture IRP. Similar to the CATS model, the IRP is the output of a risk model, representing the risk of aviation accidents, with particular emphasis on ATM contributions. The IRP for 2005 was quantified using historical experience from 1990 to 2004. To obtain the risk picture for 2012, the effect of a set of ATM changes that (in 2005) were expected to be in place by 2012, were estimated by the IRP project team and Eurocontrol experts. The comparison between the results from the updated CATS model and the IRP are presented in Table 3 for the main operational issues.

The IRP does not provide estimates for the frequency of runway excursions. Note that the Eurocontrol frequencies related to fatal accidents only, while the updated CATS model includes all accidents. For the accident types with a high fatality rate (mid-air collisions, CFIT and loss of control in flight), the results from the updated CATS model correspond well with the IRP results. For ground collisions the estimated probability from the updated CATS model is much higher than those of the IRP model, but this can be explained by the fact that the fatality rate of this type of accident is much lower and the fact that the CATS model includes collisions on the apron, while the IRP model is restricted to collisions on the runway and taxiways.

Table 3 Comparison with Eurocontrol IRP

Main operational issue	Accident frequency according to updated CATS model	Fatal accident frequency for 2005 according to Eurocontrol IRP	Fatal accident frequency for 2012 according to Eurocontrol IRP
Mid-air collision	$3.67 \cdot 10^{-8}$	$5.4 \cdot 10^{-9}$	3.1·10-9
CFIT	$3.72 \cdot 10^{-8}$	$5.4 \cdot 10^{-8}$	1.5·10-8
Loss of control in flight	$4.13 \cdot 10^{-7}$	$1.3 \cdot 10^{-7}$	9.3·10-8
Ground collision	$1.17 \cdot 10^{-6}$	$6.6 \cdot 10^{-8}$	6.4·10-8

3.2.4 Risk Picture for SESAR

The Integrated Risk Picture from Eurocontrol is further improved by using the Accident Incident Model (AIM), developed within SESAR. Similar to the CATS model and the Eurocontrol IRP, the SESAR AIM consists of a risk model, which shows the risks of aviation accidents and provides a structured breakdown of their causes, with particular emphasis on ATM contributions (both positive and negative). Using the AIM, a risk picture for SESAR is being developed to represent the combined effects of the set ATM changes that are expected to be in place by 2013, 2017 and 2020. Each ATM change is modelled through adjustments representing its expected impacts on appropriate elements of the risk model. These effects, together with the effects of changes in traffic levels, can then be summed to estimate the total risks and contributory / causal breakdown for 2013, 2017 and 2020. This approach allows investigation of the improvements that are necessary to satisfy the ECAC wide safety targets. However, a Risk Picture for SESAR is still under development.

3.3 Conclusions and Recommendations

The analysis of the EASA and Eurocontrol annual safety reports shows a significant overall improvement in safety in the last 2 decades. Europe (27 EU Member States plus Iceland, Liechtenstein, Norway and Switzerland) has consistently experienced a low rate of fatal accidents compared with many other regions of the world and there have been recent years where there have been no fatal accidents within the region.

However, a pick-up in air traffic following the economic downturn of 2008, may also result in an increase in fatal and non-fatal occurrences.

About 40 % of all fatalities occur in accidents which happen during the approach and landing phases of flight. Furthermore, loss of control accidents in-flight result in higher numbers of fatalities when compared, for instance, to abnormal runway contact events (such as hard landings and runway excursions) despite being rarer occurrences. This explains the focus of the EASp on these and other events categories such as CFIT, mid-air collisions and ground collisions.

The baseline risk level for the total aviation system, which has been derived on the basis of air safety data from the NLR Air Safety database and accident scenarios – represented by an improved version of the Causal model for Air Transport Safety – for the key operational safety issues established in the EASp, shows that of the 5 event categories, runway excursions and ground collisions are more frequent than CFIT, mid-air collisions and loss of control in-flight. However, this relationship is converse to the rate of fatalities associated with these types of accidents.

The introduction of ESARRs and the collection of ATM safety data by Eurocontrol have shown an increase in reporting by ATM agencies across Europe although there are still obstacles for the full implementation of safety standards across the entire ATM system in Europe. The main safety issues identified correspond to those which are also followed by EASA and established in the EASp as the key operational safety issues. EU Commission regulation 390/2013 which lays down a performance scheme for ATM services will hopefully remove any remaining barriers for the full implementation of standard safety management regulations and further enhance operational safety for the future.

Helicopter operations in the European MS have also seen improvements in safety over the years although EMS (Emergency Medical Service) operations still account for most fatal accidents. Business aviation has improved similarly.

4 Process for Safety Performance Monitoring

4.1 Introduction and Objectives

4.1.1 Task objective

The objective of this specific deliverable is to develop an improved process for safety performance monitoring in which Safety Performance Indicators (SPIs) for each stakeholder will be linked with precursors for all the main operational issues for commercial air transport operations. This task also links in with sub-task 3.5 which establishes a process for improving aviation standards taking on board the precursors identification.

The objectives of this task are also to investigate:

- How Continuous Monitoring Approach (CMA) can be used as integral part of the life cycle processes for continued airworthiness of aircraft, and maintenance of certificates for air navigation service providers, operators, and manufacturers?
- If and how flight data obtained by Flight Data Monitoring (FDM), Flight Operations Quality Assurance (FOQA) can be used to enhance the safety benefits of a multi-stakeholder CMA in aviation?

4.1.2 Research approach

The research starts with a theoretical overview of a process for safety performance monitoring and measuring. The process is one of the twelve elements comprising the ICAO SMS framework and it is part of the ICAO SMS component – "Safety Assurance". The safety assurance process provides confidence that the organisation is operating as designed and that the SMS is effective. In particular it helps the organisation to verify its safety performance, to ensure that the risk mitigation measures are effective and to identify and assess changes and manage the associated risks.

A process of safety performance monitoring and the method improvement is based on the feedback known in the literature as the Deming Circle or PDCA Cycle.

The purpose of this study is to provide methods needed to implement the process. Special emphasis is given to determine the links between SPIs and precursors for all the main operational issues of commercial air transport operations (refer to 2.2) and the use of data from FDM or FOQA in continuous safety monitoring (refer to 3.4).

4.2 Results Summary

4.2.1 Process for safety performance monitoring

ASCOS Safety Assurance process

A long-term ICAO Global Aviation Safety Plan (GASP) objective is the implementation of predictive risk modelling systems that assure safety in a real-time, collaborative decision-making environment by the Block Upgrades strategy in the long-term. The upgrades are planned to achieve the following targets: integrated arrival, departure and surface management, full flight and flow information for a collaborative environment (FF-ICE), traffic complexity management, and full 4D trajectory based-operations (TBO). For the near-term, GASP identifies two objective groups:

- Effective Safety Oversight - effective implementation of a fundamental safety oversight in States lacking it;
- Safety Management and Predictive Risk Modelling - full implementation of State Safety Programs (SSP) in the rest of States followed, in the mid-term, by Safety Management Systems (SMS) implementation in organisations.

ASCOS proposes a method for enhancing the management system by safety performance monitoring focused on the Total Aviation System. The method is based on monitoring of 63 SPIs linked to causal factors – precursors and offers a way of using them to assure safety (refer to 2.2.4). The control of SPIs no. 1-46 assumes:

- setting target levels of SPIs for current period to reach planned objectives
- reacting to every exceedance by the Safety Manager and the team of delegated workers (equipped with adequate powers) by development of response plans using identified precursors
- implementing response plans by the Management and monitoring their results

The SPIs no. 47-63 deal with the system of organisations level and are offered for further consideration as they require more changes to the current situation.

The method allows for transforming historical lagging signals and using them together with leading signals in pro-active prevention. The transformation presupposes that a sequence of events in the future will occur as it always has in the past. E.g. past SPI TLS exceedance linked to precursor 'lack of English proficiency' will cause the exceedance again and combined with other SPIs exceedances may lead to one of the Operational Issues. Thus, the historical lagging SPIs integrated with precursors and Operational Issues possess predictive information and enhance Safety Assurance. The integration was elaborated by previous ASCOS work - the method of SPI-precursor linking steps. The mentioned 'linking steps' were called 'metaprocess to safety performance monitoring' and they go beyond the monitoring itself, but provide a tool to apply it.

The reported aggregated SPIs could be further analysed following the inductive reasoning and forming theories on deterioration of safety, using trends extrapolation focusing on coherence and simplicity as well as detecting symptoms of confirmation.

Moreover, data points (as SPIs, FDM data, or even precursors if collected, even partially) could be placed into distinct categories, often of a qualitative nature (precursors) and thus fall into a category, commonly described as "discrete choice" data. An entire class of models is available to analyse discrete choice data. For example variance-based probability models like the logit models:

- ordered logit (which recognises an inherent ordering in the categories)
- multinomial logit (which do not recognise any ranking among choices)

Provided large enough data samples are available, such probability models of occurrence and factors sensitivity analysis could be applied to examine Operational Issues from a statistical perspective.

One of the descriptive statistics allowing identifying underperforming organisation is a function of the Mahalanobis distance. It measures a unitless distance from a common point (multivariate data centroid) taking into account the correlations of data set.

The distance is calculated by the following matrix algebra formula:

$$D_M(X) = \sqrt{(X-\mu)' S^{-1} (X-\mu)}$$

Where:

X – n x k matrix of n SPIs aggregated per period in organisation k
μ – n x 1 vector of e.g. means for SPIs
S – n x n covariance matrix of the (X- μ) matrix

The atypicality distance values are found in the resulting $D_M(X)$ (diagonals of k x k matrix). Organisations with the highest atypicality distance (e.g. top 5%) are underperforming in terms of safety assurance and should be considered for further, detailed examination.

The proposed organisation of the ASCOS process for safety performance monitoring is based on the Deming cycle (Plan-Do-Check-Act). The steps defined in the process are as follows:

1. Designation of responsibilities
2. Review of safety policy and objectives
3. Definition of indicators and their specifications
4. Determining data requirements
5. Collection of information
6. Analysis of the results
7. Response to findings
8. Evaluation and correction of SPIs

By implementation of the process, the Safety Assurance component will be transitioned from prescriptive to performance-based safety management rooted in quantifiable SPIs and enhanced by the ASCOS precursors and their method of application within Management System (MS) of organisation.

Internal structure of the metaprocess of SPIs and precursors links identification

To be more informative on the representation and the evaluation of the emerging/future risks, the semi-continuously updated SPIs need to be linked to concrete information where the significant problems arise and for what reasons. 'Semi-continuous update' meaning periodical aggregation of the SPIs events, refers to ASCOS D2.1 and ASCOS D3.2 prepared a metaprocess to enable the safety performance monitoring and its continuous improvement within a MS. The metaprocess identifies links between SPIs and precursors leading to the Operational Issues.

Figure 3 presents considerations on the availability of emerging safety information in relation to a timeline for possible action. During the post flight operation phase the Safety Manager and his team use the process as described in D2.3 section 2.1.3, that includes lagging indicators, historical information and the precursors, and prepare a reaction to provide Safety Assurance of future operations. They are not able to provide a real-time reaction to emerging issues in flight operation (i.e. while flying, taxiing, taking off, landing), because these data are not available to them at the time of event occurrence.

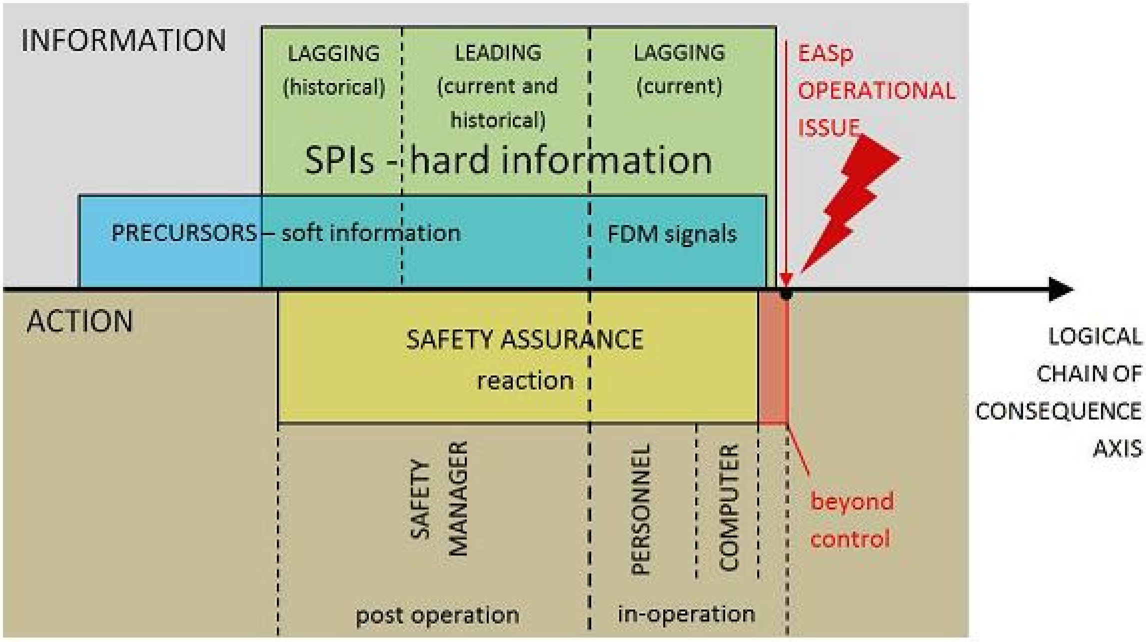


Figure 3 Safety Assurance using SPIs and precursors

A list of precursors, characterised in ASCOS D3.1 and presented in ASCOS D3.2 (about a dozen as examples), was massively populated, up to 500 different precursors. The new precursors, including occurrences (uneventful events), as well as deviations were identified using the following rules:

a. Precursors should be identifiable at one of 4 levels corresponding to the SPIs levels:
   - Human (human errors, lack of adherence to procedures, pilot incapability, etc.)
   - Technology (system failures, malfunctions etc.)
   - Organisations (e.g. workload distribution)
   - System of organisations (requirements definition, regulations, etc);
b. Precursors should be semantically separable (there should not be precursors which cover the same event, even partially);
c. Set of defined precursors should exhaust the specified range of factors identified as influencing the safety (e.g. adverse weather).

An example of ASCOS enhanced Safety Assurance

For the purpose of this example, the analysis was limited to one lagging SPI only. Yet, individual SPIs are not expected to be very informative. Usually several of the SPIs have to be considered and looked upon from the Management System perspective as well as using statistical inference (refer to 4.1).

Consider a simplified example of Safety Assurance within MS using one SPI – Technology level SPI no 7 "Rate of landing gear system failures/flight". The event measured by SPI7 may lead to Runway Excursion during landing.

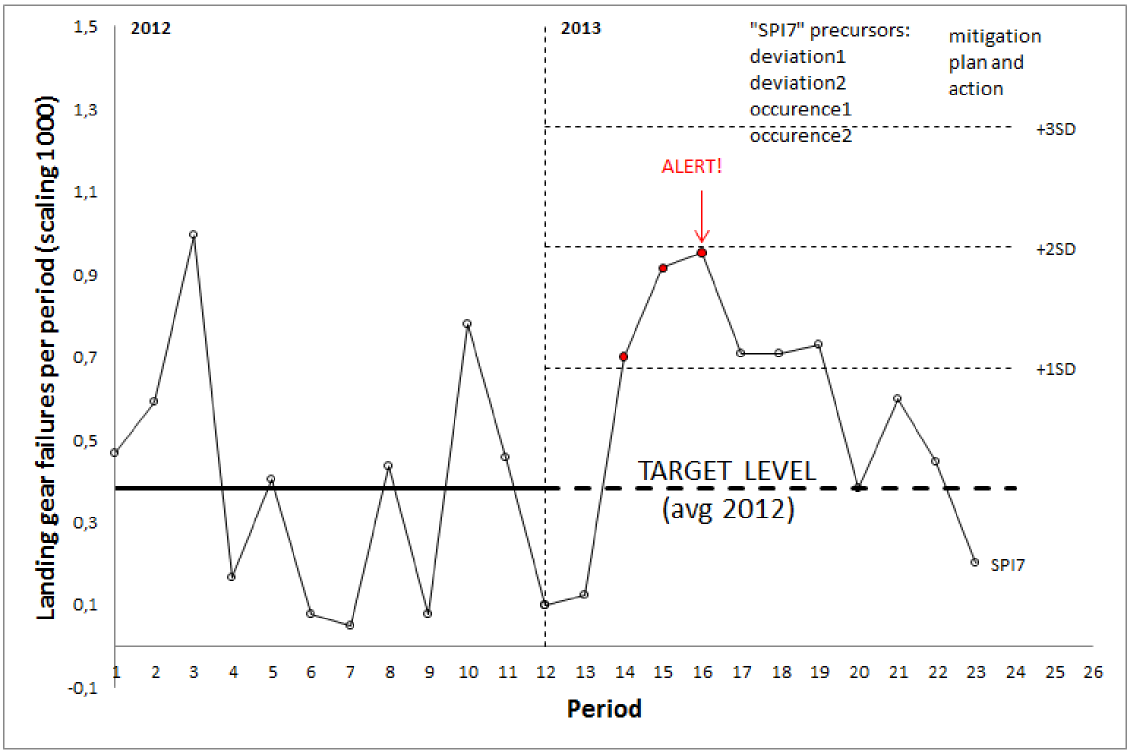


Figure 4 Safety performance monitoring, one SPI example (X-axis: periods=months since implementation of MS, Y-axis: SPI7 rate in 1000s monthly aggregated at a service provider level)

The practical approach to respond to this exceedance could for example follow the Eight Disciplines Problem Solving approach (8D: Plan; Use a Team; Define and describe the Problem; Develop Interim Containment Plan; Determine, Identify, and Verify Root Causes and Escape Points; Choose and Verify Permanent Corrections (PCs) for Problem/Non Conformity; Implement and Validate Corrective Actions; Take Preventive Measures; Congratulate Your Team). Another approach to such an exceedance can be found within the safety management toolkit like the one suggested by EHEST Safety Management Manual Version for Non-Complex operators developed with consideration of Annex III of the EU regulation on Air Operations, Part ORO Subpart GEN Section II 'Management System' and the relevant AMCs and GM published in October 2012.

The management considering the post-investigation safety mitigation plan can take action and can issue adequate instructions. However, some of the discovered safety issues may go beyond service provider level requiring Civil Aviation Authority assistance (e.g. renegotiation of bilateral agreements due to different levels of ICAO requirements conformity among States to be flown from/to, changes to obligatory training procedures). At the end of a certain period the organisation reports to the European Common Repository (ECR) all of its safety occurrences that fall into the reporting requirements outlines in legislation, i.e. also those not monitored by SPIs, related to SPIs levels.

Relationship with other components of the SMS framework

The Safety Assurance component addressed in this document needs to be implemented within a Management System and needs to support the remaining components of the SMS:

- Safety Policy and Objectives;
- Safety Risk Management;
- Safety Promotion.

4.2.2 Safety Data Collection, Analysis and Exchange

Criteria for data quality

The type of safety data needed to calculate SPIs includes the collected exposure data and sums of occurrences reports concerning number of accidents and incidents, events, non-conformance or deviations and hazards. Data collection needs to use existing reporting infrastructure, notably the ECCAIRS reporting system. The quality of the data that is used to enable effective decision making must be considered throughout SSP and SMS development and implementation.

Additionally, prior to implementation, ASCOS should take into consideration the less than perfect quality of input that is likely to be encountered. The analysis is supplemented by data quality criteria:

- Data validity;
- Data completeness;
- Data timeliness;
- Data availability;
- Data accuracy.

Collected data need to be created and stored in a standardized format to facilitate data exchange and analyses for continuously monitored safety.

Evaluation of feasibility and implementation issues related to proposed processes of safety performance monitoring in ECCAIRS Reporting System

Given this particular scope, the high number of SPIs and the limited areas of concern for which SPIs have been developed some considerations are made regarding the implementation of the tool(s):

- The tool(s) should be focused on monitoring occurrence data from an ECCAIRS 5 compatible repository;

- Considering that the SPI definitions may be subject to reconsiderations and alterations, the tool to be developed should be kept as flexible as possible;
- Where possible usage will be made of existing analytical means which are part of, or linkable to, the ECCAIRS Reporting System;
- Given that the limited timeframe of the ASCOS project, the amount of new occurrence data available for analysis will be small.

An evaluation of the proposed indicators was carried out to determine to what extent they could be developed taking into account the current ECCAIRS taxonomy. Based on this evaluation, the issues related to the following indicators were observed:

- Technical - related to the failures of critical systems other than installed on aircraft such as rate of aerodrome de-icing facilities failure/flight. The current ECCAIRS taxonomy does not provide for a classification of the failure of the facilities instead covers the ground –de-icing activity as a whole;
- Organisation - The current ECCAIRS taxonomy does not have a specific descriptive factor that covers some of the defined Organisation related SPIs. For others, precise definitions need to be developed.

In principle, it would thus be feasible to develop and maintain the proposed indicators. Nevertheless, issues related to implementation continue to exist and would need to be resolved.

Based on the draft of regulations concerning the ECR, the ECR will continue to exist in the future. Access will be simplified for some actors in the aviation system.

In regards to access to matching exposure data, the matter appears to be more complicated. Data in the ECR not only relate to the occurrences occurring within the Reporting States, but also to aircraft registered in or operated by the Reporting States. The information regarding the number of flights carried out outside of Europe is not known. There are also commercial exposure data providers that collect data on the number of flights by aircraft type, but such commercially available data is not complete as not all operators provide related information.

By definition, data analysis is based on data. Thus, if no data is present or the data reported is incomplete or incorrect, the analysis will fail to provide reliable results.

In the development of rates, occurrences need to be mapped to related exposure data. For rates related to aircraft, the number of movements of a given aircraft type needs to be linked to the occurrences in which this type was involved. Development of such mapping has been complicated in the past because of the various ways in which aircraft types have been described.

It should be noted that recent developments of type designators and developments of the CAST-ICAO reference database have been coordinated. Thus, while the problem of obtaining the matching exposure data exists for aircraft presently in service, it may be reduced or eliminated for new aircraft entering service.

The use of data from the Flight Data Monitoring (FDM), Flight Operations Quality Assurance (FOQA) in continuous safety monitoring

There are basically two approaches of setting up flight data database at a European aggregation level. In the first approach operators provide predefined parameters or events from their FDM programme to the central database. In the second approach the operators simply provide all their raw flight data recordings (time traces) to the database. Both approaches are discussed in more detail.

The first approach is central collection of predefined FDM parameters/events. It is easiest one for the entity that collects stores and analyses the data. Values of the parameters are simply stored into a database including some background data like type of aircraft and date. Event exceedances can be collected in this way. Routine events can also be collected in this way. However, this will give a continuous flow of data from the airline operators to the entity as the parameters are recorded for each flight. Difficulties arise in this approach from the wide variation of parameter definitions that are being used by the operators.

In the second approach is central collection of raw flight data, where the airlines provide raw flight data to a central database where the data is further processes and analysed by an entity to determine the aggregate FDM parameters/events. The second approach lacks the important drawbacks of the first approach. As raw data are collected in this approach, the entity that collects and analyses the data can use its own definitions and criteria for the parameters. A major drawback to the second approach is that all the collected raw flight data need to be stored, processed and analysed using special software tools. Also expert knowledge in flight data analysis and flight operations is required within the staff of the entity that is responsible for this process.

In both approaches de-identification of the flight data will be needed. Identification of flight crews should not be possible. However, identification of aircraft types is essential for using the flight data for continued airworthiness purposes.

The ECCAIRS tool suite is aimed at facilitating occurrence reporting and as such is not suited to do any kind of flight data processing nor can it be used for the identification of event exceedances and routine events. Changing the ECCAIRS software to be able to do this is also not feasible. Specialised FDM software is needed for that purpose. However, the event exceedances and routine events data obtained from the flight data can be stored into the ECCAIRS system together with the corresponding background data like aircraft type, weather etc. without major changes to the ECCAIRS software. Possible required taxonomy issues can technically be resolved easily. Getting community agreement on changes may prove difficult.

Flight data provide an excellent source to enhance the safety benefits of continuous monitoring approach in aviation. It is feasible to use flight data to monitor (trends) flight operations and flight crew behaviour and compare this information with expected operational and behavioural performance. The most flexible and effective approach is to collect raw time trace flight data, however this requires significant resources to manage.

The Automatic Safety Data Gathering in ATM as a source for continuous safety monitoring

In analogy with FDM, the Automatic Safety Data Gathering (ASDG) may be defined as the process of using an automated system to detect occurrences that may be related to the safety performance of the ATM system, to collect and record relevant context data, and to assist with the interpretation of the occurrence data. Since the late nineties, this process has been encouraged by EUROCONTROL with the design of the Automatic Safety Monitoring Tool (ASMT), a tool that supports the monitoring of safety performances at the level of the overall ATM Safety. The information obtained with this tool can help the Air Navigation Service Providers (ANSPs) to define improvement actions.

For each detected occurrence, ASMT stores the relevant data (shortly before, during and shortly after the event) into a database that can be later queried to extract the data or to review the occurrence in a dedicated replay window. The recording of all these events correspond to different ASMT software modules, which can be configured independently at local level, focusing the priority on one or the other aspect, depending on the safety policies and SMS of the specific ANSP.

Flight simulator data as input for continuous safety monitoring

The simulators provide a controlled environment for analysing influences on human performance. Studies involving flight simulators and air traffic control simulators are particularly relevant for pilot performance and air traffic controller performance.

Assuming the human factor data generated during professional programs of simulated flights are as valid as real-flight data, the ASCOS SPIs of Human level automatically detected among this data may serve as safety performance evaluation of the diagnosed personnel.

Protection of safety data

Information provided by aviation personnel is essential for safe operation of a complex and vulnerable air transport system. Potentially fatal accidents and incidents in the transport system operation can be prevented only when the underlying or contributing safety issues are known in time. Often the only source of an early warning of a safety issue or a deficiency is the personnel.

Given the potential for misuse of safety data that have been compiled strictly for the purpose of advancing aviation safety, database management must include protection of the data. Protection considerations include:

a. Adequacy of protection – access to information. Regulation vis-a-vis safety management requirements.
b. Policies limiting information flows (need to know only).
c. De-identification.
d. Security of information systems
e. Prohibitions on unauthorized use and publication of data and derived results…

4.2.3 Safety performance monitoring process for system of organisations

The list of ASCOS SPIs includes a level for System of organisation indicators elaborated for the aggregate performance monitoring. In fact any other ASCOS SPIs could be aggregated to this level, however only System of organisation SPIs count hazards that originate from the interfaces between different organisations. The idea of ASCOS is to include the events of System of organisation SPIs within the existing occurrence reporting and within State Safety Programmes of the EASA Member States. It is assumed, that the obtaining of these SPIs, the same as any other ASCOS SPIs, would be done by the help of sums of occurrences from the ECCAIRS database matched with the adequate exposure data.

The same philosophy of the management of change (PDCA) described for Safety Assurance at a service provider level (concerning Technology, Human and Organisation SPIs) would apply to the use of System of organisation level SPIs.

The main difference would concern the leading SPIs and the precursors that were linked to these SPIs. Apart from other qualities (e.g. their normalisation would be determined case by case), the leading SPIs are positioned in different location in the chain of events. The precursors linked to these SPIs are no longer “precursors”, but the results. They are the effects of the events measured by the leading SPIs. The nomenclature, however, was not changed due to the metaprocess structure.

The SPIs no. 47-63, however, are the SPIs that go beyond the required extension to the EU regulations on the occurrence reporting and were not recommended by the Section 6.4.1 of ASCOS D2.1 due to general nonconformity to six criteria:

1. Comprehended by those in charge with responsibility of using them;
2. Cost of obtaining and using measures is consistent with benefit;
3. Sensitive to change in environmental or behavioural conditions;
4. Minimum variability when measuring the same conditions;
5. Representative to what is to be measured;
6. Quantifiable and permitting statistical inferential procedures.

4.3 Conclusions and Recommendations

4.3.1 Conclusions

ASCOS method is aligned to the long-term ICAO Global Aviation Safety Plan (GASP) to have appropriate performance indicators, to verify the causal factors and use the alert levels. The method supports the EASA recommended Management System (MS) and transition from quality management to SMS;

ASCOS performance based safety monitoring process corresponds to the Continuous Monitoring Approach (CMA) used as integral part of the stakeholders’ life cycle processes for the purpose of the Safety Assurance SMS component. The safety level is continuously monitored and semi-continuously measured;

ASCOS method offers Safety Performance Indicators (SPIs) linked to causal factors – precursors. An elaborated metaprocess allows for method improvement. A large number of occurrence reports will be required to obtain statistical confidence. The method is more oriented on precursors mitigation approach instead of traditional accident and incidents mitigation approach. It enables the prevention, mitigation or elimination of phenomena (precursors) directly leading to high risk events. When the TLS of the SPIs is exceeded, the list of identified precursors support root cause analyse and implementation of adequate risk mitigation plans;

ASCOS SPIs can be quantified using the occurrences stored in the ECCAIRS database combined together with appropriate exposure data;

Flight data provides an excellent source for monitoring in flight operations, system performance and flight crew behaviour. FDM provides feedback on the assumptions made in certification and helps to identify new/changed hazards and assess associated risks;

Bow-tie models contain events which can be quantified or associated with FDM parameters and occurrence reports from voluntary reporting programs;

ATM related ASCOS SPIs (such as separation infringements, level busts) are easily comparable especially if they are classified with a common scheme such as the EUROCONTROL Risk Analysis Tool (RAT).

4.3.2 Recommendations

ASCOS suggests the use of ASCOS SPIs method by service providers in their SMS Safety Assurance, in the process for safety performance monitoring and management. Due to the high number of possible consequences of a typical precursor, it is necessary to quantify the linkage between occurrence probability and chance for a given precursor to have occurred. It can be achieved by focussing more on the identified precursors when developing occurrence scenarios;

It is proposed that the SPIs are collected using the ECCAIRS database and aggregated at the service provider level, state level and EU level. Wherever applicable, it is recommended to stay aligned to the ADREP taxonomy. Inclusion of the best practices, already used by EU local CAAs, mentioned by EASp is advised;

Some minor additions to the taxonomy could be suggested to the ECCAIRS Taxonomy Working Group;

Data verification tools would be needed;

Samples of classifications for various occurrence scenarios should be prepared that clarify the required event type sequences for standard occurrence scenarios;

Linking the collected data with archived weather reports would be needed (already done by some operators).

Two approaches to FDM as the source for the SPIs are recommended:

1. Central collection of predefined FDM parameters/events allowing a continuous flow of data from the airline operators to the entity with a need to collect corresponding exposure data to normalise the data;
2. Central collection of raw flight data allowing easy data collection (already used e.g. in the US FAA ASIAS system), but requiring special software tools to store, process and analyse.

No matter what approach is chosen for continued airworthiness purposes, it is recommended to address data quality issues, requirements including a common taxonomy and data format, etc. at operator level as well as the potential use of FDM in airlines and ASDG in ATM for continuous safety monitoring at a regulatory level including de-identification of the flight data, but identification of aircraft types.

5 Tools for Continuous Safety Monitoring

5.1 Introduction and Objectives Introduction and Objectives

5.1.1 Introduction

In the context of ASCOS WP2 "Continuous Safety Monitoring", Work Package 2.4 is aimed at developing "Tools for Continuous Safety Monitoring". The tools should use safety data extracted from an ECCAIRS compatible repository (ECR, ADREP or national occurrence databases) complemented with (historical) exposure data as available from existing sources where applicable completed with numbers based on expert judgement.

5.1.2 Objectives

The ASCOS Tool for Continuous Safety Monitoring was developed specifically to permit the construction of Safety Performance Indicators as proposed in ASCOS WP 2.1 "Framework Safety Performance Indicators" - Appendix A "List of Safety Performance Indicators" to the extent that the proposed Safety Performance indicators could be based on the evaluation of the frequency of occurrences reported in an ECCAIRS5 based occurrence reporting system.

The Safety Performance Indicators proposed are in the form of timelines of occurrence rates, the number of occurrences pro-rated by the amount of related activity. The tool was designed to monitor the development of such occurrence rates permitting to compare current dates with historic ones (see ASCOS WP 2.3) and to permit the easy comparison of a set of occurrences related to ASCOS activities with a set not related to ASCOS.

Another design goal was to limit the complexity of the tool. This may have limited to flexibility in the use of the tool. However, even in the designed simple tool, the user has to manage several control parameters in the construction of the Safety Performance Indicators. Adding parameters to enhance flexibility would have made the tool even more complex.

5.2 The ASCOS Tool for Continuous Safety Monitoring (ATSCM)

5.2.1 Introduction

The ATCSM is a program which interacts with an ECCAIRS5 occurrence database and user provided exposure data to develop rates of occurrences, the Safety Performance Indicators (SPI). The SPIs are presented in graphical form to the user.

The tool is equipped with menus that facilitate the development and maintenance of libraries of Safety Performance Indicators. Within a given library, the SPIs can be grouped in categories. One level of categorisation is available.

Each SPI in the library represents the combination the result of a query to an ECCAIRS5 database and matching exposure data. The user must assign exposure data individually to the SPIs during the development of the SPI.

The exposure data itself is loaded into the tool by the user at the time of configuring the SPI project. Provision of exposure data does not fall within the scope of this project, it will be the user's responsibility to ensure that appropriate exposure data is fed into the tool.

The ATCSM has been developed to permit the development of SPIs in the form of timelines of occurrence rates, to have the capability to visually compare results from two data sets in respect to certain issues as well as the capability to allow a user to visually compare historic occurrence rates with current occurrence rates.

5.2.2 Simple timeline SPI

In respect to the development of "simple" timelines, the user needs to define the appropriate query to retrieve the occurrence data from the ECCAIRS database and assign related exposure data.

Example:

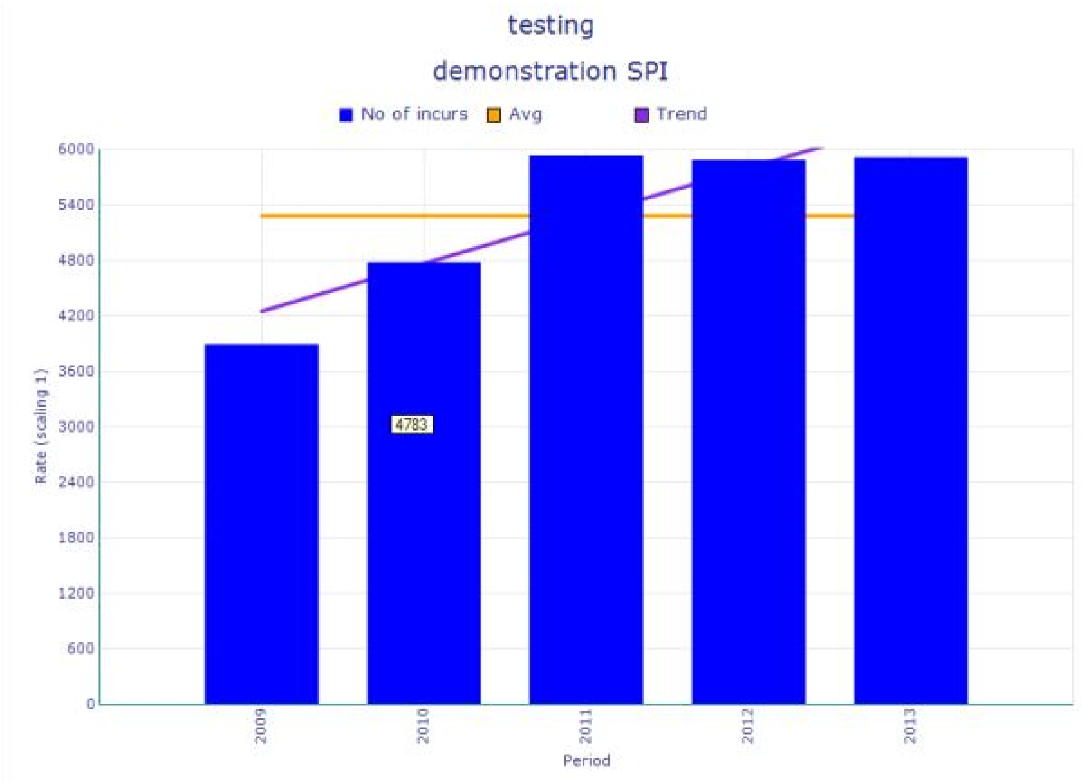


Figure 5 Example of an SPI based on a single timeline

5.2.3 Set comparison SPI – concurrent display of two sets of rates

At the level of the SPI library the user can define two "filters" to identify the two sets of occurrence data to be displayed in the same SPI graph. One is referred to as the "Base" filter and one as the "Benchmark" filter. For example, the user could define the "Base" filter to select all occurrences in which there was a "correct" crew reaction to a GPWS warning and as the second set using the "Benchmark" filter those occurrences in which an incorrect crew reaction had been recorded. [2] Figure 6 shows the two test data sets merged into one graph, Figure 7 the two sets in separate in graphs.

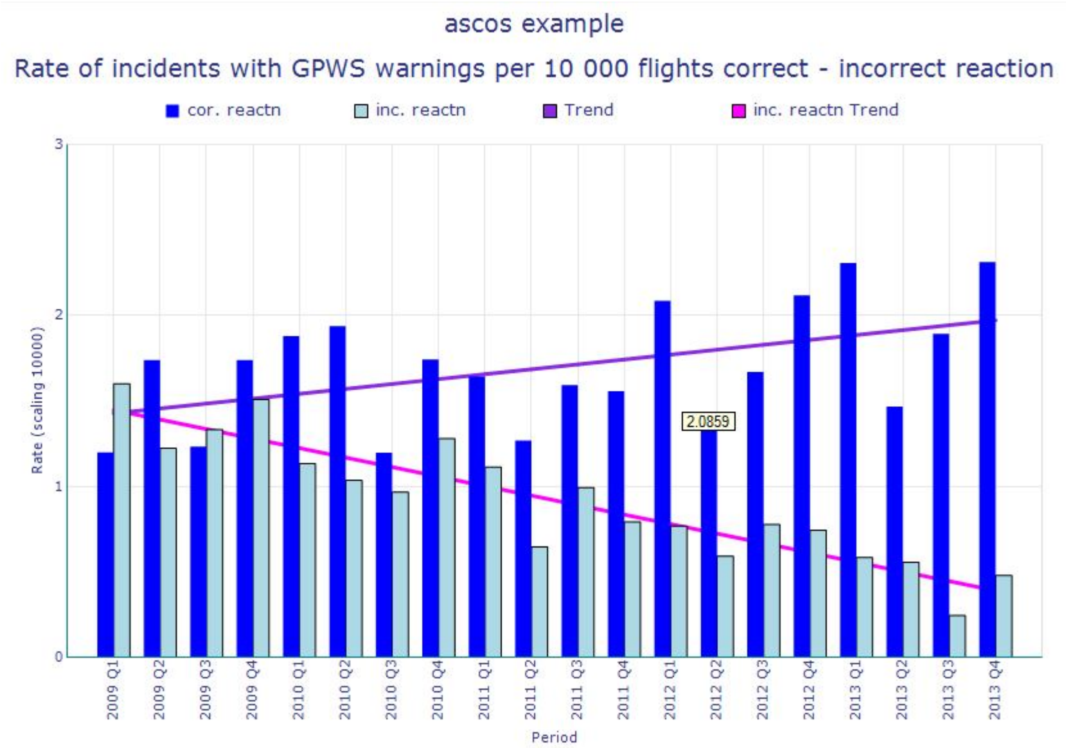


Figure 6 Example of an SPI showing development of two data sets in a merged graph

[2] Results shown are based on occurrence data generated by the JRC to test the ATCSM

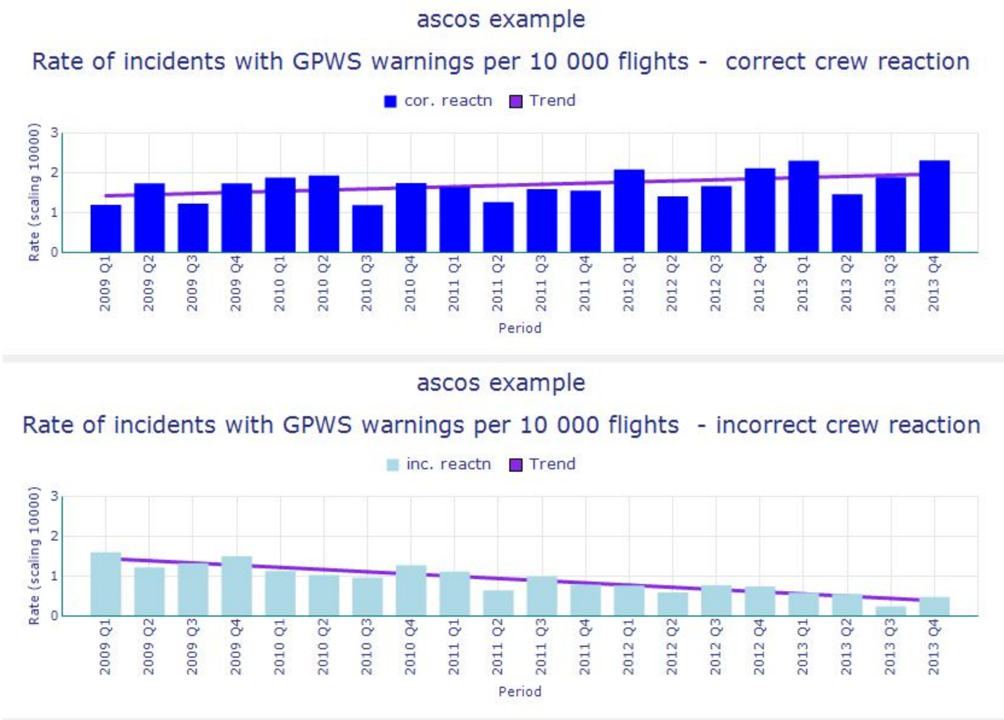


Figure 7 Example of an SPI showing development of two data sets in separated graphs

5.2.4 Historic evaluation SPI

The tool has been developed with a view to permit the evaluation of current data in relation to historic data. The requirement for such type of analysis was outlined in ASCOS WP 2.3 which shows how an alert level could be defined:

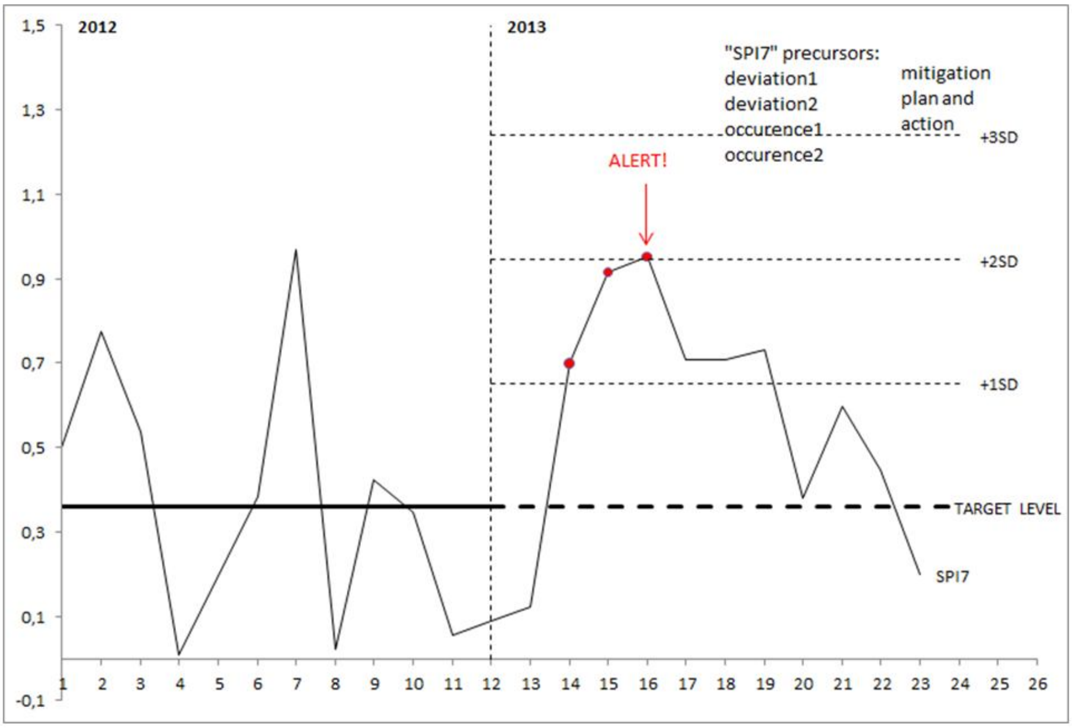


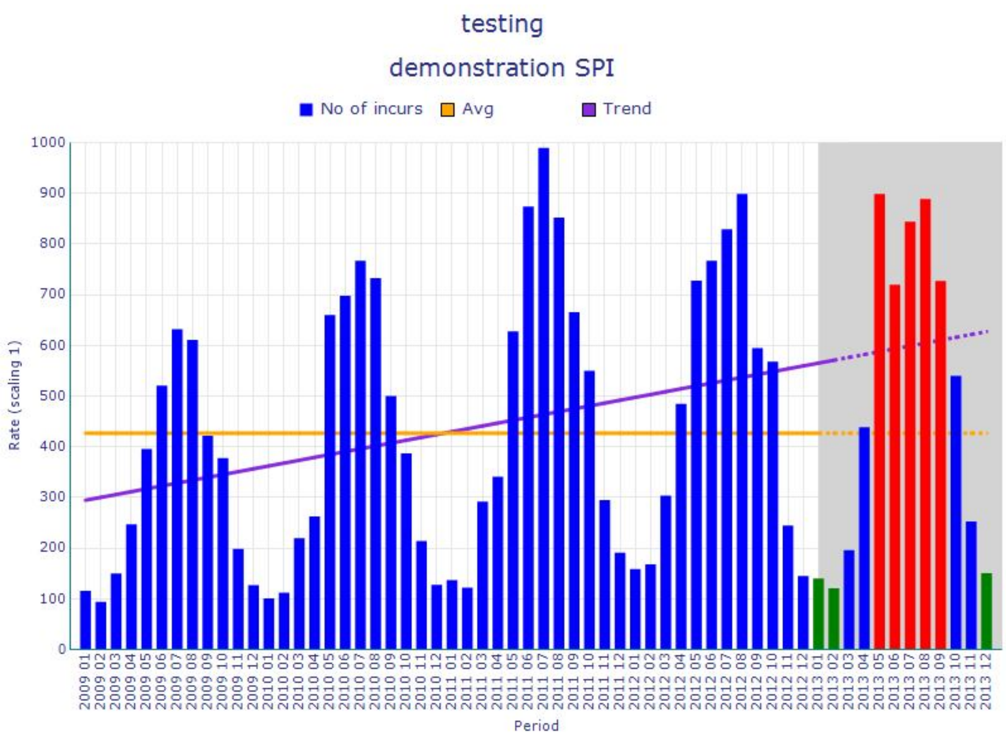
Figure 8 Image of figure 2 from report of ASCOS WP 2.3

Based on this example, the ATCSM was designed to “split” the graph pane into two areas: the left, called “initial” area and the right called “evaluation” area. The dividing line between the two areas can be moved by the user to the left and right as required.

The evaluation area is indicated with through showing grey background, while the background of the initial area in the SPI graph is white.

The calculations related to the average, standard deviation, trend are based on the visible initial data are only, but the lines, if selected to be shown by the user, are “extrapolated” from the “initial” into the evaluation area. Data points which fall below the average minus one standard deviation are coloured in green, data parts exceeding the average plus one standard deviation are coloured in red.

Below is an example showing a hypothetical number of occurrences with numbers in some month of the evaluation period exceeding the average plus standard deviation in red and one month with the number falling below average minus one standard deviation in green.



:

Figure 9 SPI graph showing initial and evaluation area

5.3 Results Summary

The ASCOS Tool for Continuous Safety Monitoring was tested using randomly generated test data. To enable this occurrence data generation, the JRC developed a specific tool to convert Excel data into the ECCAIRS occurrence data format.

A heuristic test of the tool was carried out. It led to several recommendations in respect to the improvement of the user interface. All, except one, were incorporated in a revised version of the tool. Further recommendations for improvement stemmed from a workshop in August at the JRC in which the tool was tested. The majority of these have been implemented in the meantime.

The proposed SPIs (see WP5.1) were constructed as well as the SPIs proposed by the Network of Analysts.

This work shows the tool to be functioning as designed. Certain limitations have been noted. They include the need to provide exposure/usage data in a specific format as well as requirements limiting the type of SPI graphs within a given SPI library. These limitations could be overcome with additional efforts, but also at the cost of adding to the complexity of the tool itself.

Much of the success of the use of the tool will depend on the quality of the data to be analysed. In the context of ASCOS, there is the additional need to filter out ASCOS related effects on the safety of aviation from other developments. Given that introduction of ASCOS related products will be a slow process, no immediate impact could be expected and, in consequence, it will take some time until the impact of ASCOS can be observed through the use of the ATCMS.

5.4 Conclusions and Recommendations

The ATCMS provides the capability to develop occurrence rates for the purposes of constructing safety performance indicators (SPI). Many such indicators have been proposed within the scope of ASCOS. Of those, the ones which are based on occurrence data stored in ECCAIRS compatible databases can be developed with the ATCMS.

Quality and usability of SPI's not only depends on the capabilities of software used to construct the indicators. The software only reflects the reality as found in the reported data. Thus, quality of the base data is essential. Quality and availability of data, however, remains an issue.

6 Conclusions and recommendations

Overall, ASCOS Work Package 2 has fulfilled its aim to develop a methodology and the supporting tools for multi-stakeholder Continuous Safety Monitoring. This was achieved through:

- Defining a framework for and delivering a set of Safety Performance Indicators for the total aviation system;
- A baseline risk picture was determined for the total aviation system using available industry data and complementing the results using the CATS risk modelling tool;
- Development of an improved process for safety performance monitoring, specifically exploring the possibility of tapping into new existing and emerging data sources such as Flight Data Monitoring;
- And finally, the creation of and implementation of tools which are supportive of continuous safety monitoring.

The tools developed within Work Package 2 are ECCAIRS compatible meaning that they can be used directly by the many ECCAIRS users across the world for continuous monitoring of their desired safety performance indicators. The developed tool for Continuous Safety Monitoring has been demonstrated at the ECCAIRS Steering Committee Meeting on 9/10 October 2014, with participation of most EU Civil Aviation Authorities, Safety Investigation Authorities, EASA, EC DG-MOVE, ICAO, EUROCONTROL, and other aviation stakeholders. It is planned to make the tool (and supporting material, including User Manual) available through the ECCAIRS web site (eccairsportal.jrc.ec.europa.eu). Further validation of the tool takes place in ASCOS WP5 Validation.

ASCOS Work Package 2 has thus delivered on the objectives laid out in the ASCOS description of work and in the course of its activities also highlighted areas which can be the subject of further review or research in the future, such as the feasibility of centrally collecting predefined FDM parameters for use in a continuous safety performance monitoring process. However, in this context, it should be noted that it has turned out difficult with ECCAIRS – if not impossible - to do any kind of flight data processing on operational data recorded on the aircraft for identification of event exceedences and routine events. Clearly flight data obtained by FDM will be very valuable for providing even more frequent risk assessments and further improved safety monitoring. It is therefore recommended to investigate the feasibility of developing FDM tools that allow storage and processing of flight data in a “Risk Observatory”. Integrating FDM data with other data sources like occurrence reports and incident/accident data enhances frequent analysis of safety performance indicators even further.

References

#	Authors(s), Title, Year
1	A.L.C. Roelen (NLR) , J. Verstraeten (NLR) , L. Save (Deep Blue) , N. Aghdassi (Avanssa), ASCOS D2.1 “Framework Safety Performance Indicators” version 1.5, 2014
2	N. Aghdassi (Avanssa), A.L.C. Roelen (NLR), A.D. Balk (NLR), ASCOS D2.2 “Total Aviation System Baseline Risk Picture” version 1.3, 2013
3	A. Iwaniuk (IoA), P. Michalak (CAA PL), G. van Es (NLR), B. Dziugieł (IoA), W. Miksa (IoA), M. Mączka (IoA), N. Aghdassi (AVA), R. Menzel (JRC), L. Save (DBL), ASCOS D2.3 “Process for Safety Performance Monitoring” version 1.0, 2014
4	Reinhard Menzel, Wietse Post (JRC), Simone Rozzi, Luca Save (Deep Blue), ASCOS D2.4 “Tools for Continuous Safety Monitoring” version 1.0, 2014
5	ASCOS Website, http://www.ascos-project.eu
6	A.L.C. Roelen, J.G. Verstraeten, L.J.P. Speijker, S. Bravo Muñoz, J.P. Heckmann, L. Save, T. Longhurst; Risk models and accident scenarios in the total aviation system, at http://www.ascos-project.eu, 2014
7	J.G. Verstraeten, A.L.C. Roelen, L.J.P. Speijker; Safety performance indicators for system of organisations, at http://www.ascos-project.eu, 2014
8	A. Simpson, S. Bull, T. Longhurst. Outline Proposed Certification Approach. ASCOS D1.3, version 1.2, 18-12-2013.
9	J.P. Magny (JPM), A.L.C. Roelen (NLR), J.J. Scholte (NLR), T. Longhurst (CAAi), A. Iwaniuk (IoA); Total aviation system safety assessment methodology, ASCOS D3.1, Version 1.6, 2013.

Appendix A Terminology

Bow-Tie diagram. Such a diagram illustrates a hazard, an undesirable event, safety events and potential outcomes, and risk controls put in place to minimise the risk. Bow-Tie method involves asking a structured set of questions in a logical sequence.

Deviations. Procedural or flight path deviations. A precursor type that may be observed randomly, but could become combined and, thus, result in a major occurrence.

Lagging indicator. Metrics that measure safety events that have already occurred including those unwanted safety events that are to be prevented (SM ICG).

Leading indicator. Metrics that provide information on the current situation that may affect future performance (SM ICG).

Management System (MS). A management system of an air operations pursuant to EC 216/2008 including specific requirements in terms of safety and corresponding to the size, nature and complexity of operator.

Precursor. Identifiable event that may be used as early warning for known or potential hazards.

- Events identified and currently monitored, for which the potential to become hazardous is known to be significant.
- Events not known yet, but for which induced risks may have been initially underestimated therefore not enough reduced, neglected or even unidentified up till now, unless revealed by an actual occurrence of the hazard.

Safety Assurance. One of four components of the ICAO recommended SMS. These are processes and activities undertaken by the service provider to determine whether the SMS is operating according to expectations and requirements.

Safety Management System (SMS). A systematic approach to managing safety including, the necessary organizational structures, accountabilities, policies and procedures.

Safety Manager. An accountable manager with a direct safety responsibility required within Management System of organisation.

Safety Performance Indicator. A data-based parameter used for monitoring and assessing safety performance.

Safety performance target. The planned or intended objective for safety performance indicator(s) over a given period.

Safety performance. A State or a service provider's safety achievement as defined by its safety performance targets and Safety Performance Indicators.

Safety Policy and Objectives. One of four components of the ICAO recommended SMS. It outlines the principles, processes and methods of the organization's SMS to achieve the desired safety outcomes.

Safety Promotion. One of four components of the ICAO recommended SMS. It encourages a positive safety culture and creates an environment that is conducive to the achievement of the service provider's safety objectives.

Safety Risk Management. One of four components of the ICAO recommended SMS. It systematically identifies hazards that exist within the context of the delivery of its products or services.

Safety risk. The predicted probability and severity of the consequences or outcomes of a hazard.

Safety. The state, in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level.

Service providers. The term "service provider" refers to the organizations listed below:

- air traffic services (ATS) (including AIS, CNS, MET and/or SAR services);
- approved maintenance organizations;
- approved training organisations;
- operators of aeroplanes or helicopters authorized to conduct international commercial air transport;
- operators of certified aerodromes;
- organisations responsible for the type design or manufacture of aircraft.

State Safety Programme (SSP). An integrated set of regulations and activities aimed at improving safety.

Uneventful events. A precursor type including events that already occurred. Although the events are being uneventful, they could have a more severe outcome under different circumstances.

Uniformity of nature. The principle used to justify inductive reasoning in scientific research presupposing that a sequence of events in the future will occur as it always has in the past.