Framework Safety Performance Indicators

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ASCOS safety certification

This document provides a Framework for safety performance indicators for the total aviation system. The performance indicators are described at four levels: technical, human, organisation and system of organisations.

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Acronyms

Acronym	Definition
ACAS	Airborne Collision Avoidance System
ACC	Area Control Center
ADREP	Accident/Incident Data Reporting
AIB	Accident and Incident Board
ANSP	Air Navigation Service Provider
APM	Approach Path Monitor
ASMT	Automatic Safety Monitoring Tool
ATA	Air Transport Association of America
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
CAA	Civil Aviation Authority
CAIT	Controlled Airspace Infringement Tool
CATS	Causal Model for Air Transport Safety
CFIT	Controlled Flight Into Terrain
EASA	European Aviation Safety Agency
EASp	European Aviation Safety Action plan
EC	European Commission
ECCAIRS	European Co-Ordination Centre for Aviation Incident Reporting Systems
EGPWS	Enhanced Ground Proximity Warning System
ESD	Event Sequence Diagram
FAA	Federal Aviation Administration
FC	Flight Crew
FDM	Flight Data Monitoring
GPWS	Ground Proximity Warning System
HMI	Human Machine Interface
IAES	International Atomic Energy Agency
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System

IRP	Integrated Risk Picture
ISO	International Organisation for Standardization
MSAW	Minimum Safety Altitude Warning
MTO	Man Technology Organisation
NoA	Network of Analysts
NSA	National Supervisory Authority
RA	Resolution Advisory
RAT	Risk Analysis Tool
RIMCAS	Runway Incursion Monitoring Collision Avoidance System
RNP	Required Navigation Performance
ROC	Risk Of Collision
SMS	Safety Management System
SOP	Standard Operating Procedure
SPI	Safety Performance Indicator
STCA	Short Term Conflict Alert
TAWS	Terrain Awareness and Warning System
TSA	Temporary Segregated Areas
UHF	Ultra High Frequency
USOAP	Universal Safety Oversight and Audit Program
VHF	Very High Frequency

Executive Summary

In the context of developing a methodology and the supporting tools for multi-stakeholder continuous safety monitoring, the objective of this specific deliverable is to define a framework of safety performance indicators for the total aviation system. Aviation safety performance indicators are defined at four different levels:

- Technology
- Human
- Organisation
- System of organisations

For each level, proposed safety performance indicators are compared with a list of characteristics of a good measure of safety performance:

- 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 indicators are also linked to the main operational Issues of the European Aviation Safety Plan:

- Runway excursion
- Mid-air collision
- Controlled flight into terrain
- Loss of control in flight
- Runway incursions
- Fire, smoke and fumes

A complete overview of proposed indicators is provided in Appendix A.

To facilitate quantification and semi-continuous updating of the safety performance indicators, it is recommended that each proposed safety performance indicator 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, preferably by using automated tools for continuous safety monitoring. The latter will also reduce the costs of data gathering and processing to quantify the safety performance indicators. It should be ensured that 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.

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1 Introduction

1.1 Project 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 (ICAO, 2010a; ICAO 2010b). 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 use 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. This is a result of the fact that safety is a somewhat abstract notion (see section 1.1) and that safety, until recently, 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.

1.2 Task objective

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

1.3 Research approach

The research starts with a concise theoretical overview of safety performance. This will be used to systematically identify several classes of safety performance indicators. The purpose of this classification is twofold: Firstly, it will result in a complete (covering the whole aviation system) and balanced (in the sense that all indicators are of a similar level of detail) list of safety performance indicators due to a systematic approach; Secondly, it allows a clear distribution of the work amongst the different ASCOS partners involved in this task. While the framework will cover the total aviation system, the emphasis will be on the main operational issues as defined in the European Aviation Safety Plan in order to be fully aligned with the safety strategies of the EC and EASA.

A separate framework will be developed for each class of safety performance indicators, which are then merged back into a single framework for the total aviation system, taken into account practical considerations such as linking with other ASCOS tasks and objectives.

2 Theoretical background on safety performance indicators

2.1 Safety performance

The problem of measuring safety performance has been a topic for discussion for at least 50 years (Kjellén, 2009). Traditionally, accident rates were used to measure the performance of aviation safety, but when safety improved accidents became rare events and alternative ways to derive safety performance were required.

To be able to define safety performance indicators it is first necessary to understand what is meant with 'safety'. ISO defines safety as the freedom from unacceptable risk, were risk is a combination of the probability of occurrence of harm and the severity of the harm (ISO, 1999). Harm is physical injury or damage to the health of people either directly or indirectly as a result of damage to property or the environment. According to this definition, safety is subjective because what is acceptable to one group of people might be unacceptable to another group of people. Safety also has a probabilistic aspect, and this is one of the reasons why it is a difficult subject to measure, since absence of harm does not necessarily indicate the absence of risk.

In case of aviation safety, the severity of the harm is described by ICAO's definition of an accident as an occurrence resulting in fatalities, serious injuries or severe damage to the aircraft (ICAO, 2001). Using this definition, aviation safety can be described as the absence of an unacceptable accident probability, and safety performance can be described as the accident probability that is achieved in relation to the accident probability that is considered acceptable. Therefore, aviation safety performance indicators should provide an indication of the probability of an accident.

2.2 Accidents as event sequences

Tarrents (1963) proposed incidents as a basis for safety performance indicators. ICAO defines an incident as an occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of the operation (ICAO, 2001). This definition fits well with the assumption that accidents involve the occurrence of a set of successive events that produce unintentional harm. The start of this sequence is a deviation or perturbation that disturbs the existing equilibrium or state of homeostasis. Heinrich developed a theory that introduces an additional dimension to such accident chain model. He compared the occurrence of an accident to a set of lined-up dominoes (Heinrich et al., 1980). Central to Heinrich's original statement of the model is the assertion that the immediate causes of accidents are of two different types; unsafe acts and unsafe conditions. Heinrich's domino model was also useful to explain how by removing one of the intermediate dominoes, the remaining ones would not fall and the injury would not occur. Safety performance can be described according to the domino model as the number of dominoes that have fallen. The likelihood of all dominoes falling over (which defines an accident) is increasingly higher the more dominoes are already down. According to this model, incidents are cases were a few but not all dominoes have fallen and they can indeed be considered as indicators of safety performance.

Reason (1990) took Heinrich's unsafe acts and unsafe conditions a step further by refining the distinction between different types of failures that line up to create an accident. Building upon work by Rasmussen (1983), Reason describes an accident as a situation in which latent failures, arising mainly in the managerial and organisational spheres, combine adversely with local trigger events (weather, location etc.) and with active failures of individuals at the operational level. Latent failures are failures that are created a long time before the accident, but lie dormant until an active failure triggers their operation. Their defining feature is that they were present within the system well before the onset of an accident sequence. According to Reason, the layers of defence that have been set up to prevent accidents are not perfect but contain 'areas of permeability'. On each layer of defence the areas of permeability vary over time in both their location and their size, and these changes have different time constants at different levels of the system. This concept is often graphically illustrated as slices of holed cheese, each slice representing a barrier at a different organisational level. The holes in the cheese are barrier failures and an accident occurs when the holes line up (Figure 1). Since the holes determine the likelihood of an accident they can be considered as indicators of safety performance.

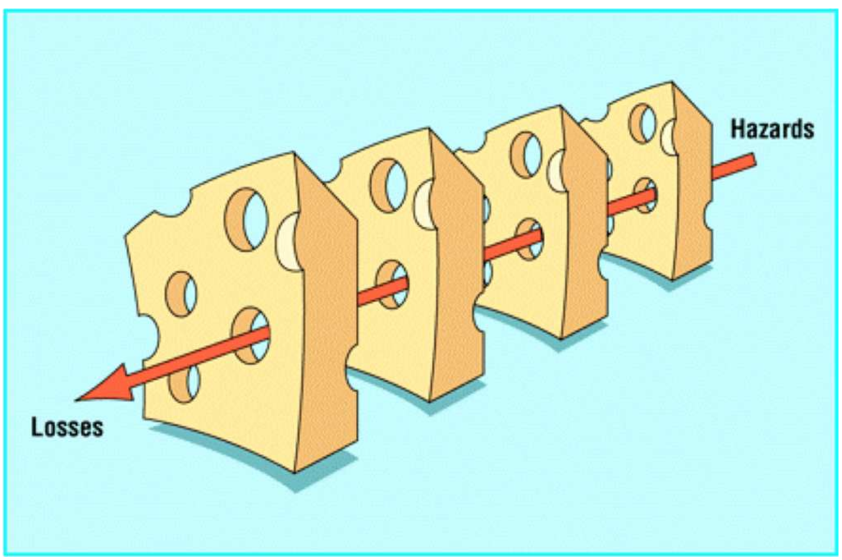

Figure 1: Swiss cheese rendition of Reason's model

Assessing the holes in the barriers can be done by identifying and counting barrier failure events. The number of barrier failure events divided by the exposure is the failure rate of the barrier. This failure rate can be used as an estimate for the likelihood or probability of barrier failure. The advantage of this approach is that it is relatively easy to count unwanted outcome events and no detailed knowledge of the barrier itself is required. The disadvantage is that operational experience is needed to estimate the probability.

Another way to assess the holes in the barrier is to analyse the characteristics of the barriers and based on that analysis estimate in what way and how frequent the barrier will fail. The advantage of this approach is that operational experience is not necessarily required and therefore this can be done even if the barrier is still in the design phase and not yet operational. The disadvantage is that comprehensive knowledge of the barrier is required and therefore this type of analysis is generally more difficult than counting unwanted outcome events.

The models of Heinrich and Reason are conceptual models and do not provide detailed descriptions of falling dominoes or barrier holes that can be used directly as definitions or descriptions of safety performance indicators. However, models that are used in risk assessments often apply those concepts and they contain the necessary detail to derive safety performance indicators directly. Examples of such accident sequence models are the Integrated Risk Picture (IRP) of Eurocontrol (Perrin et al., 2006; Kirwan, 2007) and the Causal Model for Air Transport Safety (CATS) of the Dutch Civil Aviation Authority (Ale et al., 2006). These models are based on phenomenological knowledge and operational experience and are quantified with operational performance data and expert judgement. Although full validation of these models against an independent dataset is impossible (as all available data was used to construct the models), trust in the models was gained by applying them to a series of test cases and comparing their results with each other and with modelling efforts elsewhere in the US. The model elements could be potential safety performance indicators.

Individual safety performance indicators are not expected to be very informative on safety. If, for example, the rate of engine failure is used as an SPI, an increase in the engine failure rate does not necessarily mean that safety has decreased. Event sequence models like IRP and CATS can be used to integrate information on all available safety performance indicators into a single risk picture.

Event sequence models like IRP and CATS are predominantly constructed of active failure events and do not contain many latent failure events. Modelling and quantifying the influence of management on safety is notoriously difficult (Lin, 2011). This characteristic in combination with the fact that accident sequence models are mainly quantified from (past) operational data means that event sequence models are a source of lagging indicators as they capture failure results from a past time period and therefore characterise historical performance. Leading indicators on the other hand are identified through comprehensive analysis of the organisations. Although the distinction between leading and lagging indicators is subject to confusion (Hopkins, 2009; Ale, 2009) it is relevant to consider other measures of how well the safety controls are functioning than just undesired outcome events. The difficulty with many leading indicators is that they are associated with organisational and managerial issues which are difficult to quantify and whose relation with accident risk is less obvious.

2.3 Safety barriers

The term 'barrier[1]' to describe a strategy for risk prevention is often linked to work by Haddon (1973). He described that there are several different types of risk prevention strategies, and that they should be systematically analysed in order to minimise risk. The term safety barrier is often used as a collective term for different means to realize the concept-in-depth. No common definition of safety barriers exists, but the following definition captures the concept well: Safety barriers are physical and/or non-physical means planned to prevent, control or mitigate undesired events or accidents (Sklet, 2006).

Haddon's classification of ten risk prevention strategies or barriers is based on energy transfer and has a logical sequence. It starts with preventing the marshalling of the form of energy in the first place and ends with reparative and rehabilitative measures following the damaging energy exchange. While this classification is logical it is not particularly useful in a practical sense for the purpose of aviation safety performance indicators, because energy transfer is not a commonly applied concept. A useful barrier classification system for ASCOS will be discussed in section 1.6.

A distinction is sometimes made between a barrier function and a barrier system, where a barrier function describes the purpose of the safety barrier and the barrier system describes how a barrier function is realized or executed (Sklet, 2006). In the perspective of ASCOS, and particularly in the context of an expected move from certification based on prescriptive regulations towards performance based regulation, the barrier function seems to be the most relevant.

2.4 Focus on EASp Operational Issues

An accident scenario describes the logical link between barrier failures and the final outcome (the accident). Therefore accident scenarios are very important when considering safety performance indicators. The accident scenarios that are the focus for ASCOS are defined by the main operational issues as defined in the European Aviation Safety Plan (EASA, 2013). They are:

- Runway excursion
- Mid-air collision
- Controlled Flight Into Terrain
- Loss of control in flight
- Runway incursions
- Fire, smoke and fumes

According to the ASCOS Description of Work, the framework of safety performance indicators should represent these main operational issues. In order to understand what this means, it is useful to compare the

[1] Different terms with similar meanings have been used as well, including defense, protection layer, safety critical element, safety function, etc.)

main operational issues with the accident scenarios that are represented in the CATS model. This model consists of 33 accident scenarios, represented as Event Sequence Diagrams (ESDs).

Event Sequence Diagrams (ESD) provide a qualitative description of series of events leading to accidents or serious incidents. An ESD consists of an initiating event, pivotal events and end states. A representation of a generic ESD is given in Figure 2. An initiating event represents a safety occurrence, or a combination of occurrences. Each pivotal event represents a possible switching point for the chain of events. The occurrence of a pivotal event represents the breach of a safety barrier. If all barriers are breached an unwanted outcome is reached the chain of events ends as an accident. If a pivotal event does not occur, the chain of events follows a different pathway and an accident is avoided. In that case the end state is a safe continuation of the flight.

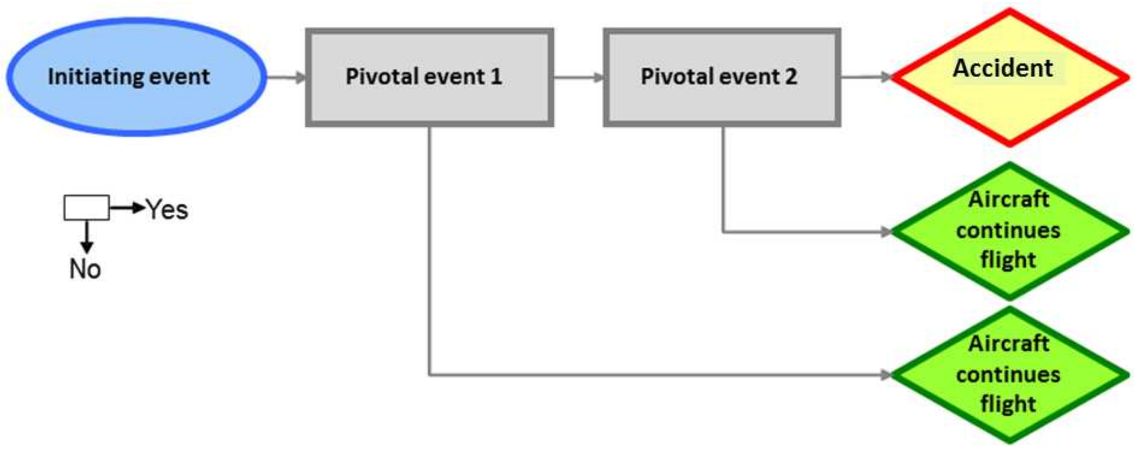

Figure 2: Event Sequence Diagram

The CATS model characterizes all historical commercial air transport accidents. For the purpose of ASCOS, the CATS model was updated by incorporating lessons learnt during the use of CATS. The updated CATS model is documented in ASCOS deliverable 3.2 (ASCOS 2013). A comparison of the updated CATS with the EASp's main operational issues shows that the six operational issues cover the majority of the CATS scenarios. A cross reference between the updated CATS scenarios and the operational issues is shown in Table 1.

Table 1: CATS and EASp Operational Issues cross reference

		EASp category					
ESD[2]	**Initiating event**	**Runway excursions**	**Mid-air collisions**	**Controlled flight into terrain**	**Loss of control in flight**	**Runway incursion**	**Fire, smoke and fumes**
1	Aircraft system failure during take-off	√					
2	ATC related event during take-off	√					
3	Aircraft directional control by flight crew inappropriate during take-off	√					
4	Aircraft directional control related systems failure during take-off	√					
5	Incorrect configuration during take-off	√			√		
6	Aircraft takes off with contaminated wing				√		
8	Aircraft encounters windshear after rotation				√		
9	Single engine failure during take-off	√					
10	Pitch control problem during take-off	√					
11	Fire, smoke, fumes on-board aircraft				√		√
12	Flight crew member spatially disorientated				√		
13	Flight control system failure				√		
14	Flight crew incapacitation				√		
15	Ice accretion on aircraft in flight				√		
16	Airspeed, altitude or attitude display failure in flight				√		
17	Aircraft encounters thunderstorm, turbulence or wake vortex				√		
18	Single engine failure in flight				√		
19	Unstable approach	√			√		
21	Aircraft weight and balance outside limits during approach				√		
23	Aircraft encounters windshear during approach/landing	√					
25	Aircraft handling by flight crew inappropriate during flare	√					
26	Aircraft handling by flight crew inappropriate during landing roll	√					
27	Aircraft directional control related systems failure during landing roll	√					
31	Aircraft are positioned on collision course in flight		√				
32	Runway incursion					√	
33	Cracks in aircraft pressure cabin						
35	TAWS alert			√			
36	Conflict on taxiway or apron						
38	Loss of control due to poor airmanship				√		

[2] The ESD numbering does not run continuously as a result of several development cycles during which some scenarios were combined. The original numbering was kept intact for better configuration control of the model.

From this table it is evident that the only ESDs that cannot be associated with one of the operational issues are ESD 33 'Cracks in aircraft pressure boundary' which has 'in-flight break-up' as an end state, and ESD 36 'ground collision imminent' which has 'aircraft damaged due to ground collision' as an end state. . Therefore it can be concluded that a focus on the six operational issues as listed in the European Aviation Safety Plan does not a-priory result in a significant restriction or delineation of the (type of) safety performance indicators that should be considered.

2.5 Characteristics of good safety performance indicators

Rockwell (1959) identified the following characteristics of a good measure of safety performance:

- 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 International Atomic Energy Agency (IAEA) adds to this that the accuracy of the data should be capable of quality control and verification and the total set of indicators should remain manageable (IAEA, 1999). Although the ability to quantify is often mentioned as a required characteristic (e.g. in Rockwell, 1959 and Øien et al., 2011), it is difficult to develop quantifiable indicators for some performance areas, such as safety culture. Another important aspect is the fact that if safety performance indicators are used in combination with safety targets, there is a risk that people 'manage the indicators' the meet the targets. Therefore it is desirable the indicator values cannot be easily manipulated.

2.6 Safety performance indicators for air navigation service providers

The introduction of safety management systems in aviation has resulted in an EC requirement for ANSPs to measure safety performance by the following three indicators (European Commission, 2010):

- The effectiveness of safety management as measured by a methodology based on the ATM safety maturity survey framework.
- Application of the severity classification using the Risk Analysis Tool (RAT) methodology on the reporting of three categories of occurrences: separation minima infringements, runway incursions and ATM-specific occurrences.
- The level of presence or absence of just culture[3] as measured through a questionnaire.

[3] Just culture' means a culture in which front line operators or others are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training, but where gross negligence, wilful violations and destructive acts are not tolerated.

Eurocontrol's ATM safety framework maturity survey is a self-assessment questionnaire that addresses nine key elements of safety management. The questionnaires have a graded scale of responses that correspond to five levels of safety maturity. An overall percentage score is calculated. The scoring system takes account of the fact that various questions have different levels of significance through the application of weighting factors (Eurocontrol, 2009b).

The severity classification of RAT (Eurocontrol, 2009a) is a method for quantifying the overall severity of one occurrence from the risk of collision/proximity (separation and rate of closure) and the degree of controllability over the incident.
There are assessment procedures for five different types of occurrences:

- More than one aircraft involved;
- Aircraft – aircraft tower;
- Aircraft with ground movement;
- Only one aircraft involved;
- ATM specific occurrences.

The assessment is based on a question-based scoring mechanism.

The third indicator is the level of presence and corresponding level of absence of just culture as measured through a questionnaire. Just culture is defined in this context as "a culture in which front line operators or others are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training, but where gross negligence, wilful violations and destructive acts are not tolerated".
The concept of just culture is defined through three main areas, potentially influencing each other:

- Policy and its implementation – dealing with the existence or non-existence of a just culture policy within organisations (regulatory/supervisory and service provision). The policy is to be measured for effectiveness and not just its mere existence.
- Legal / Judiciary – the goal is to assess whether the national legal environment is supportive or not of just culture.
- Occurrence Reporting – this is related to policies and practices of occurrence reporting.

Within SESAR, a catalogue of safety indicators that are used or could be used in ATM was developed in the context of the development of the Accident Incident model (AIM) (SESAR 2012). This provides an interesting reference because the link between indicators and a risk model is similar to what is being proposed in ASCOS.

The Single European Sky (SES) Performance Scheme aims at setting and implementing binding targets for Member States to deliver better air navigation services at lower costs. The SES Performance Scheme covers four performance areas: costs efficiency, safety, capacity and environmental impact. For the period 2012-2014 (Reference Period 1), European Union-wide targets have been set for all except safety. Regarding safety, the scheme aims to ensure that safety levels remain at least at the levels required by the EASA-defined rules and regulations which are monitored by the European Commission assisted by the independent Performance Review Body. Dedicated safety performance indicators are being developed for implementation as from 2015 and are a major priority for the Reference Period 2 (2015 – 2019). In this second Reference Period, Member States will also be expected to deliver in respect to a future safety target defined for air navigation services.

2.7 A barrier classification system for ASCOS

In section 1.2, it was described that safety barriers provide a good starting point for the identification of safety performance indicators. In order to obtain a complete list of safety performance indicators, a systematic approach towards classification of barriers is desirable. An added practical benefit of such a classification system is that it allows a clear distribution of the work amongst the different ASCOS partners involved in this task.

Many different barrier classification systems are described in literature. A commonly used classification is to distinguish between physical and non-physical barriers (see for instance Johnson 1980). This is a categorisation that takes the barrier system (see section 1.3) as the starting point. Alternatively, the barrier function can be used to distinguish between categories such as prevention, control and mitigation. An example is Eurocontrol's SOFIA tool for ATM safety occurrence investigation that applies the following three types of barriers (Eurocontrol, 2002):

- Prevention of potential conflicts;
- Resolution of potential conflict;
- Recovery from actual conflicts.

From a theoretical point there is no preference for either barrier systems or barrier functions as the principal starting point for the classification. From a practical point of view the barrier system is more useful because in general a system is less abstract than a function.

A slight variation of the physical/non-physical categorization is the distinction between human, technology and organisational systems. The term "MTO" (Man-Technology-Organisation) was introduced in Sweden with the intention to stimulate a comprehensive view on nuclear safety (Andersson and Rollenhagen, 2002). Because aviation is a more distributed system than a nuclear powerplant and has more (types of) stakeholders, the class 'system of organisations' is added to cater for those barriers that exist on the interfaces between organisations.

The high level classification into human, technology, organisations and system of organisations fits well with the number of partners involved in this ASCOS research task as well as their expertise. It allows that each partner focuses on a type of barrier that matches their area of expertise and this enables an effective distribution of activities among the partners and an efficient use of resources.

3 Indicators for Technology

This section includes the framework description, analysis and selection of indicators including justification for the ‘technology’ part of the aviation system.

3.1 Framework description

The ‘technology’ part of the MTO 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. Dedicated warning systems, such as ACAS and TAWS, are a special case within the technology class of barriers. Activation of a warning system is an indication that previous barriers have failed. Hence for warning systems both the activation of the system and the failure of the system should be used as indicators of safety performance.

Because components are physical entities it seems logical to use physical component boundaries for classification of the components. The advantage of using physical boundaries is that many existing data and component classification systems are based on such physical boundaries. Therefore this will be advantageous for both setting up a list of components that is as complete as possible as well as for estimating failure rates from failure data. However, for novel, yet to be developed systems it might be more advantageous to use functional system boundaries, because the physical boundaries are not yet defined. Especially in the context of certification this is relevant as certification mainly concerns novel systems and components.

Ideally, there is a functional and a physical classification as well as an unambiguous mapping between the two classifications.

3.2 The ATA specification 100 codes for aircraft systems

For aircraft systems, a classification system that has become an industry-wide standard is the ‘ATA chapter numbers’ system. The standard numbering system was developed and published by the Air Transport Association of America (ATA) in ATA Spec 100 Manufacturers’ Technical Data. It was first published in 1956 and until 1999 has been regularly updated. The FAA Joint Aircraft System/Component (JASC) Code Table that is used by the FAA is a slightly modified version of the ATA Specification 100 code[4]. The ECCAIRS software which is the European standard for occurrence reporting uses the JASC coding in the definition and coding of aircraft system related Descriptive Factors.

[4] One important difference between the ATA Spec 100 and the JASC code is that JASC code divides the engine section into two code groups to separate the turbine and reciprocating engines. The codes for the turbine engines are in JASC code Chapter 72, Turbine/Turboprop Engine. The codes for the reciprocating engines are exclusively found in JASC code Chapter 85, Reciprocating Engine. The other major deviation from ATA Spec 100 is on the stall warning system. In the ATA numbering this is number 2734, i.e. it falls hierarchically under 2730 ‘Elevator Control System’. With the JASC code it was decided to move the stall warning system to Chapter 3410 ‘Flight Environment data’ under the separate JASC code 3418 ‘Stall Warning System’.

Note that there is a difference in ECCAIRS between event and descriptive codes. In principle the event codes describe WHAT happened. Currently, under the CAST/ICAO Common Taxonomy Team (CICTT), there is an aircraft/component/system numbering system working group to address these differences and come to an international agreed approach, also to include new areas that are that are currently not covered by ECCAIRS. One such taxonomy is already adopted by the CICTT, it is expected to be implemented in ECCAIRS as well.

The ATA chapter numbers consist of four digits that represent system hierarchy. For instance, the landing gear system has code 3200, the main landing gear has code 3210, and the main landing gear strut/axle/truck has number 3213.

3.3 The ECCAIRS taxonomy

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.

However, there is an industry wide coding system for accidents and incidents: Globally there is ICAO's ADREP 2000 taxonomy and in Europe there is the ECCAIRS taxonomy that is based on ADREP 2000. The 'descriptive factors' part of the ECCAIRS taxonomy includes components of the aircraft, as well as ANS and Airport. Although the list of systems and components of ANS and Airports in the ECCAIRS 'Descriptive factors' is far less extensive than the list of aircraft systems and components, it still contains many elements and does seem to meet the level of detail that is likely to be required. Another difficulty is the fact that while in ECCAIRS the aircraft components are neatly classified as subsections of the main heading 'the aircraft, its systems and components' the subheading of the other air transport system components are not classified with the same consistency. There is a main heading 'air traffic management – components and systems' in the ECCAIRS list of descriptive factors which includes some includes components (such as telephone system, headsets as part of 'communication systems) but also the use of other components (such as ATM's use of traffic display system as part of ATM's surveillance system) while these components themselves are listed under a separate main heading 'ATC facilities'. Another peculiarity is that although the provision of warnings is a separate heading (which includes for instance 'ATC provision of a short term conflict alert (STCA) warning), the warning systems themselves (e.g. the STCA system) are not listed separately. As a result of these characteristics, the ECCAIRS list of descriptive factors will require some subjective interpretation to come up with a classification system for air transport system components.

The ECCAIRS taxonomy is rather extensive, particularly in the aircraft component domain. In order to keep the total set of indicators manageable, initially only main systems are selected. An exception is made for warning systems which are classified at a more detailed level. They are therefore listed separately. This results in a preliminary list of aviation system components as presented in Table 2.

.

Table 2: Preliminary list of aviation system components

Aircraft components and systems (ATA chapter)		
	Air conditioning system (2100)	
	Autoflight system (2200)	
	Communications system (2300)	
	Electrical power system (2400)	
	Cabin equipment (2500)	
	Fire protection system (2600)	
	Flight control system (2700)	
	Aircraft fuel system (2800)	
	Hydraulic power system (2900)	
	Ice/rain protection systems (3000)	
	Indicating/recording system (3100)	
	Landing gear system (3200)	
	Lighting system (3300)	
	Navigation system (3400)	
	Oxygen system (3500)	
	Pneumatic system (3600)	
	Vacuum system (3700)	
	Water and waste system (3800)	
	Integrated modular avionics (4200)	
	Cabin system (4400)	
	Central maintenance computer (4500)	
	Information system (4600)	
	Inert gas system (4700)	
	Airborne APU system (4900)	
	Cargo and accessory compartments (5000)	
	Fuselage doors (5200)	
	Fuselage structure (5300)	
	Nacelle/pylon structure (5400)	
	Empennage structure (5500)	
	Window/windshield system (5600)	
	Wing structure (5700)	
	Propeller system (6100)	
	Powerplant system (7100)	
	Turbine/turboprop engine (7200)	
	Engine fuel and fuel control system (7300)	
	Ignition system (7400)	
	Engine bleed air system (6500)	
	Engine controls (7600)	
	Engine indicating system (7700)	
	Engine exhaust system (7800)	
	Engine oil system (7900)	
	Engine starting system (8000)	
	Accessory gearboxes (8300)	

Aircraft warning systems (ATA chapter)		
	Battery overheat warning system (2431)	
	Fire protection system (2600)	
	Central warning systems (3150)	
	Landing gear position and warning (3260)	
	High speed warning system (3415)	
	Stall warning system (3418)	
	Wind shear detection system (3436)	
	Ground proximity warning system / terrain avoidance warning system (3444)	
	Traffic alert and collision avoidance system / airborne collision avoidance system (3445)	
	Door warning system (5270)	
ATM components and system		
	ATM communications systems	
		VHF radio telephony
		UHF radio telephony
		HF radio telephony
		Telephone system
		Intercom system
		Datalink system
		Data exchange network
		Recording system
		Headsets
	ATM navigation approach aids	
		VOR
		Distance measuring
		ILS
		(MLS)
		Non-directional beacon
		Precision approach radar
		Surveillance radar
	ATM surveillance systems	
		Radar source
		Radar data processing system
		Traffic display system
		Primary area radar
		Primary surface radar
		Primary approach radar
		Secondary area radar
		Secondary surface radar
		Secondary approach radar
	ATM data processing system	
	ATM power supply	

ATC warning systems		
	ATC wind shear warning system	
	ATC aerodrome warning system	
	ATC minimum safe altitude system	
	ATC short term conflict alerting system	
Aerodrome systems		
	Runway	
	Taxiway	
	Apron/ramp	
	Aerodrome structures	
	Aerodrome lighting	
	Aerodrome marking	
	Aerodrome equipment/facilities	
		Friction measurement
		Fuel storage facilities
		Refueling equipment
		De-icing facilities
		Snow/frost/ice removal equipment
		Cargo storage facilities
		Wildlife control equipment
		Facility maintenance equipment
		Foreign object removal/control equipment
		Ramp service equipment
		Passenger loading equipment
		Cargo loading/handling equipment
		Runway/taxiway maintenance equipment
		Rescue fire service equipment
Meteorological service equipment		

For components listed under the main headings ‘aircraft components and systems’, ‘ATM components and systems’ and ‘meteorological equipment’ the associated safety indicator would be the number of system failures. For components under the main headings ‘aircraft warning systems’ and ‘ATM warning systems’ the associated safety indicator would be the number of warning system activations. For most components listed under the main heading ‘aerodrome systems’ the associated indicator would be the number of components failures. Exceptions are ‘Runway’, ‘Taxiway’, ‘Apron/ramp’ and ‘Aerodrome marking’ as these systems do not fail in the sense that they stop working. Their performance can however be reduced, for example a runway can be slippery and aerodrome marking can be unclear.

3.4 Comparison with criteria

The next step in the process of developing 'technical' safety performance indicators is comparison against the criteria that are listed in section 2.5.

3.4.1 Quantifiable and permitting statistical inferential procedures

All the characteristics from the ECCAIRS taxonomy meet the criterion that the indicator should be quantifiable and permitting statistical inferential procedures. The ECCAIRS system facilitates the quantification process.

Statistical inferential procedures are procedures for drawing conclusions from data that is subject to random variation. In practice this means that we want to be able to calculate some sort of confidence level or confidence interval and this requires assuming a probability distribution (for example a normal distribution or a Fisher distribution) for each indicator. For the indicators that are considered in this chapter we assume that the Fisher distribution is the most suitable probability distribution[5] and this then allows calculation of confidence intervals.

3.4.2 Representative

The indicators are representatives of failures or degraded performance of the systems or, in case of warning systems, of activation of the system. Because each of the non-warning systems is important for safety, failure of the system will reduce safety to some extent. Therefore failures on the non-warning systems are representative of (reduced) safety.

Valid activation of the warning systems indicate that preceding safety barriers have failed, and therefore activation of warning systems is also representative of (reduced) safety. False warnings could degrade the system by encouraging the warning to be ignored.

3.4.3 Minimum variability under similar conditions

For safety performance indicators that rely on manual reporting of occurrences, whether the minimum variability criterion is met depends on the reporting discipline and the consistency in classification of the events. In most mandatory occurrence reporting schemes, the reporting is generally done by the operators of the system (airlines and ANSPs) but responsibility for the classification may vary from state to state. In some states classification is done by the operator but in other states, classification is done by the national aviation authority, based on the report that is received from the operator. European states use the ECCAIRS taxonomy for classification of the occurrences, but the service providers (e.g. airlines and ANSPs) usually use different taxonomies for their own internal use.

[5] Because it has a minimum value of 0, application of the Fisher distribution ensures that negative probabilities are avoided.

The experience of occurrence reporting over the past decade shows that even in mandatory schemes the reporting discipline severely affects the number of reported occurrences as well as the quality of data classification. EUROCONTROL for instance experienced very significant increases over time of the number of reported occurrences[6] for several types of incidents. These increases are assumed to be the result of changes in reporting practices rather than actual escalations of the number of incidents (Eurocontrol 2013). A general trend seems to be that only approximately 10 years after the introduction of a mandatory occurrence reporting scheme the system has matured to a level that the yearly number of reports has stabilized. Occurrence reporting may also be subject to variation due to changes in perception as to what qualifies as an occurrence.

An indicator who's values are obtained through automatic recording, e.g. from Flight Data Monitoring (FDM,) potentially meets the minimum variability criterion, although some attention is needed if data from different sources (e.g. different airlines, or even different aircraft types within an airline) are combined, because these sources may not use identical threshold values for defining exceedances.

Another factor that should be considered under this criterion is the rarity of the event captured by the indicator, particularly if the indicator is based on counts of the event per time period. For such events, one period may for instance show 1 occurrence, while the next period shows 2 occurrences i.e. twice as much. However, the conditions may be exactly the same and the different results are solely due to random effects. An illustration of this effect is the throwing of a dice. When comparing series of ten throws, the first may result in one 'six', while a second may result in 2 'sixes'. However, the probability of a six is exactly the same in both series. Confidence levels should be calculated to appreciate the magnitude of the influence of randomness on the performance indicator values.

3.4.4 Sensitivity to change in environmental or behavioural conditions

Because this chapter mainly considers indicators that are based on equipment failures, the criterion of sensitivity to changes in environmental and behavioural conditions is met as long as the failures are directly related to safety. The relationship between equipment failures is defined in the barrier model, so the criterion of sensitivity to changes in environmental and behavioural conditions is met under the assumption that the barrier model is correct.

Table 3 provides a list of technical indicators that can be linked directly with the event sequence diagrams of the accident scenario model as developed in ASCOS WP 3.2 (ASCOS, 2013).

[6] This concerns mandatory reports by Member States to the EUROCONTROL SRC as part of their obligations established under the EUROCONTROL Convention (CN Decision No. 115, dated 02 September 2009, approving ESARR2, Edition 3.0, for incorporating and implementation in the ATM regulatory frameworks of EUROCONTROL Contracting parties).

Table 3: Cross reference of technical indicators, associated accident scenario events and EASp operational issues.

Indicator	Associated accident scenario event	EASp operational issue
Autoflight system	ASC01a1, ASC13a1	runway excursion, loss of control in flight
Electrical power system	ASC01a1, ASC10a1, ASC11a1, ASC13a1	runway excursion, loss of control in flight, fire, smoke and fumes
Flight control system	ASC01a1, ASC04a1, ASC10a1, ASC13a1, ASC27a1	runway excursion, loss of control in flight
Fuel system	ASC11a1	Loss of control in flight, fire smoke and fumes
Hydraulic power system	ASC01a1, ASC10a1, ASC 13a1	runway excursion, loss of control in flight
Ice/rain protection system	ASC15a1, ASC11a1	loss of control in flight, fire, smoke and fumes
Landing gear system	ASC01a1, ASC04a1, ASC27a1	runway excursion
Navigation system	ASC18a1	loss of control in flight
Powerplant system	ASC09a1, ASC18a1, ASC11a1	runway excursion, loss of control in flight, fire, smoke and fumes
Aerodrome de-icing facilities	ASC06a1	loss of control in flight

3.4.5 Cost of obtaining and using measures is consistent with the benefits

The aviation industry has a strong tradition of collecting, storing and analysing failure data of both airborne and ground based equipment. Therefore there are virtually no additional costs for obtaining the raw data that are necessary to calculate indicator values. There might be some additional effort required in converting the raw data into indicator values, especially when raw data from different sources is combined in a single indicator value, but this is considered to be a minor effort. Therefore this criterion is considered to be met.

3.4.6 Comprehended by those in charge with the responsibility of using them

Performance indicators based on equipment failures are intuitively comprehendible, particularly in a technology dominated industry such as aviation.

3.4.7 Accuracy of data capable of quality control

Equipment failure data are very important data for service providers, not only from a safety perspective but predominantly because their activities are totally dependent on well-functioning equipment. The processes for obtaining this type of information, either from manual reporting or by automatic detection, are well defined. Therefore quality control of the data accuracy can be properly carried out.

3.4.8 Total set of indicators should remain manageable

Whether or not the total set of indicators is manageable depends on the number of indicators as well as the system that is used for managing them. For ASCOS, the system for managing the indicators is the safety barrier concept and the subdivision into three types of barriers (technology, humans, organisations and system of organisations). Because of the systematic approach and the fact that most data for the 'technology' indicators are already being obtained by the industry, this criterion is considered to be met.

3.5 Description and justification of the selected indicators

Of the list of technical indicators provided in Table 2, only the following can be directly associated with an accident scenario of the model developed in ASCOS WP3.2, and therefore meet all the criteria (see section 3.4.4). Consequently, the following list of technical indicators is proposed:

- Rate of autoflight 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

4 Indicators for the human component

4.1 Framework description

The 'human' part of the MTO 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.

The human errors can be analysed as holes in the safety barriers of the aviation systems being part of the human performance. In this perspective they take the form of 'unsafe acts' or 'omitted actions' which may contribute to open a window of opportunity for a potential risk to become a damage to either the health of people or the integrity of the concerned equipment, property or environment.

Different classifications of errors exist, based on both categorizations of their consequences and of their underlying causes, with special references to the involved cognitive mechanisms. The most consolidated classifications in literature falls into this second category (e.g. Reason 1990) and rely on a distinction between the different cognitive stages in which a failure of the human performance may actually occur, such as *perception*, *planning and decision making*, *memorization*, *execution*. Based on these classifications a number of different techniques have also been proposed to assess the human reliability and estimate the risk of human error occurrence in different safety critical domains. Examples are the THERP (Technique for Human Error Rate Prediction) developed in the nuclear domain (see Kirwan 1994), the CREAM (Cognitive Reliability Error Analysis Method) by Erik Hollnagel (1998) or the HERA (Human Error in ATM) developed by Eurocontrol (2003). Such techniques have generally produced good results in distinguishing different typologies of errors and in providing support for their preventions in different kinds of organisations. Nonetheless they encounter difficulties in producing quantitative data that can be considered meaningful if extrapolated from the specific context in which the errors occur. In other words it is of little use to know the number of cases in which an error concerns a 'wrong planning' or a 'wrong execution', if it is not known *what* was the subject of the wrong planning or *what* was wrongly executed and therefore which were the contextual elements favouring the occurrence of such errors.

Differently from technical failures, the human errors are known to be very numerous but with no negative consequences for safety in the large majority of cases. A single human error in isolation is generally insufficient to cause an incident or accident. Even in the case of potential danger, the majority of human errors are easily detected and recovered by the person committing them or by other people in her/his team.

From the point of view of an organisation the individual errors are so common and widespread that they are easily unnoticed and generally are not recorded, unless they produce some significant negative outcome (e.g. a pilot or a controller error may file safety report only when some severe event such as an infringement of separation minima has actually occurred). Heinrich's iceberg model (Heinrich 1980) shows how the number of errors and minor incidents are proportionally related to incidents and accidents in different kinds of organisations, see Figure 3 (numbers are indicative only). From the one side the model clarifies the well-known notion that a safety policy cannot be based solely on the monitoring and analysis of real accidents. This may actually trigger too late mitigation and prevention measures, but also rely on a too small number of accidents compared to the numerous incidents not resulting in real accidents, only due to some kind of last recovery or safety barrier. On the other side the model shows that the number of individual errors is too high for a systematic detection and that a very large majority of them will not produce any accident.

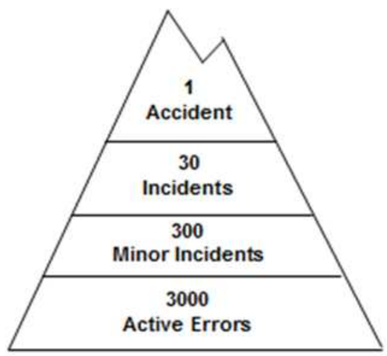

Figure 3: The iceberg model by Heinrich (1980)

In this respect the consideration (and particularly the counting) of each individual error as a safety indicator appears unreasonable for at least two reasons. The first reason is that the cost of obtaining and using such measures will not be consistent with the benefits one can expect, thus contradicting one of the characteristics of good safety indicators identified by Rockwell (see previous section 2.5). The second reason is that individual errors are normally combined with contextual factors which are essential to understand the motivations of the errors themselves. Therefore a lack of consideration of these factors will make the simple measurement of each error of little use to derive any safety recommendation. It would be impractical to collect all human errors and try to monitor these errors indications of accidents. A problem is that defining the boundaries for such errors is very difficult. What would be relevant is if humans are making the same type of errors, it may indicate problem with ergonomics (e.g. wrong design leading to incorrect actions following correct intentions). Quantification of the potential errors of human operator for design purposes may turn out to be very difficult.

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. For example, referring to the air transport system, an 'infringement of separation minima' or a 'level bust' could be considered as good indicators of an increased risk of 'Mid-Air Collisions' (i.e. one of the EASp Operational Issues to be considered in this context). In most of the cases an infringement of separation minima or a level bust are the effects of a pilot error, i.e. an *indirect* indicator of a human error with a negative impact on safety. In most of the cases a 'separation infringement' corresponds to a controller issuing an erroneous clearance or instruction or to a pilot misinterpreting or failing to follow the instruction, while a 'level bust' could correspond to a pilot failing to select the correct altitude or a controller instructing the wrong flight level. Of course these errors may have taken the form of *planning errors* or *executions errors* but they become of interest only when they result in some significant safety occurrence after combing with other contextual and contributing factors (e.g. an excessive workload due to a very high density of traffic, a late STCA alert or a wrong HMI design favouring an execution error). In other, less likely cases, a technical failure could have been the main driver for the safety occurrence, with the human error just being the inevitable consequence (e.g. an altimeter failure). However also in these cases the human error being considered is certainly of interest to understand whether there is a trend towards an increased or reduced level of safety of the overall aviation system.

Based on this approach a list of relevant safety occurrences is proposed for each of the EASp Operational Issues highlighted in section 2.4.

Table 4: Overview of relevant safety occurrences for the EASp Operational Issues

EASp Operational Issue	Safety Occurrence	Impacted Accident Scenario Event (from ASCOS WP3.2)
Fire, smoke and fumes	Fire or smoke observed in cockpit	ASC11a1
Runway incursion	Runway Incursion	ASC32a1
Loss of Control in Flight	Stall Warning	ASC38a1
	Bank Angle alert	ASC38a1
Controlled Flight Into Terrain	Near CFIT	ASC35a1 ASC35a11 ASC35a12 ASC35a13
	Deviation from Glideslope	ASC35a1 ASC35a11 ASC35a12
	Deviation from Localizer	ASC35a1 ASC35a11 ASC35a12
	Level bust at low altitude	ASC35a1 ASC35a11 ASC35a12
Mid-air Collisions	Separation Minima Infringement (ROC>7)	ASC31a12 ASC31b1 ASC31c1
	Airspace Infringement	ASC31a15 ASC31b1 ASC31c1
	Level Bust	ASC31a13 ASC31b1 ASC31c1
Runway Excursions	In Take-off Phase	
	High speed Rejected TakeOff	ASC02d2
	In Landing Phase	
	Go-around not conducted following unstabilized approach	ASC19f2
	Long landing event	ASC25d2 ASC26c2
	Excessive approach speed event	ASC25a11

The table above shows in the first two columns on the left respectively the EASp Operational Issues and the associated safety occurrence proposed as an SPI. The third column on the right lists the potentially impacted events included in the ASCOS Accidents Scenarios described in ASCOS deliverable D3.2 Total Aviation System Safety Assessment Methodology (ASCOS 2013). Further details on the selection and justification of the proposed indicators are given in the following section 4.3, also highlighting the potential human errors associated to each occurrence.

4.2 Comparison with criteria

In the following subsections the 'human' safety performance indicators presented above are compared against the criteria proposed by Rockwell and listed in Section 2.5.

4.2.1 Quantifiable and permitting statistical inferential procedure

The proposed framework of indicators is all based on lagging indicators, i.e. it concerns already happened events and represents actions previously taken by the aviation system operators in the context of each of the main EASp Operational Issues. In essence these indicators are counts of events which may be later corrected for traffic levels, allowing comparisons among different geographical areas at supranational, national, regional and-sub regional level and in principle comparisons among different airlines, airport and operators. As such these indicators can be used for both descriptive statistics and inferential statistics. They allow the identification of hot spots of specific events and regression analyses to investigate the role of specific variables.

Such characteristics derive from the fact that the proposed framework gives priority to those indicators that can be easily monitored with automatic tools, thus minimizing possibility for different interpretations of what level of severity is required to call something an incident. Currently, states report vastly differing quantities of occurrences due to interpretation differences.

Of course this approach has the limitation of focusing attention on the most severe near misses and incidents and reduces the opportunity for other more fine grained analyses based on the consideration of other less severe events, normally deemed useful for the purposes of safety analysis. However such methodological choice does not imply that other safety performance indicators corresponding to less severe events and requiring a non-automatic collection are less important (e.g. some of those available only through pilots and controller's voluntary reporting). On the contrary the proposed approach aims at a distinction between the indicators that are better suited for identifying global trends at the level of the total aviation system and those indicators (including the 'leading' ones) which can be more conveniently used for the monitoring of safety inside each specific organisation (e.g. inside individual ACC units, airlines or airports).

4.2.2 Representative of what is to be measured

As mentioned in section 4.1 the proposed framework of safety performance indicators is not directly representative of the individual human errors committed in everyday operations. It is just representative of the most severe effects of those unsafe operations normally associated to human errors. Due to the socio-technical nature of the global aviation system, in some cases it may be difficult to distinguish purely human failures (e.g. short term memory failures, perceptive errors or omitted supervisory controls) from critical interactions between the human component and the technical component of the system (e.g. a lack of situation awareness associated to a poor information presentation or an erroneous performance associated to a clumsy automation support). Therefore the safety indicators do not establish any linear link between specific human errors and unsafe outcomes, but limit their roles to highlighting significant trends in terms of safety occurrences in the context of each EASp Operational Issues. Only after a trend is identified (e.g. an increase of severe infringements of separation minima in a certain airspace area) is it possible to investigate the potential role of specific human errors committed by front line operators and trying to understand their motivations in order to identify possible mitigation measures. Again, as argued in section 4.1, this approach appears as the best compromise between trying to keep track of all human errors and focusing exclusively on real accidents. In the first case it should be clear that counting and keeping track of all human errors is simply impossible, due to the great number of human errors which are immediately corrected or simply go unnoticed due to other compensatory mechanisms. While in the second case it is universally acknowledged that real accidents are only the tip of the iceberg of a large majority of incidents which did not result in an accident only thanks to some technical, procedural or human safety barriers embedded in the aviation system (e.g. the activation of a safety net, a contingency procedure to operate in a degraded mode or the last recovery by a human operator).

4.2.3 Minimum variability when measuring the same conditions

The same arguments raised before for the indicators of technology apply here to the indicators of human behaviours. For safety performance indicators that rely on manual reporting of occurrences, whether the minimum variability criterion is met depends on the reporting discipline and the consistency in classification of the events. The experience of occurrence reporting over the past decade shows that even in mandatory schemes the reporting discipline severely affects the number of reported occurrences as well as the quality of data classification. This is because of a lack of good information about what happened, making it difficult to apply the right codes. EUROCONTROL for instance experienced very significant increases over time of the number of reported occurrences for several types of incidents. These increases are assumed to be the result of changes in reporting practices rather than actual escalations of the number of incidents (Eurocontrol 2013). In this respect indicators where the values are obtained through automatic recording, e.g. from Automatic Safety Monitoring Tool (ASMT) or Flight Data Monitoring (FDM,) have the potential to meet the minimum variability criterion. Also in this case, however, a considerable effort is required to harmonize the methods for data collection and to ensure a combination of homogeneous data (e.g. different ANSPs or different airlines may not use identical threshold values for defining the same safety occurrence). Furthermore safety and just culture issues should not be underestimated in order to limit the risk of a 'big brother' syndrome inside each organisation as well as opposition by unions and professional associations of the different operators.

Also based on these considerations, the proposed approach is to focus the automatic monitoring on a quite limited set of safety indicators for each EASp operational issue, corresponding to the most severe near miss and incident occurrences. There is an expectation that in this way the effort of harmonization will be more realistic even at a very large scale and the obstacle to the automatic reporting will be limited by the severity of the events, which are likely to be anyhow reported by at least one of the actor of the aviation system (e.g. depending of the perception of responsibility, a severe loss of separation is likely to be reported anyhow by either the flight crew or the controller at the concerned sector).

4.2.4 Sensitive to change in environmental or behavioural conditions

The focus on a limited set of severe safety occurrences for each of the EASp Operational Issue may potentially reduce the sensitivity to change in environmental or behavioural conditions. For example in a limited time period there might be virtually no difference between two ATC units in terms of severe Separation Minima Infringements or Runway Excursions, even in case one of the two units is perceived by the operators to experience significant safety issues that the other unit is not facing. This problem seems inevitable if the purpose is to collect data at a very large scale to identify trends for the total aviation system. However this appears as a good compromise to meet the other criteria proposed by Rockwell, also considering that the issue can be at least partially mitigated by choosing long monitoring periods. Furthermore, as mentioned above, it is essential to complement this approach with the collection and analysis of other more fine grained safety performance indicators to be used at local level, with fewer opportunities for comparison with other similar contexts, but more possibilities for a quick identification of effective mitigating actions.

4.2.5 Cost of obtaining and using measures is consistent with the benefit

Although definite conclusions cannot be driven in this context, there is an expectation that the highest costs will be necessary to establish safety culture and harmonization programs to encourage the different actors of the total aviation system to contribute in a consistent manner to the proposed safety monitoring system. On the contrary most of the monitoring tools are already fully operational (e.g. FDM) or available at a very limited cost and would require only a configuration effort for the analysis of data they are able to generate and a harmonisation of event triggers. In principle the limited number of safety occurrences taken into consideration should help to limit the above mentioned costs, at least as far as the harmonization effort is concerned. On the other hand these costs should be positively compensated by the advantage of having global safety trends identified at the total aviation system level, overcoming the limitations of the current system mainly based on accident data and voluntary reporting of incidents.

4.2.6 Comprehended by those in charge with the responsibility of using them

The proposed SPIs are intuitively comprehendible by all the aviation experts and fully consistent with what is normally analysed in the Safety Management Systems present in most of the organisations of the total aviation system.

4.3 Description and justification of the selected indicators

This section describes in detail the safety occurrences which have been selected as SPIs associated to human errors. A definition is initially provided for each of the EASp Operational Issues. The following contents are provided in a tabular format:

- The title of the safety occurrence selected for each EASp Operational Issue
- A description of the safety occurrence
- A list of possible human errors associated to each safety occurrence
- A list of possible automatic safety monitoring tools to collect data concerning the specific safety occurrence.

As mentioned before the safety occurrences are selected among those which are deemed more representative of the specific EASp Operational Issue and by giving priority to those that can be more easily detected by automatic monitoring tools.

It is worth noting that although a special attention is devoted to the safety occurrences, the accidents themselves (i.e. in this case the EASp Operational Issues) are included among the SPIs. In other words, although less interesting in quantitative terms, less representative of the overall safety level and obviously more difficult to manage in a just culture perspective - i.e. with the concerned judicial authority likely to interfere with any safety investigation and with all the aviation actors facing the problem in an emotional perspective - the accidents are included together with the proposed safety occurrences in the set of SPIs to derive overall trends at the level of the total aviation system.

In order to facilitate the quantification, the comparability and the automatic detection of safety occurrences, the proposed framework of SPI deliberately exclude any leading indicators, giving priority to the lagging indicators, due to the fact that it is easier to both measure and analyse them based on objective criteria. However this approach does not disregard the importance of leading indicators as a means to monitor and encourage the establishment of both good Safety Management Systems and Safety Culture and assumes that an adequate set of leading indicators will be proposed in relation to the safety at the level of both Organisations and System of Organisations.

In some cases a specific severity threshold is indicated to define whether a certain safety occurrence should be counted or not when measuring an SPI. For example it is proposed to select only the Infringement of Separation Minima with a ROC (Risk of Collision) higher then 7, based on the Risk Analysis Tool (RAT) developed by Eurocontrol (2009a). This method calculates the risk of collision as a combination of two different scores in a dedicated marksheet: a score indicating the minimum separation achieved between two aircraft (e.g. in the marksheet 7 corresponds to a separation included between the 25% and the 50% of the applicable separation minima) and a score indicating the rate of closure between the two aircraft. For example a rate of closure of 1 corresponds to a low rate of closure, included between 60 kts and 1000 ft per minute. In this case the safety occurrence would be included in the counting anyway, because of the very small minimum separation achieved. However, in other cases with the same rate of closure but with a wider minimum separation achieved (e.g. more than the 75% of applicable separation minima) it would not be considered as a safety occurrence to be calculated at a global level, but only as an occurrence to be investigated at local level after a qualitative consideration of its actual dangerousness after a qualitative consideration of the actual risk..

For other safety occurrences no specific thresholds have yet been selected, but it is proposed to identify them, also based on specific aircraft types (e.g. a specific degree of 'Deviation from Glideslope' can be established to decide whether to include it in the counting of the safety occurrences associated to the EASp Operational Issue 'Controlled Flight Into Terrain').

As far as human errors are concerned, the table describing each SPI only presents a list of possible unsafe acts or omissions associated to the specific occurrence. For example an incorrect pilot readback not corresponding to the actual level selected onboard is indicated as one of the possible causes of a near CFIT (Near Controlled Flight Into Terrain). However the list is not intended to be exhaustive and only represents errors in the form of 'phenotypes', exclusively based on what could be observed. The list does not speculate on the phenotypes (Hollnagel 1998), i.e. on the causes that may have favoured the specific errors. For example an erroneous ATC clearance is mentioned among the possible errors associated to an Infringement of Separation Minima. However it is not clarified whether this may have been caused by either an erroneous planning in the separation management task, due to a lack of situation awareness, or by an erroneous execution in the communication of the clearance to the pilot, for example due to some kind of interference from another task. As a matter of fact the possible classes of these causes and the room for different interpretations is too wide for being captured in a quantitative manner and be considered useful for the safety monitoring at a global level.

Finally the list of possible monitoring tools associated to each safety occurrence is elaborated by both combining tools available on the ground (e.g. ATC tools) and on the cockpit (e.g. FDM). In case the tool is specifically designed for off-line safety monitoring (e.g. the ASMT), it is just mentioned as such. While if the tool is primarily designed for other purposes (e.g. ground and airborne based Safety Nets) but can provide useful data for off line monitoring, it is mentioned together with the term 'log files' (e.g. MSAW log files, or EGPWS log files).

4.3.1 Fire, smoke or fumes

Uncontrolled fire on board an aircraft, especially when it is in flight, represents one of the most severe hazards in aviation. In-flight fire can ultimately lead to loss of control, either as a result of structural or control system failure, or as a result of crew incapacitation. Fire on the ground can result in casualties if evacuation and emergency response in soft swift enough.

Safety Occurrence	Description	Possible associated human errors	Possible automatic detection tool
Fire, smoke or fumes observed in cockpit	Fire, smoke or fumes in or on the aircraft in flight or on the ground.	• Error in maintenance or servicing of the aircraft.	• Flight Data Monitoring (FDM)

4.3.2 Runway incursion

A runway incursion is occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and take-off of aircraft (ICAO 2007).

Safety Occurrence	Description	Possible associated human errors	Possible automatic detection tool
Runway Incursion	Any occurrence at an aerodrome involving the incorrect presence of an aircraft vehicle or person on the protected area of a surface designated for the landing and take off of aircraft (ICAO 2007).	• Erroneous clearance issued by ATCO • Clearance erroneously executed by FC or vehicle driver • Call-sign confusion • Incorrect phraseology • Incorrect readback	• RIMCAS log files

4.3.3 Loss of Control in Flight

Loss of control accidents usually occur because the aircraft enters a flight regime which is outside its normal envelope, often, but not always, at a high rate, thereby introducing an element of surprise for the flight crew involved. Loss of control in flight has been one of the most significant causes of fatal aircraft accidents for many years (SKYbrary excerpt).

Safety Occurrence	Description	Possible associated human errors	Possible automatic detection tool

Stall Warning	A warning generated in the cockpit as a result of a sudden reduction in the lift generated by aircraft wings or stabilizers.	• Pilot inability to manage low level wind shear or high level Clear Air Turbulence. • Attempted flight with total load or load distribution outside of safe limits.	• FDM • EGPWS Stall Warning log files
Bank Angle alert	An alert produced as a result of an overbank event, i.e. a situation in which the specific bank angle limit of the aircraft is exceeded, preventing the aircraft wings and stabilizers from generating any lift.	• Lack of situational awareness by FC concerning excessive bank angle • FC temporarily unaware that aircraft that the Autopilot is disengaged and failing to scan Flight Navigation Display while undertaking other duties • Pilot inability to manage low altitude wind shear or high altitude Clear Air Turbulence.	• FDM • E-GPWS Bank Angle alert (Mode 6) log files

4.3.4 Controlled Flight Into Terrain

Controlled Flight into Terrain (CFIT) occurs when an airworthy aircraft under the complete control of the pilot is inadvertently flown into terrain, water, or an obstacle. The pilots are generally unaware of the danger until it is too late (SKYbrary excerpt).

Safety Occurrence	Description	Possible associated human errors	Possible automatic detection tool
Near CFIT	An inflight near collision with terrain, water, or obstacle without indication of loss of control (CAST/ICAO 2011).	• Altitude component of clearance/avoiding action erroneously executed by FC • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback	• MSAW log files • TAWS or EGPWS Excessive Closure Rate to Terrain alert (Mode 2) log files

Deviation from Glideslope	An event in which the final path followed by the aircraft during an ILS approach is above or below the glideslope of a predefined threshold.	• Erroneous execution by FC of ILS approach procedure on the vertical plan	• APM log files • EGPWS Glideslope (Mode 5) alert log files
Deviation from Localizer	An event in which the final path followed by the aircraft during an ILS approach deviates laterally from the localizer of a predefined threshold.	• Erroneous execution by FC of ILS approach procedure on the horizontal plan	• APM log files • TAWS log files
Level bust at low altitude	A level bust resulting in the aircraft flying below the Minimum Sector Altitude.	• Altitude component of clearance/avoiding action erroneously executed by FC during descent • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback • Etc.	• ASMT • TAWS log files

4.3.5 Mid Air Collisions

A Mid-Air Collision (MAC) is an accident where two aircraft come into contact with each other while both are in flight (SKYbrary excerpt)

Safety Occurrence	Description	Possible associated human errors	Possible automatic detection tool
Separation Minima Infringement (ROC>7)	A situation in which prescribed separation minima were not maintained between aircraft (Eurocontrol 2009c) with a ROC (Risk of Collision) higher than 7 (Eurocontrol 2009a).	• Erroneous clearance/avoiding instruction issued by ATCO • Clearance/avoiding action erroneously executed by FC • Call-sign confusion	• ASMT

		• Incorrect phraseology • Incorrect pilot readback	
Airspace Infringement	Airspace infringement occurs when an aircraft enters notified airspace without previously requesting and obtaining clearance from the controlling authority of that airspace, or enters the airspace under conditions that were not contained in the clearance (SKYbrary excerpt).	• Erroneous clearance/avoiding instruction issued by ATCO • Clearance/avoiding action erroneously executed by FC • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback • TSA not detected by ATCO or FC.	• CAIT log files • APW log files
Level Bust	A level bust (or altitude deviation) occurs when an aircraft fails to fly at the level for which it has been cleared. A level bust is defined by EUROCONTROL as: "Any unauthorised vertical deviation of more than 300 feet from an ATC flight clearance." (SKYbrary Excerpt). A level bust may take two main forms: 1) An aircraft in level flight climbs or descends without clearance 2) An aircraft climbing or descending fails to level off accurately at the correct level	• Altitude component of clearance/avoiding action erroneously executed by FC • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback	• ASMT

4.3.6 Runway Excursions

A Runway Excursion occurs when an aircraft on the runway surface departs the end or the side of the runway surface. Runway excursions can occur on take-off or landing (FSF 2009). They consist of two types of events:

- **Veer-Off:** A runway excursion in which an aircraft departs the side of a runway
- **Overrun:** A runway excursion in which an aircraft departs the end of a runway

Safety Occurrence	Description	Possible associated human	Possible automatic

		errors	detection tool
In Take-off Phase			
High speed Rejected TakeOff	An event in which a take-off is rejected when the aircraft speed is already greater than the V1 Speed.	• Inadequate directional control by FC. • Aircraft weight calculation error • Erroneous aircraft configuration for take-off • Failure to follow SOP for take-off by FC.	• Flight Data Monitoring (FDM)
In Landing Phase			
Go-around not conducted following unstabilised approach	An event in which the FC decides not to perform a go-around manoeuvre and to land even though the final approach is unstabilised.	• Inadequate directional control by FC • Inadequate altitude control by FC • Failure to timely detect need for go-around • Failure to select the appropriate runway based on the wind	• Flight Data Monitoring (FDM)
Long landing event	An event in which the distance between runway threshold and touchdown point is greater than a predefined threshold (e.g. 2000ft or 1/3 of the overall runway length)	• Inadequate altitude control by FC • Inadequate control of braking system during landing. • Failure to comply with SOPs in landing phase • Failure to timely detect need for go-around	• Flight Data Monitoring (FDM)
Excessive approach speed event	An event in which the calibrated air speed at the runway threshold exceeds the Vref+20 kts.	• Inadequate speed control in landing phase by FC. • Inadequate braking system control in landing phase by FC. • Failure to comply with SOPs in landing phase	• Flight Data Monitoring (FDM)

		• Failure to timely detect need for go-around	

4.3.7 Summary of the Safety Performance Indicators for the human component

The following pages provide in a tabular format a summary of all the SPIs identified for the human component. For each EASp Operational Issue the following information is provided:

- the selected safety occurrences
- the list of possible human errors associated to each safety occurrence
- the list of possible automatic safety detection tools to collect the data concerning the specific safety occurrence
- the list of potentially impacted events included in the ASCOS Accidents Scenarios described in D3.2 (Total Aviation System Safety Assessment Methodology) (ASCOS 2013).

In principle, once the proposed SPIs have been consolidated, information about the link between SPIs and Accident Scenarios can be updated each time new accident data becomes available.

EASp Operational Issue	Safety Occurrence	Possible associated human errors	Impacted Accident Scenario Event	Possible automatic detection tool
Fire, smoke or fumes	**Fire, smoke or fumes observed in cockpit or cabin**	• Error in maintenance or servicing of the aircraft.	ASC11a1	• Flight Data Monitoring (FDM)
Runway incursion	**Runway Incursion**	• Erroneous departure clearance or taxi clearance issued by ATCO • Departure or taxi clearance erroneously executed by FC • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback	ASC32a1	• RIMCAS log files
Loss of Control in Flight	**Stall Warning**	• Pilot inability to manage low level wind shear or high level Clear Air Turbulence. • Attempted flight with total load or load distribution outside of safe limits.	ASC38a1	• Stall Warning System log files • EGPWS or TAWS Stall Warning log files
	Bank Angle alert	• Lack of situational awareness by FC concerning excessive bank angle	ASC38a1	• Flight Data Monitoring (FDM)

EASp Operational Issue	Safety Occurrence	Possible associated human errors	Impacted Accident Scenario Event	Possible automatic detection tool
		• FC temporarily unaware that aircraft that the Autopilot is disengaged and failing to scan Flight Navigation Display while undertaking other duties • Pilot inability to manage low level wind shear or high level Clear Air Turbulence.		• E-GPWS or TAWS Bank Angle alert (Mode 6) log files
Controlled Flight Into Terrain	Near CFIT	• Altitude component of clearance/avoiding action erroneously executed by FC • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback	ASC35a1 ASC35a11 ASC35a12 ASC35a13	• MSAW log files • TAWS or EGPWS Excessive Closure Rate to Terrain alert (Mode 2) log files
	Deviation from Glideslope	• Erroneous execution by FC of ILS approach procedure on the vertical plane	ASC35a1 ASC35a11 ASC35a12	• APM log files • EGPWS or TAWS Glideslope (Mode 5) alert log files
	Deviation from Localizer	• Erroneous execution by FC of ILS approach procedure on the horizontal plane	ASC35a1 ASC35a11 ASC35a12	• APM log files • EGPWS or TAWS log files
	Level bust at low altitude	• Altitude component of clearance/avoiding action erroneously executed by FC during descent. • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback • Etc.	ASC35a1 ASC35a11 ASC35a12	• ASMT • EGPWS or TAWS log files
Mid-air Collisions	Separation Minima Infringement (ROC>7)	• Erroneous clearance/avoiding instruction issued by ATCO • Clearance/avoiding action erroneously executed by FC • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback	ASC31a12 ASC31b1 ASC31c1	• ASMT
	Airspace Infringement	• Erroneous clearance/avoiding instruction issued by ATCO • Clearance/avoiding action erroneously executed by FC • Call-sign confusion • Incorrect phraseology • Incorrect pilot readback • TSA not detected by ATCO or FC.	ASC31a15 ASC31b1 ASC31c1	• CAIT log files • APW log files
	Level Bust	• Altitude component of clearance/avoiding action erroneously executed by FC • Call-sign confusion	ASC31a13 ASC31b1 ASC31c1	• ASMT

EASp Operational Issue	Safety Occurrence	Possible associated human errors	Impacted Accident Scenario Event	Possible automatic detection tool
		• Incorrect phraseology • Incorrect pilot readback		
Runway Excursions	**In Take-off Phase**			
	High speed Rejected TakeOff	• Inadequate directional control by FC. • Aircraft weight calculation error • Erroneous aircraft configuration for takeoff • Failure to follow SOP for takeoff by FC.	ASC02d2	• Flight Data Monitoring (FDM)
	In Landing Phase	•		
	Go-around not conducted following unstabilized approach	• Failure to timely detect need for go-around	ASC19f2	• Flight Data Monitoring (FDM)
	Long landing event	• Inadequate altitude control by FC • Failure to comply with SOPs in landing phase • Failure to timely detect need for go-around	ASC25d2 ASC26c2	• Flight Data Monitoring (FDM)
	Excessive approach speed event	• Inadequate speed control in landing phase by FC. • Failure to comply with SOPs in landing phase • Failure to timely detect need for go-around	ASC25a11	• Flight Data Monitoring (FDM)

5 Organisation

5.1 Framework description

On average, the rate of fatal accidents has been decreasing since the 70s and 80s, reaching record lows in the 21st century. This decrease has been mostly driven by technology and the development of more reliable aircraft, improvements in training tools and air transport infrastructure. However, in the last decade or so, this rate has reached what appears to be a level of stagnation; a point where technology alone cannot bring about the step changes in aviation safety which will further reduce the rate of fatal accidents.

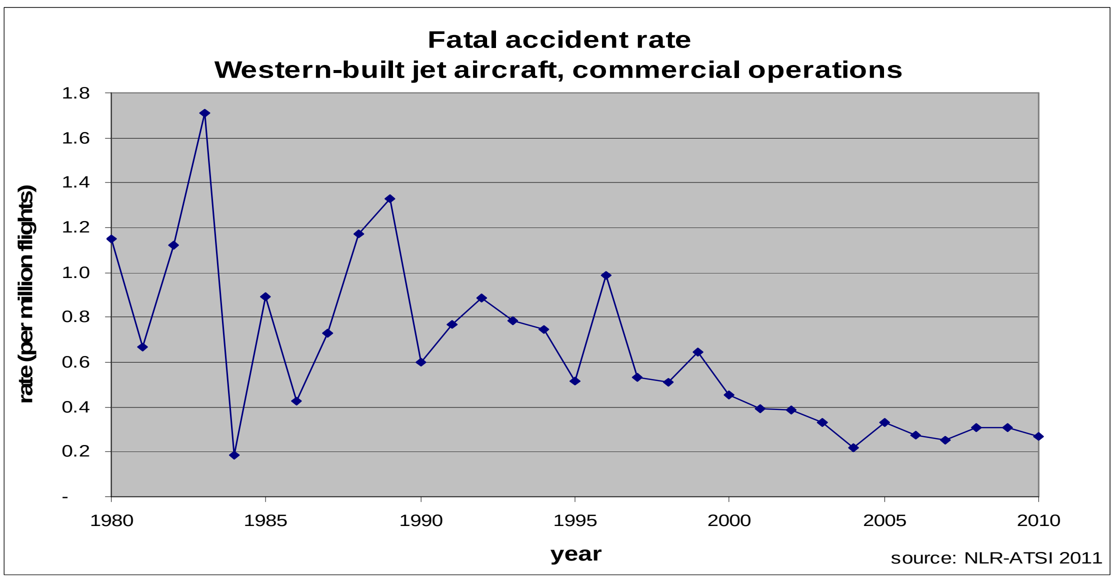

Figure 4: Fatal accident rate over the period 1980-2010

According to Airbus, the world's overall passenger aircraft inventory will more than double from today's 15,500 to 32,500 by 2031 (Airbus 2012). This means that if fatal accident rates remain constant, the number of fatal accidents will also be at least double in 2031, resulting in about 20 aircraft accidents each year resulting in mass fatalities (Boeing 2012). Therefore, there is an urgent need to further reduce an already low rate of fatal accidents.

Aerospace technology has made great strides over the years and aircraft systems have become increasingly more reliable and this is causing attention to shift to other issues which are ever-present to some degree in aircraft accidents today. These are essentially organisational issues and human factors, which in themselves are also related to each other.

The industry's response to tackle organisational issues has been, essentially, the introduction of safety management systems. When ICAO first issued its Safety Management Manual in 2006, it took the first step towards creating a structured approach to managing safety (and operational risk) across the key players in the aviation industry, starting with the regulators. The second edition of this document, issued in 2009, further developed the principles of the first issue and offered the concept of shared accountability for safety within an organisation which presents a holistic approach to safety management and emphasises the importance of a culture of safety. With the introduction of Annex 19, SMS is now based on standards and recommended practices.

Therefore, 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. Considering the different forms of organisation within the aviation industry, the relatively recent introduction of safety management systems and the lack of consistency in requirements at regulator level means that the task of establishing appropriate safety performance indicators which are universally representative to all won't be without its challenges.

5.2 Comparison with criteria

This step will compare the process for developing organisational safety performance indicators (within the context of safety management systems) with the criteria that were developed by Rockwell in 1959 (see section 2.5).

5.2.1 Quantifiable and permitting statistical inferential procedures

Organisational safety performance indicators are quantifiable because the essential principals of a safety management system are equal to any organisation. The challenge lies in the fact that the concept of safety management systems is relatively new and regulatory requirements for their introduction are only now beginning to emerge. As safety management systems become more widely adopted and oversight is conducted of their implementation and performance by regulatory authorities, quantifiable data will become available which will allow inferential statistical procedures to be applied.

5.2.2 Representative

The success of a safety management system is directly related to the safety culture of an organisation. Safety culture is an ever-evolving and high volatile 'commodity' within an organisation and measuring it falls beyond the scope of this exercise and presents very specific challenges of its own.

Nevertheless, it is possible to set representative safety indicators at a common level which will allow measurement of the key components of a safety management system, which are conducive to a thriving safety culture within an organisation. For instance, one can measure the presence of a safety reporting system, the existence of a formal safety policy etc, within a group of organisations in order to gain a representative impression of the condition of their safety management system.

5.2.3 Minimum variability under similar conditions

Variability will depend largely on the quality of the oversight and the data collected during audits of organisations by the regulatory authority. Once the requirements for safety management systems have been clearly established, audit checklists can be developed by the regulatory authorities to monitor compliance and gather comparable data across different organisations.

5.2.4 Sensitive to change in environmental or behavioural conditions

In order to establish safety performance indicators which have more sensitivity to change due to environmental or behavioural conditions, organisational safety performance indicators must probe deeper into the state of the organisation's safety culture rather than merely measuring elements of the structural set-up of the safety management system. This means that we should try and gain a measurement of the safety culture within an organisation, something which is highly sensitive to environmental and behavioural conditions. In order to achieve this one could for instance compare between the rate of mandatory, voluntary and confidential reports, or measure the spread within the community of reporters.

5.2.5 Cost of obtaining and using measures is consistent with the benefits

Safety management systems, as a structured way of managing organisational risk across the aviation industry are still in their infancy and there will be a cost associated with their introduction and oversight.

This cost may include acquiring hardware and software to manage safety data (such as reports, flight data or safety recommendations), training of personnel and changing company documentation to comply with the safety management system philosophy.

However, in the medium and long term, safety management systems are expected to bring savings to the industry, whether it is from a lower accident rate or a drive towards greater self-monitoring and safety assurance by organisations, instead of the need for intervention by regulatory authorities. The savings obtained from all of these will in the long run far outweigh any initial cost which may be involved in obtaining and using the data to better manage organisational (and operational) risk.

5.2.6 Comprehended by those in charge with the responsibility of using them

As safety management systems become more prevalent across every organisation within the aviation industry, safety performance indicators for measuring their implementation and success will also become readily comprehendible by everyone involved.

5.2.7 Accuracy of data capable of quality control

The data will primarily be obtained through oversight activities of the regulatory authority. The processes regarding this activity are normally well defined and with the creation of checklists for auditing and evaluating safety management systems, quality control of the data will be possible.

5.2.8 Total set of indicators should remain manageable

The safety barrier concept used by ASCOS to determine safety performance indicators, was chosen precisely to allow the development of a more manageable set of indicators. The systematic approach across the four subdivisions of barriers (technology, humans, organisations and system of organisations) and the emerging requirements for management of organisation-generated-risks means that appropriate safety performance indicators will be set to meet this criterion.

5.3 Selection of indicators including justification

Within the context of safety management systems, the following section will establish a selection of organisational safety performance indicators for the following key operational issues stated in the EASp:

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

The safety performance indicators are selected considering the criteria set in section 2.5 and the discussion of section 5.2 regarding their application to the organisational context.

5.3.1 Runway Excursions

Runway excursions are one of the aviation industry's most common type of occurrences. Fortunately, despite their frequent occurrence, they rarely result in the destruction of the aircraft or mass fatalities. Nevertheless, their frequency is a cause of concern for airlines, regulators and the flying public and therefore the various stakeholders are committed to reducing runway excursion events and also ensuring that when they do occur, mass fatalities are prevented.

From an aircraft operator's perspective, one way to identify hazards which could result in runway excursion events, could be by analysing through flight data monitoring (FDM), instances of unstable approaches and deep landings. These are typical precursors which can result in a runway excursion. The timely analysis of these precursors within an airline, for instance, will allow those who are accountable for flight operations and training to review practices, procedures and skills applied on the line by crew members, and take the necessary corrective actions.

Other hazards which can be equally monitored through FDM are the delay in applying brakes and thrust reversers as well as ground spoilers failing to deploy.

Runway contamination and degraded runway friction coefficient can be other factors that could contribute significantly to the occurrence of a runway excursion. However, establishing reliable safety performance indicators that satisfy the criteria in section 2.5 is currently a challenge. Nevertheless, within the context of the safety management system of an aerodrome, the regular measurement and tracking of runway friction coefficients can be an important safety performance indicator when it comes to helping prevent the occurrence of runway excursions.

Therefore the following organisational safety performance indicators are selected for runway excursions.

- Measuring the occurrence of unstable approaches;
- Measuring the occurrence of long landings;
- The number of times the flight crew fails to deploy ground spoilers;
- Measuring the delay in application of brakes;
- Measuring the delay in application of thrust reversers.

5.3.2 Mid-air collisions

Safety performance indicators for mid-air collisions can be set both within aircraft operators and ATC organisations.

Within an aircraft operator, safety reports and flight data monitoring can be important sources of data for monitoring the precursors to a mid-air collision. For instance safety reports from crews regarding loss of separation with other aircraft or the flight crew's response to TCAS RA warnings through FDM can be safety performance indicators within an aircraft operator.

Within the context of safety management systems, the safety reports would have to be analysed and shared with the ATC organisation involved in order to communicate the event but also to gather follow-up information regarding the reason which led to the loss of separation.

If an adverse trend is monitored regarding flight crew's response to TCAS RA warnings, this information must be communicated internally within the airline to the corresponding flight operations and training stakeholders so that appropriate corrective action is taken to mitigate this hazard.

Other safety performance indicators within an aircraft operator which can be tracked to prevent mid-air collisions are the occurrence of level-busts and navigation errors. The data source for such events is typically safety reports submitted by flight crew or reports received from ATC organisations for follow-up by the aircraft operator.

ATC organisations can also track loss of separation events and set their own safety performance indicators. They can also measure level-bust and navigation error events but other data sources such as recording the number of short-term conflict alert (STCA) warnings can help establish safety performance indicators for managing hazards which could result in a mid-air collision.

The following is a selection of organisational safety performance indicators for mid-air collisions:

- Measuring the number of level-busts;
- Measuring the number of navigation errors which result in a loss of separation with another aircraft;
- Monitoring flight crew's response (correct/incorrect) to TCAS RA warnings;
- Analysing loss of separation safety reports submitted by flight crew and those received from ATC;
- Measure the number of genuine STCA warnings.

5.3.3 Controlled flight into terrain

Controlled flight into terrain was for many years the aviation industry's greatest concern as it was the accident type causing the most fatalities. The introduction of terrain awareness and warning system (TAWS) such as ground proximity warning system (GPWS) and enhanced GPWS have fortunately resulted in a significant reduction of these types of events. Nevertheless, the nature of the events means that when they do occur they have catastrophic consequences.

Therefore, there is an interest in the industry to continuously monitor and act on the hazards which can contribute to the occurrence of CFIT events.

Aircraft operators, for instance, can use flight data monitoring to check whether flight crew respond correctly to EGPWS warnings. They can also investigate any instances of navigational errors which may have resulted in a loss of separation of the aircraft with terrain.

The operator's safety reporting system can also help identify trends. These may be specific to runway, location, type of aircraft or indeed a crew-wide issue. In any case, the safety management system will ensure that the relevant information gets shared internally throughout the organisation to relevant stakeholders and externally to national aviation authorities, ATC, navigational chart suppliers, etc., for the necessary follow-up.

ATC organisations can also collect data of events where aircraft lost separation with terrain. Safety performance indicators can be based on the number of times minimum safe altitude warnings (MSAW) are activated.

The following is a selection of safety performance indicators for monitoring precursors to the occurrence of CFIT accidents:

- Measuring the number of EGPWS events through safety reports or FDM;
- Counting flight crews' response (correct/incorrect) to genuine EGPWS warnings;
- Measuring navigational errors which result in a loss of separation with terrain;
- Measure the number of MSAW warnings.

5.3.4 Loss of control in flight

Loss of control events in flight, pose the greatest challenge when it comes to setting safety performance indicators at an organisational level.

Aircraft operators are the most appropriate organisations for monitoring precursors of loss of control events in flight. But even then, it is difficult to define which parameters to measure because such events are extremely rare and when they occur there are a large variety of causal factors which can result in loss of control in flight.

The most common elements present in loss of control in flight accidents have to do with the use of automation to some great extent, loss of situational awareness of the flight crew with regards to the aircraft's behaviour, departure from controlled flight and finally an absence or inappropriate response by the flight crew to regain controlled flight.

The aircraft operator could use its safety reporting system to monitor reports where crew became unaware or lost situational awareness of the behaviour of the aircraft, under control of automation. However, these events are very rare and as such unsuitable for trend monitoring as a safety performance indicator.

Another option is to track instances of misuse of automation both through flight data monitoring and safety reports and establish that as your safety performance indicator for loss of control events in flight. Finally, monitoring near-stall events and high bank angles through FDM can also help identify potential negative trends that could potentially lead to loss of control events in flight.

Therefore, the following selection is made for operational safety performance indicators regarding loss of control events in flight:

- Result of monitoring misuse of automation events through FDM and safety reports;
- Measuring through FDM near-stall events;
- Measuring through FDM high bank angle events.

5.3.5 Runway incursions

Runway incursions typically involve risk of collision between two aircraft or an aircraft with a ground vehicle.

Aircraft operators can become aware of runway incursion events through their own safety reporting system or by receiving notification from ATC.

ATC can also track runway incursions and ensure that any hotspots are represented on airport charts and that runway holding-point markings are clear and unambiguous.

The following is therefore the selected safety performance indicator for ground collisions:

- Measuring through safety reports of runway incursion events.

5.3.6 Fire, smoke or fumes

Uncontrolled fire on board an aircraft, especially when it is in flight, represents one of the most severe hazards in aviation. In-flight fire can ultimately lead to loss of control, either as a result of structural or control system failure, or as a result of crew incapacitation. Fire on the ground can result in casualties if evacuation and emergency response is not swift enough.

The following are therefore the selected safety performance indicators for fire, smoke or fumes:

- Measuring the number of fire/smoke/fumes events through safety reports or FDM;
- Average airport emergency response time.

6 System of Organisations

6.1 Framework

6.1.1 Introduction

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 none of the 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.

The number of stakeholders involved in or affected by a change in air transport operations is very large. Figure 5 gives an overview of groups of stakeholders, with a few example stakeholders per group indicated.

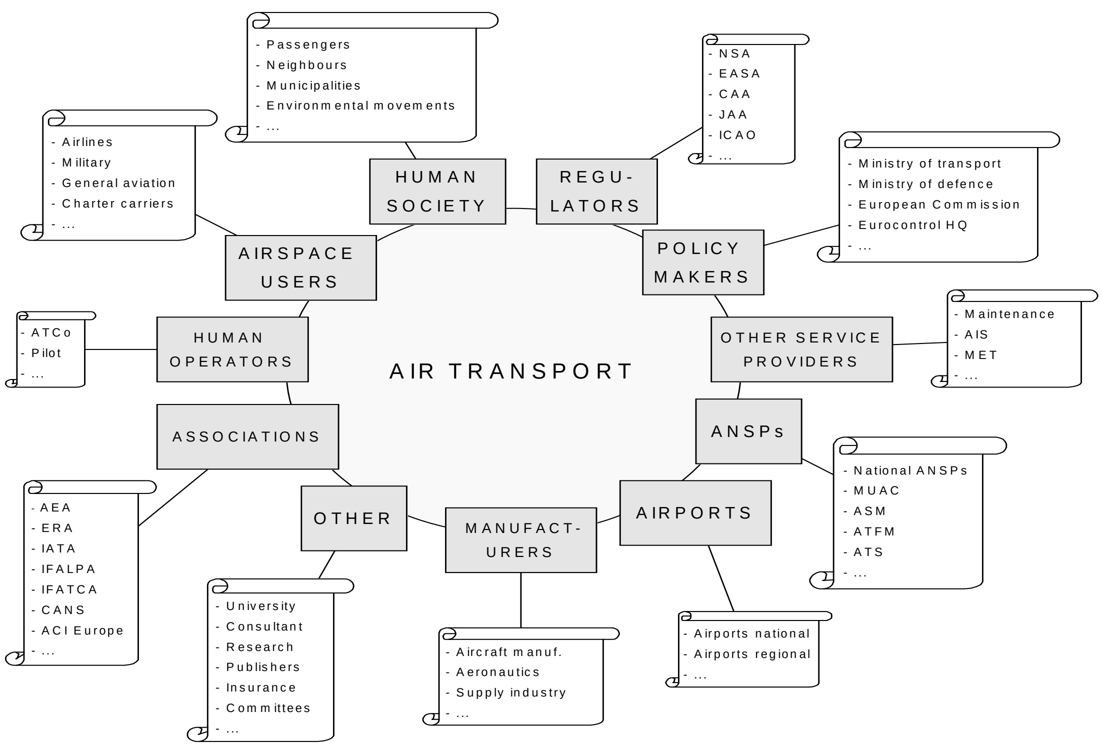

Figure 5: Stakeholders in the air transport system

One can look at safety performance indicators for “system of organisations” from two perspectives:

- Safety performance indicators can be considered from the perspective of how well the individual organisations interact. This requires identification of the individual systems and their interfaces and interactions.

- Safety performance indicators can be considered from the perspective of the aggregate performance of the system of organisations.

These two categories of safety performance indicators for “system of organisations” are detailed in the two sections below.

6.1.2 SPI for the functioning of a system of organisations

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** of an air transport system the system functions as designed, and;
- When there is a **harmonized** approach to safety performance management activities at different organisations.

6.1.3 SPI to facilitate monitoring and measurement of the aggregate safety performance

Safety performance indicators can be defined that facilitate monitoring and measurement of the aggregate safety performance of the system of organisations. With aggregate safety performance the combined safety performance of the industry is meant. For example, one can measure the number of stall warnings for a specific operator, but one can also measure the number of stall warnings for all operators combined.

Most safety performance indicators introduced in the previous chapters can be used for measuring the aggregated safety performance of the system of organisations. The advantage is that those indicators, when using input from the complete system, give an aggregate overview of safety performance.

Because of the increased scope such safety performance indicators are more sensitive to changes in environmental or behavioural conditions. The increased scope also improves the outcomes of statistical inferential procedures. Confidence intervals will be smaller when the scope is increased.

Some safety performance indicators are even only relevant when looking at the system of organisations, because the occurrence of events which is used as an indicator is too rare for individual organisations. An example is accidents. For a specific aviation organisation the safety performance indicator ‘accident rate’ is largely irrelevant. It does not provide minimum variability when measuring the same condition, and in case of changes in conditions of the system it will not prove sensitive. For the system of organisations, the accident rate can be relevant. Which indicators are relevant on an organisational and aggregate level depends on the size of an individual organisation and the size of the system of organisations. Generically one can say that indicators that are only relevant on a system of organisation level are accident rates and serious incident rates.

Because safety performance indicators to facilitate monitoring and measurement of the aggregate safety performance are mostly similar to safety performance indicators introduced in the previous chapters of this report, the focus of the remainder of this chapter will be on indicators for the proper functioning of a system of organisations.

6.2 Indicators for system of organisations

In section 6.1.2 four elements of a properly functioning system of organisations are introduced. In this section safety performance indicators per element are introduced. The elements interfaces and interaction are discussed in one section because they are both related to the links between the different organisations in the complete system.

6.2.1 Interfaces and interaction

A system of organisations can only function if there are links between the individual organisations. Operational hazards may originate from an organisation's own line of business, but may also originate at the interfaces of these organisations. Hazards that originate from the interfaces between different organisations are particularly important because of the risk that nobody feels responsible for mitigating them. Past aviation accidents often had causes that originated from improper interface management (Roelen, 2004). Figure 6 shows the main disciplines in the total aviation system and how they interlink.

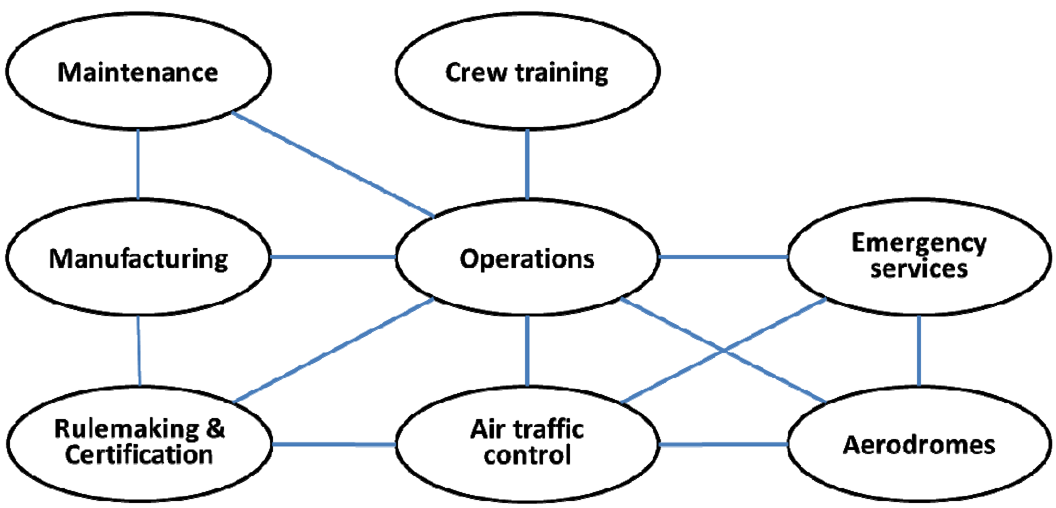

Figure 6: Interfaces between the main disciplines in the total aviation system

In Table 5 indicators for operational hazards on the interface of organisations are given. It is noted that the indicators that are introduced in this section are only described generically. In Section 6.4 the selected indicators will be described in more detail.

Table 5: Proposed safety performance indicators for interfaces

Indicator	Rationale
System combined runway incursion rate	Runway incursions involve the interface of the operation of aerodromes, operators and air traffic management.
System combined taxiway incursion rate	Taxiway incursions involve the interface of the operation of aerodromes, operators and air traffic management.
System combined airprox rate	Airproxes involve on the interface of operations of operators and air traffic management.
System combined erroneous weather prediction rate	Erroneous weather predictions can affect an aerodrome, ANSP and operator, but are the responsibility of meteorological services.
Bird strike rate	Bird control efforts involve the interface of operations of aerodromes, operators and air traffic management.

Besides the measurement of safety performance by interface-related operational hazards, one can also measure the interactions between organisations. The importance of proper interaction between aviation stakeholders is long known as is demonstrated by the following example:

> In the beginning of the 1960s the BAC 1-11 was developed. The BAC 1-11 was an example of an aircraft that incorporated a novel configuration of swept wings, tail mounted jet engines and a T-tail. A prototype aircraft was destroyed in October 1963. Control was lost when as a result of separated airflow from the wing and the engine nacelles the elevator became ineffective. This situation is called a deep-stall.
>
> The investigation report of the BAC 1-11 deep stall accident in 1963 gave consideration to the extent of information exchange between research establishments and the aircraft industry, and among constructors themselves. It emerged that no formal action had been taken in respect to the experience which had accumulated from incidents with other aircraft types of similar configuration as the BAC 1-11. The report concluded that knowledge gained from incidents and accidents may not always be made known among the industry owing to the lack of effective formal or standing arrangements, and that a more regular basis for the exchange of experience among aircraft constructors and research establishments on new problems affecting safety encountered during aircraft development would have considerable value (Smith 1965).

Table 6 lists a number of generically described indicators (or group of indicators) that can be used to measure the level of interaction between organisations and the outcomes of that interaction.

Table 6: Proposed safety performance indicators for interaction

Indicator	Rationale
Number of Inter-organisational meetings	This indicator counts the number of specific inter-organisational meetings. This includes meetings between operators and their most used aerodromes, between the operator and the ANSP at their home base, etc.
Quality of mandatory occurrence scheme	This indicator is a measurement for the quality of a mandatory reporting system. It should measure if there is an appropriate integration, consolidation and aggregation of data collected from the various aviation sectors. A prerequisite is the existence of a mandatory reporting scheme.
Quality of voluntary occurrence scheme	This indicator is a measurement for the quality of a voluntary reporting system. It should measure if there is an appropriate integration, consolidation and aggregation of data collected from the various aviation sectors. It should also measure if there is consistency in reporting, and if underreporting is minimized. A prerequisite is the existence of a voluntary reporting scheme.
Frequency of meeting of network of analysts	A Network of Analysts (NoA) can facilitate the development and continuing improvement of harmonized safety performance indicators used by industry (e.g. airlines, ATC, aerodromes etc.). A network can review the quality and consistency of data, establish the necessary data streams, investigate new safety indicators, monitor the emergence of new safety-critical areas, share experiences and coordinate analyses of common interest across the industry. A NoA can also carry out analysis of safety data to support safety action plans, as well as identifying emerging issues for possible inclusion in the future. A NoA should meet regularly (say at least 4 times a year). The actual achieved frequency of meetings can be used as indicator.
Level of just culture	Under "Just Culture" conditions, individuals are not blamed for 'honest errors', but are held accountable for willful violations and gross negligence (Skybrary). An appropriate level of just culture assures stakeholders will report their 'honest errors'. Indicators that measure the level of just culture can be used, e.g. results from a just culture assessment questionnaire.
Level of follow up on recommendations of AIBs	One of the core elements of a properly functioning total aviation system is the feedback loop that is provided by incident and accident investigations carried out by accident and incident boards (AIB). Such investigations often result in recommendations to the industry for improvement. The level of follow up on these recommendations can be used as an indicator.

6.2.2 Lifecycle

An important notion of a system of organisations is that it spans a lifecycle of many years; starting from research at universities and research organisations, followed by the development of aircraft by design organisations, resulting in the actual operation of the aircraft by an operator. During the many years of operation MRO organisations play an important role to keep the aircraft airworthy. During the lifecycle of an aircraft a lot of lessons are learnt. These lessons need to be disseminated, also to those organisations that are involved in the development of next generation systems with their own lifecycle.

Table 7 lists a number of generically described indicators (or group of indicators) that can be used to measure how safety improvement is incorporated in an entire lifecycle.

Table 7: Proposed safety performance indicators for lifecycle

Indicator	Rationale
Assessed impact of airport infrastructural changes	Indicator(s) to monitor if and how the safety impacts of (technical) infrastructural changes to airports are assessed (e.g. taxiway layout, new holding points etc.).
Assessed impact of aircraft modifications	Indicator(s) to assess the impact of design changes of existing aircraft (modifications, new engines, retrofits) on operator safety performance.
Assessed impact of ATM provision modifications	Indicator(s) to monitor the safety impact of changes to ATM (e.g. new radar, new software).
Training level of pilots at operators	Indicator(s) to assess the impact of changes in training methods used by training organisations on operator safety performance.
Safety impact of grandfather rights	Indictor(s) to measure the safety impact of aircraft that are operated using an out-dated certification regime (grandfather rights)
Use of roadmaps for the introduction of novelties	Indicator(s) to monitor the use of roadmaps for the introduction of novelties (for example the implementation of new techniques such as RNP)
Identification means of future risks (performed on a regular basis)	Indicator(s) to measure the adequacy of the means employed to identify future emerging risks.

6.2.3 Harmonization

ICAO's foreseen Annex 19 provisions are intended to harmonize the implementation of safety management practices for states and organisations involved in aviation activities. Table 8 *lists a number of generically described indicators (or group of indicators) that can be used to measure the level of harmonization of the system of organisations.*

Table 8: Proposed safety performance indicators for harmonization

Indicator	Rationale
Common risk classification framework used by CAAs and industry	To ensure risks of different organisations can be compared a common risk classification framework should be used. A risk classification framework consists of categories of severity and likelihood of hazards.
Commonality between safety performance indicators used by industry	To ensure that the outcomes of safety performance indicators of different organisations can be compared, there needs to be a degree of commonality. For example for runway incursions the same severity levels must be included in the indicator (for example only Class A and B).
Number of organisations that have fully implemented SMS before final transitional dates allowed.	Since SMS is meant to harmonize safety management, the number of organisations that have implemented an SMS could be used as an indicator.
Average system wide SMS maturity and effectiveness indices	Implementation of SMS can be done in several levels of maturity. There are methods available to measure the maturity of an SMS. Indices can be used to monitor the average maturity of SMS's used in the system of organisations. It is then assumed that this maturity measure is related to SMS effectiveness and safety level of the system.
Average level of regulatory compliance of states.	As a measure of overarching harmonization between states the average level of regulatory compliance with EU regulations and ICAO provisions can be monitored, e.g. from USOAP audits and EASA standardisation inspections.

6.3 Comparison with criteria

In the following subsections the "system of organisation" the criteria for proper safety performance indicators as proposed by Rockwell and listed in section 2.5 are discussed in the light of the generic safety performance indicators presented above.

6.3.1 Quantifiable and permitting statistical inferential procedures

An indicator is quantifiable if it is capable of being counted or measured. While counting occurrences may seem a simple activity, it requires a careful definition of the indicator such that it is unambiguous whether an occurrence should be counted or not. Without a proper definition there is the possibility that the same occurrence is interpreted differently by different analysts.

The indicators for the assessment of the safety performance at the interfaces of organisation are properly quantifiable. By clearly stating the scope of what to be monitored (e.g. for runway incursions only a certain severity class) random variations in measurements are minimized, making statistical inferential procedures possible.

Some of the indicators proposed for the interaction and lifecycle categories are straightforward measures, for example simply counting meetings. For these indicators statistical inferential procedures are largely irrelevant.

Some of the proposed indicators depend on specifically designed metrics for quantification. Examples are level of just culture and SMS maturity. These indicators are only quantifiable if a framework exists to measure them. EUROCONTROL has developed a metric to determine SMS maturity (Eurocontrol 2009b, 2009d). EUROCONTROL measures the maturity of ANSPs' safety management systems using a dedicated survey methodology. The Safety Maturity Survey Framework establishes the extent of progress made by ANSPs with respect to the introduction of ATM safety management systems and how the SMS framework relates to safety in operations and engineering. The maturity survey is based on self-assessment.

6.3.2 Representative to what is to be measured

In the end one needs to measure accident risk; the likelihood of the occurrence of event with such a severity that it is an accident. Therefore there should be an association between the indicator and accident risk. An association does not necessarily mean that the indicator and accident risk are causally related. It is however difficult to determine the exact association between the correct functioning of the system of organisations and accident risk. It is however not unreasonable to assume there is a positive relation between a correct functioning system of organisation and aviation safety. Therefore one can measure the functioning of system of organisation with safety performance indicators.

6.3.3 Minimum variability when measuring the same conditions

It is obviously a desirable characteristic for any measuring device to read the same value under equal conditions. For some of the proposed indicators, for example counting meetings, there will be minimum variability when measuring the same conditions, because these conditions are essentially created by the meeting themselves. For metrics that are specifically designed for the indicator, such as maturity of SMS, variability is possible if the criteria are unclear and self-assessments are done inconsistently. That is why in the EU context the results of the assessments of the service providers are reviewed by the NSAs and this action is verified by EASA audits.

6.3.4 Sensitive to change in environmental or behavioural conditions

Sensitivity of an indicator is needed to assure changes in environmental and behavioural conditions can indeed be observed with the use of the indicator. Sensitivity is also important for indicators that involve judgement or interpretation, for instance indicators that are self-assessments; does the assessment indeed give different results if conditions have change. Some indicators measure behavioural conditions, for example the number of meetings, and are therefore sensitive to change as well.

6.3.5 Cost of obtaining and using measures is consistent with benefit

The benefits of safety performance indicators are difficult to quantify by any means, and estimating the benefit for each indicator individually is virtually impossible. Therefore in practice this criterion means that the costs for obtaining and using the indicators should be acceptably low. There are several aspects that might drive costs upwards for the generic indicators introduced above: (1) the metric to be measured still needs to be developed, (2) the indictor can only be used by experts (e.g. indicators involving grandfather rights in certification), and (3) the indicator needs extensive analysis (e.g. assessments of safety impacts over a lifecycle).

6.3.6 Comprehended by those in charge with the responsibility of using them

Clearly this depends on who will be responsible of using them, which is not clear at this point. There are some suggested indicators that might be problematic in this aspect, because they are not intrinsically clear right away: e.g. level of just culture, SMS maturity, safety impact of grandfather rights.

6.3.7 Total set of indicators should remain manageable

In the next section indicators that match the six criteria mentioned above and will be described in more detail. This set of selected indicators should be such that it is still manageable.

6.4 Description and justification of selected indicators

Table 9 matches the (categories of) indicators introduced in section 6.2 with the criteria introduced in the previous section. Each indicator is scored for six criteria. The criterion “total set of indicators should remain manageable” is an overall criterion that can only be checked if a total set of indicators is available. The following scoring categories are used:

(green)	The criterion is easily matched
(yellow)	It will cost effort (for example research) to match the criterion
(red)	The criterion cannot be matched by the indicator

6.4.1 Indicators and criteria

The criterion “quantifiable and permitting statistical inferential procedures” is easily matched for about half of the indicators. For the other half it will cost effort to develop a framework for the measurement of the indicator. For example for the level of just culture a framework must be developed that makes it possible to measure such a level based on dedicated parameters.

The criterion “representative to what is to be measured” is also easily matched by around half of the indicators. For other indicators it again depends on the chosen metric for the indicator. If for example the quality of a mandatory occurrence scheme is only assessed by the number of reports each year it will not be representative to what is to be measured. It is believed that setting up roadmaps for the introduction of novelties is too far removed from actual accident risk. Although the use of roadmaps is advisable, measuring the use by an indicator is not representative for accident risk or the proper functioning of a system of organisations.

Most indicators provide minimum variability if the same conditions are measured. If one simply counts meeting, and in the first year there are 8 meetings, and in the second year as well, the indicator will read 8 for both years. For some indicator it again will take some effort to assure a proper metric is used. For example; for the indicator “commonality between safety performance indicators used by industry” it must be made very clear what is defined as common. If it is not defined clearly different assessors can have a different opinion, creating the possibility that there is variability even if the conditions are the same.

Table 9: Proposed (categories of) indicators matched against criteria

Indicator	Quantifiable and permitting statistical inferential procedures	Representative to what is to be measured	Minimum variability when measuring the same conditions	Sensitive to change in environmental or behavioural conditions	Cost of obtaining and using measures is consistent with benefit	Comprehended by those in charge with responsibility of using them
System combined runway incursion rate	(green)	(green)	(green)	(green)	(green)	(green)
System combined airprox rate	(green)	(green)	(green)	(green)	(green)	(green)
Operator combined erroneous weather prediction rate	(green)	(green)	(green)	(green)	(green)	(green)
Bird strike rate	(green)	(green)	(green)	(green)	(green)	(green)
Number of Inter-organisational meetings	(green)	(yellow)	(green)	(green)	(green)	(green)
Quality of mandatory occurrence scheme	(yellow)	(yellow)	(yellow)	(yellow)	(yellow)	(yellow)
Quality of voluntary occurrence scheme	(yellow)	(yellow)	(yellow)	(yellow)	(yellow)	(yellow)
Frequency of meeting of network of analysts	(green)	(yellow)	(green)	(green)	(green)	(green)
Level of just culture	(yellow)	(yellow)	(yellow)	(yellow)	(yellow)	(yellow)
Level of follow up on recommendations of AIBs	(yellow)	(green)	(yellow)	(yellow)	(yellow)	(yellow)
Assessed impact of airport infrastructural changes	(yellow)	(green)	(green)	(yellow)	(yellow)	(yellow)
Assessed impact of aircraft modifications	(yellow)	(green)	(green)	(yellow)	(yellow)	(yellow)

Assessed impact of ATM provision modifications	yellow	green	green	yellow	yellow	yellow
Training level of pilots at operators	yellow	yellow	green	yellow	yellow	yellow
Safety impact of grandfather rights	yellow	green	green	yellow	yellow	yellow
Use of roadmaps for the introduction of novelties	green	red	green	green	green	green
Identification means of future risks (performed on a regular basis)	yellow	green	green	yellow	green	green
Common risk classification framework used by CAAs and industry	green	yellow	green	yellow	green	green
Commonality between safety performance indicators used by industry	yellow	yellow	yellow	yellow	yellow	green
Nr of org that have fully implemented SMS before final dates allowed	green	green	green	green	green	green
Average system wide SMS maturity and effectiveness indices	yellow	yellow	green	yellow	yellow	yellow
Average level of regulatory compliance of states	yellow	yellow	green	yellow	yellow	green

Somewhat less than half of the indicators are sensitive to change in conditions. For some it depends on the chosen, and specifically developed, metric. It depends on how of the metric makes actual measurement possible. For example, if one develops a very detailed metric to measure SMS maturity it is likely that it cannot be assessed on a regular basis, decreasing the sensitivity to changes in environmental and behavioural conditions.

The cost of obtaining and using measures depends on how easy the indicator can be measured. Combined runway incursion rates are easily measured using an event reporting scheme. Measuring if the impact of airport infrastructural changes is properly assessed might be costly however. It is believed though, that since the benefits can be significant, eventually reducing accident risk, all indicators can be worth the effort in cost.

Simple indicators measuring events or simply counting meetings are easily comprehended by those in charge with responsibility of using the indicators. For indicators with a uniquely designed metric it might not be clear right away what the actual measure is and dedicated training for the responsible might be necessary.

6.4.2 Selected indicators

The indicators that are selected are those that follow the following 2 rules:

1. At least match 2 criteria easily (green)
2. Can in theory match every criteria (no red)

Some of the indicators introduced earlier in this chapter are only generically described. In this section proposals for actual indicators will be made for those generic indicators that match the two rules given above.

All indicators that measure the safety performance at the interfaces between organisations easily match the criteria. Since the indicators are straight forward they do not have to be elaborated.

Hence, the first set of selected indicators is equal to how they are first introduced:

No.	Name of indicator	Associated EASp Operational Issue
1	System combined runway incursion rate	Runway incursion
2	System combined airprox rate	Mid-air collision
3	Operator combined erroneous weather prediction rate	Runway excursion, Loss of control in flight
4	System combined bird strike rate	Runway excursion, Loss of control in flight

For interaction only those indicators that simply count number of meetings sufficiently match the criteria. For the others the dedicated metrics that need to be developed cause to much concern with regard to eventually matching the criteria. A suggestion for more specifically defined indicators measuring the amount of interaction in the system of organisations is given below:

No.	Name of indicator	Associated EASp Operational Issue
5	Total number of formal safety related meetings involving at least to different type of organisations (e.g. an aerodrome and ANSP) per year	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.
6	Total number of formal meetings of network of analysts to discuss safety performance measurement	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.

Most selected indicators under the category “lifecycle” depend on the realization of safety assessments. It is believed that the experience in the execution of safety assessments is mature enough in the aviation industry to base indicators on. The indicators suggested here are Boolean; they are either true of false. The indicators as introduced in Section 6.2 are elaborated into:

No.	Name of indicator	Associated EASp Operational Issue
7	The safety impact of each significant airport infrastructural change is assessed and deemed acceptable before the actual introduction of the change	Runway excursion, Runway incursion, Fire, smoke and fumes.
8	The actual safety impact of each significant airport infrastructural change is evaluated at most after 3 years of implementation of the change	Runway excursion, Runway incursion, Fire, smoke and fumes.
9	The safety impact of each significant aircraft modification is assessed and deemed acceptable before the actual introduction of the modification	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.
10	The actual safety impact of each significant aircraft modification is evaluated at most after 3 years of implementation of the modification	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.

11	The safety impact of each significant ATM provision modification is assessed and deemed acceptable before the actual introduction of the modification	Mid-air collision, CFIT, Runway incursion
12	The actual safety impact of each significant ATM provision modification is evaluated at most after 3 years of implementation of the modification	Mid-air collision, CFIT, Runway incursion
13	The safety impact of an aircraft flying under an outdated certification scheme is assessed after each significant change in certification rules	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.
14	A proper means to identify future risks is set-up and altered when deemed necessary	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.
15	Future risk are identified on a regular basis (at least each year new risks should be identified) using a dedicated means to do so	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.

Two proposed “harmonization” indicators do not match the criteria sufficiently. For “commonality between safety performance indicators used by industry” it is deemed infeasible to come up with an indicator that can be readily updated and clearly defines when indicators can be considered common. Furthermore it is believed that the SMS framework will assure commonality, therefore the implementation of that framework can be measured as well. For “average system wide SMS maturity and effectiveness indices” it is believed that it will cost a lot of effort to come up with such indices and the related metric. Furthermore, it is unsure if such an indicator will have a sufficient link with accident risk. The other proposed indicators do match the requirements, and the elaborated versions are given below:

No.	Name of indicator	Associated EASp Operational Issue
16	A common risk classification framework is used by CAAs and industry (using the same criteria for likelihood and severity of events)	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.
17	The number of organisations that have fully implemented a Safety Management System before the final transitional dates allowed.	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.
18	The average level of regulatory compliance of states (for example using ICAO USOAP CMA[7] or EASA audits) should be measured every three years and should increase every three years	Runway excursion, Mid-air collision, CFIT, Loss of control in flight, Runway incursion, Fire, smoke and fumes.

[7] universal safety oversight audit programme continuous monitoring approach

7 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. There are several ways in which occurrence data can be normalised. Examples of typical normalisation data are total number of kilometres flown, flights hours, airport movements, passenger-kilometres and number of flights conducted. Safety indicators based on kilometres flown, flight hours and other equivalent denominators are not necessarily the most appropriate as most aviation safety occurrences take place during take-off, initial climb, approach, and landing flight phases. The time spent or the distance flown in these phases are independent of the total flight duration or distance travelled between two airports. Changes in the average trip duration or average distance flown can therefore influence the calculated safety performance when using these data to normalise occurrences. Therefore the number of flights are considered to be the most appropriate for normalisation of occurrence data (i.e. lagging safety indictors). 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, see also section 8.2 as well as linking the SPIs with a source of normalisation data such as EASA's warehouse for aviation production data.

For leading safety indicators there is no common recipe for normalisation. Instead the proper normalisation should be determined case by case, taking into account the intended scope and use of the safety performance scheme of which the indicators are a part.

8 Practical considerations

8.1 Linking with CATS and Baseline risk picture

Whenever a system of multiple performance indicators is used, it is desirable to have a system in place that allows assessment of how the overall performance of the system is affected by changes of the values of the various individual indicators. Otherwise it is not possible to know if and how the overall performance changes when e.g. one performance indicator value increases while another performance indicator value decreases. All indicator values have to be aggregated to an overall indication of performance. In the case of aviation safety, the overall indication of safety performance is the accident probability, therefore a system is required that links the SPIs to the overall accident probability. For event based indicators (lagging indicators) such a system is provided by the accident risk model CATS as described and further developed in ASCOS work packages 2.2 and 3.2.

8.2 Linking with ECCAIRS

The ECCAIRS system has become the world standard for 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. In some cases this may seem problematic as the ECCAIRS system was initially developed for a different purpose and hence the events as defined in the ECCAIRS taxonomy are not mutually exclusive.

9 Conclusions and recommendations

9.1 Conclusions

Aviation Safety Performance Indicators have been defined at four different levels:

- Technology
- Human
- Organisation
- System of Organisations.

For each level, proposed safety performance indicators have been compared with a list of characteristics of a good measure of safety performance:

- 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 indicators have also been linked to the main operational Issues of the European Aviation Safety Plan:

- Runway excursion
- Mid-air collision
- Controlled flight into terrain
- Loss of control in flight
- Runway incursion
- Fire, smoke and fumes.

A complete overview of proposed indicators is provided in Appendix A.

9.2 Recommendations

To facilitate quantification and semi-continuous updating of the safety performance indicators, it is recommended that each proposed safety performance indicator 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.

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Appendix A List of Safety Performance Indicators

Technology

Rate of autoflight 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[8] or EASA audits) should be measured every three years and should increase every three years

[8] universal safety oversight audit programme continuous monitoring approach