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Safety performance indicators for system of organizations in aviation

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Safety performance indicators for system of organizations in aviation

J.G. Verstraeten, A.L.C. Roelen, L.J.P. Speijker (NLR)



A key step in an improved certification process is a framework for Safety Performance Indicators (SPIs) in the total aviation system. The main objective of this study is to develop Safety Performance Indicators for the system of organizations in aviation, and relate these to the main operational issues identified in the European Aviation Safety plan (EASp), established by EASA.

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Abstract

Fundamental changes in the institutional arrangements for aviation regulation in Europe, the introduction of new technologies and operations, and demands for higher levels of safety performance call for the adaptation of existing certification processes. The European Commission (EC) Project 'Aviation Safety and Certification of new Operations and Systems' (ASCOS) contributes to removal of certification obstacles and supports implementation of technologies. A key step in an improved certification process is a framework for Safety Performance Indicators (SPIs) in the total aviation system. The main objective of this study is to develop Safety Performance Indicators for the system of organizations in aviation, and relate these to the main operational issues identified in the European Aviation Safety plan (EASp), established by EASA. Specific research objectives:

- To identify and summarize key European activities on Safety Performance Indicators;
- To provide a concise theoretical overview of safety performance;
- To develop a list of characteristics (criteria) of a good measure of safety performance;
- To develop and select safety performance indicators for the system of organizations in aviation;
- To relate the safety performance indicators to the main operational issues identified in the EASp;
- To provide guidance on the quantification of selected safety performance indicators.

There is a need to develop safety performance indicators for the total aviation system. Such safety performance indicators should meet quality criteria to assure they are quantifiable, representative to safety performance, comprehensible and can be cost-efficiently used. Developed safety performance indicators should be related to the main operational safety issues as identified by EASA and EC in the European Aviation Safety plan (EASp). This paper focuses on the development of safety performance indicators for the class 'system of organizations', which will form a part of a single framework for the total aviation system. Both lagging (measuring past outcomes or events) and leading (measuring safety before any event in the actual operation needs to take place) safety performance indicators are drafted for (1) the safety performance at interfaces between organisations, (2) the level of interaction, openness and sharing of information between different stakeholders, (3) the safety performance of an air transport system throughout its lifecycle, and (4) the level of harmonization in the approach to safety performance management activities at different organisations.

The suggested lagging safety performance indicators match the quality criteria. For leading indicators it needs to be validated that they are representative as measurement for accident risk, although it can be assumed there is a positive relation between a correct functioning system of organisation and aviation safety. Effort is required to validate that positive relation. A baseline risk picture can be obtained by expanding the safety performance indicators into a causal risk model that formally represents the causal and statistical associations between the safety performance indicators and accident probabilities for various accident scenarios. The system of safety performance indicators and the causal risk model only provide a snapshot view of safety. In order to be useful in support of continued operational safety there must also be a process for continuous safety monitoring.

Ref: Safety Performance Indicators in Aviation

Page: 2

Issue: 1.0

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Table of Contents

Abstract	1
List of Figures	4
List of Tables	5
1 Introduction	7
1.1 Background and scope	7
1.2 Needs	8
1.3 Objectives	8
1.4 Research approach	8
2 Current European playing field	9
3 Safety performance indicators state-of-the-art	11
3.1 Safety performance measurement history	11
3.2 Criteria for proper safety performance indicators	11
3.3 The total aviation system	12
3.4 Leading and lagging indicators	13
4 Safety performance indicators for system of organisations	14
4.1 The system of organisations	14
4.2 Definition and selection of safety performance indicators	15
4.2.1 Safety performance indicators for the interfaces	15
4.2.2 Safety performance indicators for interactions	16
4.2.3 Safety performance indicators for lifecycle	17
4.2.4 Safety performance indicators for harmonization	18
4.3 Quantification	20
5 ASCOS perspective	22
6 Conclusions and recommendations	23
7 References	25

Ref: Safety Performance Indicators in Aviation

Page: 4

Issue: 1.0

Classification: Public

List of Figures

Figure 1: stakeholders in the air transport system _____ 14

Ref: Safety Performance Indicators in Aviation

Page: 5

Issue: 1.0

Classification: Public

List of Tables

Table 1: Safety performance indicators for interfaces between organisations _____ 16

Table 2: Safety performance indicators for measuring the interaction between organisations _____ 16

Table 3: Safety performance indicators for measurement continuing safety performance over a lifecycle ____ 17

Table 4: Safety performance indicators to measure the level of harmonization of the system of organisations 20

Ref: Safety Performance Indicators in Aviation

Page: 6

Issue: 1.0

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1 Introduction

1.1 Background and scope

Certification risk has been cited as an obstacle for the introduction of many innovative technologies and operational concepts. Fundamental changes in the institutional arrangements for aviation regulation in Europe, the introduction of new technologies and operations, and demands for higher levels of safety performance call for the adaptation of existing certification processes. The European Commission (EC) Project 'Aviation Safety and Certification of new Operations and Systems' (ASCOS) contributes to the removal of certification obstacles and supports implementation of technologies to reach the EU ACARE Vision 2020 [1] and Flight Path 2050 [2] goals. ASCOS outlines an approach to certification that [3, 4]:

- Is more flexible with regard to the introduction of new operations, systems and products;
- Is more efficient, in terms of cost, time and safety, than the current certification processes;
- Considers the impact on safety of all elements of the total aviation system and the entire system life-cycle in a complete and integrated way.

Moving towards performance based regulation, based upon agreed safety performance in combination with risk based approach to standardization, is expected to lead to improvements in the way that safety risks are controlled [4]. Anticipating on future risks and hazards by using a "proactive approach" helps to make the certification process robust to new developments. Introducing 'continuous safety monitoring' will ensure that new and essential safety data is effectively used immediately after it will be available. Promising options for adaptations of the existing certification processes include [4]: 'change between performance-based and compliance-based or vice versa', 'proof of concept approach', 'enforce existing rules and improve existing processes', and 'cross-domain fertilization'. Introducing certification process adaptations cannot be done without giving due account to safety considerations: each of these options requires evidence on safety assurance as key element in a certification process. In this respect, it is relevant to note that the need for safety improvement is also recognized in the ACARE Beyond Vision 2020 (Towards 2050) [5], which states that 'society is increasingly reluctant to accept failures in the Air Transport System, which exerts more pressure on safety considerations'. The Flightpath 2050 Vision for Aviation [2] specifically aims for a *holistic, total system approach to aviation safety, integrated across all components and stakeholders. This will be supported by new safety management, safety assurance and certification techniques that account for all system developments. Just culture will be adopted as essential element of the safety process* [2]. Clearly, there is a need for new safety based design systems and supporting tools that address the *total aviation system*, while being able to anticipate on *future and emerging risks* that may exist in a future aviation system that will differ from today's aviation system. Although a total aviation system approach is becoming more widely supported in aviation, there is still a lot to be done before this will actually be embedded in certification processes and safety management. Safety topics that require further research – in particular from a total aviation system point of view – are e.g. development of a framework of Safety Performance Indicators (SPI) [6], establishment of a baseline risk picture and safety performance targets [7], definition of a process for continuous safety monitoring, development of risk models and accident scenarios representing the future aviation system, and subsequent incorporation of the – total aviation system – safety methods and tools in safety standards.

1.2 Needs

Acceptable Means of Compliance and Guidance Material for the implementation and measurement of Safety Key Performance Indicators (SKPIs) in the ATM domain have been developed by EASA. However, in the context of developing a new methodology and supporting tools for multi-stakeholder continuous safety monitoring, there is a need to define a framework of safety performance indicators for the total aviation system. Such safety performance indicators should meet quality criteria to assure they are quantifiable, representative to safety performance, comprehensible and can be cost-efficiently used. Developed safety performance indicators should be related to the main operational safety issues as identified by EASA and EC in the European Aviation Safety plan (EASp) [8].

1.3 Objectives

The main objective of this study is to develop Safety Performance Indicators for the system of organizations in aviation, and relate these to the main operational issues identified in the European Aviation Safety plan, established by EASA. This will be realized through specific research objectives:

- To identify and summarize key European activities on Safety Performance Indicators;
- To provide a concise theoretical overview of safety performance;
- To develop a list of characteristics (criteria) of a good measure of safety performance;
- To develop and select safety performance indicators for the system of organizations in aviation;
- To relate the safety performance indicators to the main operational issues identified in the EASp;
- To provide guidance on the quantification of selected safety performance indicators.

1.4 Research approach

Firstly, the key European activities on Safety Performance Indicators are identified and described. This includes the applicable European Commission regulations and already existing Acceptable Means of Compliance and Guidance Material. Next, the research starts with a concise theoretical overview of safety performance indicators. In ASCOS this is used to systematically identify several classes of safety performance indicators, resulting 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. It is argued that safety performance indicators will be defined at four levels/classes: technology, human, organization, and system organizations. 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: runway excursions, mid-air collisions, controlled flight into terrain, loss of control in flight, runway incursions, and fire, smoke and fumes. This ensures alignment with the safety strategies of the European Commission and EASA. This paper focuses on the development of safety performance indicators for the class 'system of organizations', which will form a part of a single framework for the total aviation system. What is considered important to measure will be compared with what is possible given current data. A gap analysis will show what data needs to be gathered to ensure that safety can really be monitored effectively. This will allow the further development and validation of a continuous monitoring process.

2 Current European playing field

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 EC assisted by the Performance Review Body. Introduction of safety management systems in aviation has resulted in EC requirement to measure safety performance through use of safety performance indicators [9, 10, 11, 12].

The safety Key Performance Indicators (KPIs) and performance targets must be established and implemented in line with the safety objectives and standards laid down in Regulation (EC) No 216/2008 [9]. Specific and measurable key performance indicators should be selected, on the basis of which responsibility for achieving the performance targets can be assigned. The associated targets should be achievable, realistic and time-bound, and aim at effectively steering the sustainable performance of air navigation services [12]. This includes the following safety KPIs under the EC performance regulation:

- Effectiveness of Safety Management and Just Culture
- Methodology for severity classification of reported safety-related occurrences.

SPIs are being developed for implementation as from 2015 and are priority for 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. In this context, it is relevant to note that EC Regulations No 691/2010 [10] and No 1216/2011 [11] should be repealed with effect of 1 January 2015.

EASA Member States are now developing and using SPIs as part of their State Safety Programmes (SSPs). In support of this, EASA has developed Acceptable Means of Compliance (AMC) and Guidance Material (GM) for measuring the safety Key Performance Indicators (KPIs) and Performance indicators (PIs) in accordance with the performance scheme Regulation (EC Regulation No 691/2010 [10] as amended by No 1216/2011 [11] for period 2012 – 2014 and EC Regulation No 390/2013 [12] for period 2015 – 2019) [13, 14].

EUROCONTROL also provides supporting material. The EUROCONTROL 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. The scoring system takes account of the fact that various questions have different levels of significance through the application of weighting factors [15, 16]. The EUROCONTROL severity classification of RAT 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 [17]. 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, and ATM specific occurrences. The assessment is based on a question-

based scoring mechanism. The level of presence and corresponding level of absence of just culture can be measured through a questionnaire. In this context, just culture is defined 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”.

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 SESAR Accident Incident Model (AIM) [18]. This provides an interesting reference because the link between indicators and a risk model is similar to what is being proposed in ASCOS. Definitions of lagging and leading indicator currently used within the European ATM community are clarified. A classification of lagging and leading indicators is proposed that allows them to be assigned to the individual Accident Incident Models, as is currently used in the SESAR JU Project.

3 Safety performance indicators state-of-the-art

3.1 Safety performance measurement history

Measuring safety performance has been studied for at least 50 years [19]. Traditionally, accident rates were used to measure the performance of aviation safety. When safety increased, accidents became rare events and alternative ways to derive safety performance were required.

Safety is the freedom of unacceptable risk, where risk is a combination of the probability of occurrence of harm and the severity of the harm [20]. 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. Safety 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 [21]. 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.

3.2 Criteria for proper safety performance indicators

To be able to judge the suitability of an indicator or a set of indicators preferable characteristics have to be defined. In general it is already stated that aviation safety performance indicators should provide an indication of the probability of an accident. That means they have to be quantifiable and that there needs to be a relation with accident probability. Rockwell [22] identified the following criteria for a good measure of safety performance:

- **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.
- **Valid or representative to what is to be measured.** In the end one needs to measure accident risk; the likelihood of the occurrence of an 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.
- **Provide minimum variability when measuring the same conditions.** Any measuring device should read the same value under equal conditions.
- **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 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 changed.

- **Cost of obtaining and using measures is consistent with the benefits.** 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.
- **Comprehended by those in charge with the responsibility of using them.** As a general rule, the higher up in the chain of command, the less specialist knowledge is available. Therefore indicators that are being used by safety specialists should be different from those used by a general manager.

These characteristics must be valid for each indicator. The International Atomic Energy Agency (IAEA) adds a characteristic that must be matched by the set of indicators [23]:

- **The total set of indicators should remain manageable.** The set of safety performance indicators should not contain too many indicators rendering the management impracticable. The practical number of indicators depends on the size of the aviation system of the state and the funds available for state safety management.

3.3 The total aviation system

To ascertain a set of safety performance indicators represents the total aviation system a systematic approach is needed. Reason [24] describes an accident as a situation in which latent failures 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. 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. Since the holes determine the likelihood of an accident they can be considered as indicators of safety performance.

The term ‘barrier’ to describe a strategy for risk prevention is often linked to work by Haddon [25]. 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 [26].

A slight variation of the physical/non-physical categorization is the distinction between human, technology and organizational systems. The term “MTO” (Man-Technology-Organisation) was introduced in Sweden with the

intention to stimulate a comprehensive view on nuclear safety [27]. Because aviation is a more distributed system than a nuclear powerplant and has more (types of) stakeholders, the class 'system of organizations' is added to cater for those barriers that exist on the interfaces between organizations. This paper focuses on safety performance indicators to measure the proper functioning of the system of organizations.

3.4 Leading and lagging indicators

The ICAO Safety Management Manual (SMM) [28] defines three methodologies for identifying hazards. For each methodology safety performance indicators can be defined resulting in different types of indicators. The three methodologies are:

- a) **Reactive.** This methodology involves analysis of past outcomes or events. Hazards are identified through investigation of safety occurrences. Incidents and accidents are clear indicators of system deficiencies and therefore can be used to determine the hazards that either contributed to the event or are latent.
- b) **Proactive.** This methodology involves analysis of existing or real-time situations, which is the primary job of the safety assurance function with its audits, evaluations, employee reporting, and associated analysis and assessment processes. This involves actively seeking hazards in the existing processes.
- c) **Predictive.** This methodology involves data gathering in order to identify possible negative future outcomes or events, analysing system processes and the environment to identify potential future hazards and initiating mitigating actions.

Indicators associated to reactive processes are often called lagging indicators. In some documentation (e.g. [29]) precursor indicators are used as additional indicator type. These indicators measure events that are precursors to major accidents, e.g. unstable approaches, level busts, and engine shut-downs. The breakdown into lagging indicators and precursor indicator is not deemed useful since both measure past events during flight. Furthermore, using such a breakdown implies that true leading indicators measure only accidents. In the current extremely safe air transport system such indicators are not a meaningful measure of safety performance.

Both proactive and predictive processes can be measured using leading indicators. They are leading in the sense that they measure safety before any event in the actual operation needs to take place. This makes them a very useful tool for safety improvement, because mitigating measures can be realized before any harm takes place. This could potentially result in a significant improvement of safety, i.e. a significant reduction of the probability of an accident. Lagging indicators are mostly very straightforward and widely used. Leading indicators are relatively new. To fully use the potential of leading indicators research is required to establish the relation between the indicator and accident risk.

4 Safety performance indicators for system of organisations

4.1 The system of organisations

The aviation system can be considered as a system of organisations in the sense that several different organisations cooperate to achieve an overall objective that 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 1 gives an overview of groups of stakeholders, with a few example stakeholders per group indicated [30].

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. 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.

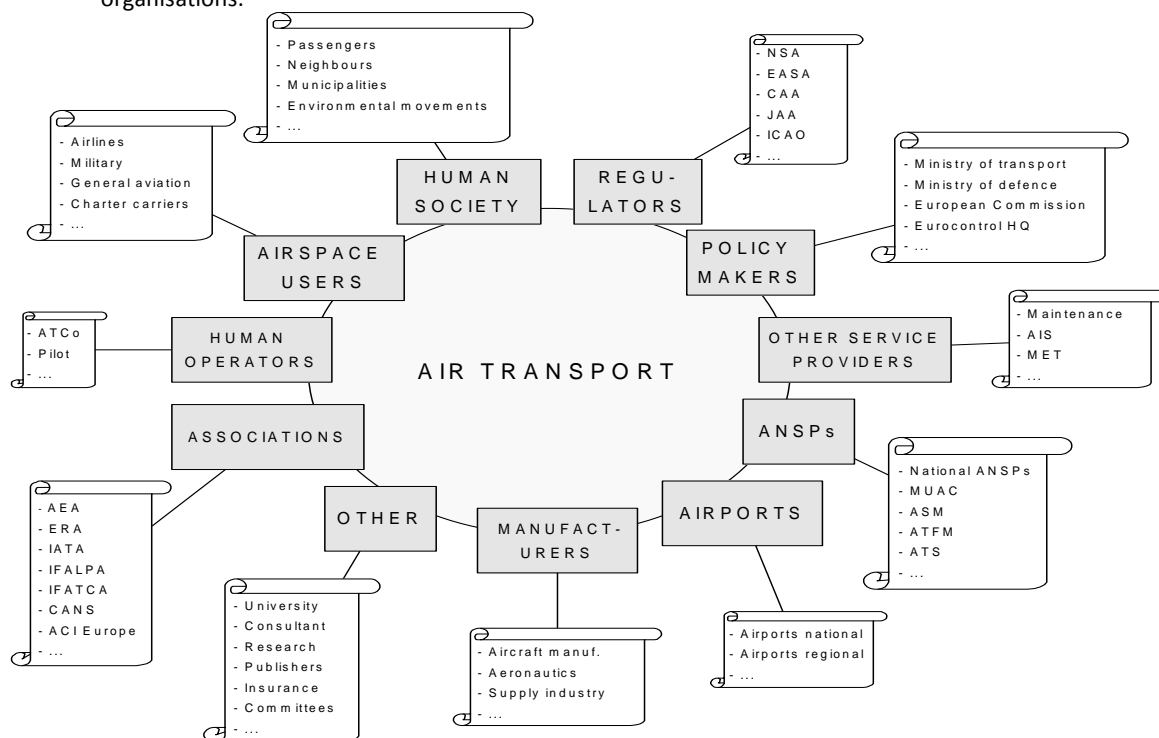


Figure 1: stakeholders in the air transport system

4.2 Definition and selection of safety performance indicators

In ASCOS [6] various safety performance indicators are defined per element for a properly functioning system of organisations. These indicators are scored against the six criteria for good safety performance measurement. The following scoring categories are used:

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

A final set of safety performance indicators is selected from the initial set based on the score. The indicators that are selected are those that:

- At least match 2 of the 6 criteria easily, and;
- Can in theory match every criterion (i.e. if effort is invested into the development).

In the following sections the final set of safety performance indicators is introduced. It will be discussed what kind of effort is still required to assure the indicator matches all six criteria. If for a specific indicator a criterion is not discussed it can be assumed that that criterion is easily matched.

Per element a list of indicators is given including a rationale behind the indicators. It is also indicated which EASp operational issue (OI) can be associated with the safety performance indicator. The OIs are:

- Runway excursion (RE)
- Mid-air collision (MAC)
- Controlled flight into terrain (CFIT)
- Loss of control in flight (LOC-I)
- Runway incursions (RI)
- Fire, smoke and fumes (F-NI)

For some indicators multiple OI are applicable. To assure applicability of only one OI such indicator can be further detailed using for example the specific flight phase for which the indicator is used. So if an indicator can be associated to both runway excursions and loss of control in flight the indicator can be split up in those applicable to take-offs and landing and those applicable to en-route. Some indicators capture an aggregate level of safety performance, for those indicators all operational issues are valid.

In Europe acceptable means of compliance and guidance material are drafted for the implementation and measurement of safety Key Performance Indicators [13, 14]. It is noted that it is not yet determined if the SPI introduced below comply with the European guidance material. It is recommended to do so.

4.2.1 Safety performance indicators for the interfaces

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. Table 1 lists safety performance indicators for measuring safety performance at the interfaces between organisations.

Table 1: Safety performance indicators for interfaces between organisations

Name of indicator	Rationale	EASp OIs
System combined runway incursion rate	Runway incursions involve the interface of the operation of aerodromes, aircraft operators and air traffic management.	RI
System combined airprox rate	Airproxes involve the interface of the operation of aircraft operators and air traffic management.	MAC
Operator combined erroneous weather prediction rate	Erroneous weather predictions can affect an aerodrome, ANSP and aircraft operator, but are the responsibility of meteorological services.	RE, LOC-I
System combined bird strike rate	Bird strikes involve the interface of operations of aerodromes, aircraft operators and air traffic management.	RE, LOC-I

Effort required to match criteria

All indicators that measure the safety performance at the interfaces between organisations easily match the criteria. The suggested safety performance indicators are straightforward lagging indicators. It is recommended to properly define what is meant with an erroneous prediction of weather.

4.2.2 Safety performance indicators for interactions

Besides the measurement of safety performance using lagging indicators, one can also measure the interactions between organisations with leading indicators for a more proactive approach. The importance of proper interaction between aviation stakeholders is long known, which is for example demonstrated by a 1965 accident report (BAC 1-11 deep stall accident in 1963) which 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 [31]. Table 2 lists safety performance indicators for measuring the interaction between organisations.

Table 2: Safety performance indicators for measuring the interaction between organisations

Name of indicator	Rationale	EASp OIs
Total number of formal safety related meetings involving at least two different types of organisations (e.g. an aerodrome and ANSP) per year	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.	All
Total number of formal meetings of network of analysts to discuss safety performance measurement	A Network of Analysts (NoA) can facilitate the development and continuing improvement of harmonized safety performance indicators used by	All

	<p>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).</p>	
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Effort required to match criteria

The two indicators suggested for interactions are clearly easily quantifiable and comprehensible. It is difficult however to validate that it is representative as measurement for accident risk. 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 (i.e. in this case the interaction between stakeholders) and accident risk. It is not unreasonable to assume there is a positive relation between a correct functioning system of organisation and aviation safety. Effort is required to validate that positive relation.

4.2.3 Safety performance indicators for 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 one operator or multiple operators. During the many years of operation maintenance, repair and overhaul 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 3 lists the safety performance indicators for the measurement of the proper and continuous safety performance over specific lifecycles.

Table 3: Safety performance indicators for measurement continuing safety performance over a lifecycle

Name of indicator	Rationale	EASp OIs
The safety impact of each significant airport infrastructural change is assessed and deemed acceptable before the actual introduction of the change	Indicator to monitor if the safety impacts of (technical) infrastructural changes to airports are assessed (e.g. taxiway layout, new holding points etc.) to assure safe operation of the airport throughout its lifecycle and to disseminate lessons learnt.	RE, RI
The actual safety impact of each significant airport infrastructural change is evaluated at most after 3 years of implementation of the change	Indicator to assure that it is evaluated if initial safety impact assessments were appropriate. This evaluation can result in lessons-learnt to assure continuous improvement of safety assessments throughout the lifecycle.	RE, RI
The safety impact of each significant aircraft modification is assessed and deemed acceptable before the	Indicator to assess the impact of design changes of existing aircraft (modifications, new engines, retrofits) on operator safety performance to assure safe operation of	All

actual introduction of the modification	the aircraft throughout its lifecycle and to disseminate lessons learnt.	
The actual safety impact of each significant aircraft modification is evaluated at most after 3 years of implementation of the modification	Indicator to assure that it is evaluated if initial safety impact assessments were appropriate. This evaluation can result in lessons-learnt to assure continuous improvement of safety assessments throughout the lifecycle.	All
The safety impact of each significant ATM provision modification is assessed and deemed acceptable before the actual introduction of the modification	Indicator to monitor the safety impact of changes to ATM (e.g. new radar, new software) to assure safe operation of ATM throughout the lifecycle and to disseminate lessons learnt.	MAC, CFIT, RI
The actual safety impact of each significant ATM provision modification is evaluated at most after 3 years of implementation of the modification	Indicator to assure that it is evaluated if initial safety impact assessments were appropriate. This evaluation can result in lessons-learnt to assure continuous improvement of safety assessments throughout the lifecycle.	MAC, CFIT, RI
The safety impact of an aircraft flying under an outdated certification scheme is assessed after each significant change in certification rules	Indicator to measure the safety impact of aircraft that are operated using an out-dated certification regime (grandfather rights) to assure safe operation of the aircraft throughout its lifecycle and to disseminate lessons learnt.	All
A proper means to identify future risks is set-up and altered when deemed necessary	Indicator to measure if an appropriate method to identify future emerging risks is set-up to assure proper safety performance proactively.	All
Future risks are identified on a regular basis (at least each year new risks should be identified) using a dedicated means to do so	Indicator to measure if future risks are identified on a regular basis to assure the proper and continuous safety performance.	All

Effort required to match criteria

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 or false, this makes quantification straightforward and makes them comprehensible and cost-efficient. Most efforts will be required not in using the indicators but in developing the proper techniques to assess and evaluate changes, and to identify future risks.

4.2.4 Safety performance indicators for harmonization

ICAO Annex 19 [0] provisions are intended to harmonize the implementation of safety management practices for states and organisations involved in aviation activities.

Ref: Safety Performance Indicators in Aviation

Page: 19

Issue: 1.0

Classification: Public

Table 4 list safety performance indicators to measure the level of harmonization of the system of organisations.

Table 4: Safety performance indicators to measure the level of harmonization of the system of organisations

Name of indicator	Rationale	EASp OIs
A common risk classification framework is used by CAAs and industry (using the same criteria for likelihood and severity of events)	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.	All
The number of organisations that have fully implemented a Safety Management System (SMS) before the final transitional dates allowed.	Since an SMS is meant to harmonize safety management, the number of organisations that have implemented an SMS can be used as an indicator.	All
The average level of regulatory compliance of states (for example using ICAO USOAP CMA ¹ or EASA audits) should be measured every three years and should increase every three years	As a measure of overarching harmonization between states the average level of regulatory compliance with EU regulations and ICAO provisions can be monitored.	All

Effort required to match criteria

It will require effort to validate the positive relation between a harmonized system and the avoidance of accidents, and to determine proper measurements to quantify issues such as regulatory requirement. To assure sensitivity to changes in harmonization levels measurement must be done frequently increasing costs of obtaining the results; a proper balance needs to be found. The indicator measuring the number of organisations that have fully implemented a Safety Management System is only valid up until the final transitional date.

4.3 Quantification

The indicators used to measure the functioning of interfaces between organizations are mostly based on safety occurrences (e.g. accidents, serious incidents, occurrences etc.). Simply counting the number of safety occurrences 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 is considered to be the most appropriate for normalisation of lagging indicators. Quantification of a particular safety performance indicator then requires counting the number of occurrences

¹ universal safety oversight audit programme continuous monitoring approach

Ref: Safety Performance Indicators in Aviation**Page:**

21

Issue: 1.0**Classification:**

Public

of the event described by the indicator as well as the associated number of flights. Data availability is therefore obviously an important issue.

For leading safety performance indicators there is no common recipe for normalisation and for some of the indicators suggested in this paper normalisation is very straightforward, e.g. counting meetings per year and assuring safety assessments are done per opportunity to do so. Clearly, 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.

5 ASCOS perspective

Within ASCOS, the development of a framework of safety performance indicators is not an isolated effort but is interconnected with the development of a baseline risk picture for aviation, a process for safety performance monitoring and the development of associated tools.

Significant improvement of safety can only be realised if the priorities are focused on areas that provide the highest contribution to risk. It is imperative that States and organisations remain focused on their safety priorities. Therefore, specific activities in ASCOS are aimed at developing a capability to perform a risk evaluation of the total aviation system and the identification of safety priorities through the creation of a baseline risk picture for Europe.

The baseline risk picture is obtained by expanding the safety performance indicators into a causal risk model that formally represents the causal and statistical associations between the safety performance indicators and accident probabilities for various accident scenarios. The model can then be used to estimate the accident probability based on the safety performance indicator values, thereby providing a baseline risk picture. Safety priorities can be established by considering the contribution of the various accident scenarios to the baseline risk picture.

The system of safety performance indicators and the causal risk model only provide a snapshot view of safety. In order to be useful in support of continued operational safety there must also be a process for continuous safety monitoring. By using data that is continuously gathered through flight data monitoring and occurrence reporting to feed the safety performance indicators and subsequently the causal risk model, the risk picture is constantly updated and safety priorities can be reallocated if required.

Currently the tools to collect and process data for continuous safety monitoring are not yet fully developed. Software for flight data monitoring is available and extensively being used by the airlines, but the capabilities to integrate information from various sources is limited and in Europe there is not yet a system in place like the Aviation Safety Information Analysis and Sharing (ASIAS) in the US that collects, stores and analysis raw flight data for the purpose of flight safety. On the other hand, the development of ECCAIRS and Directive 2003/42/EC on occurrence reporting in civil aviation [0] provides a firm basis for developing tools for collection and analysis of data. From this basis ASCOS will develop tools for integration and analysis of flight and occurrence data at a European level to support continuous safety monitoring.

6 Conclusions and recommendations

The main results documented in this paper are safety performance indicators valid for the system of organizations in aviation. These safety performance indicators are important because they measure the proper functioning of the barriers that exist on the interfaces between organizations.

Safety performance indicators are drafted for (1) the safety performance at interfaces between organisations, (2) the level of interaction, openness and sharing of information between different stakeholders, (3) the safety performance of an air transport system throughout its lifecycle, and (4) the level of harmonization in the approach to safety performance management activities at different organisations.

The main goal of aviation safety performance indicators is to provide an indication of the probability of an accident. This can be done using lagging and leading indicators. The total set of indicators should remain manageable. Each individual indicator should match the following criteria:

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

The suggested lagging safety performance indicators match these criteria. For leading indicators it needs to be validated that they are representative as measurement for accident risk. In general it can be said that it is not unreasonable to assume there is a positive relation between a correct functioning system of organisation and aviation safety. Effort is required to validate that positive relation. Some of the indicators suggested are Boolean; they are either true or false. Boolean indicators are straightforward to quantify, comprehensible and cost-efficient. To assure sensitivity to changes safety performance measurement must be done frequently increasing costs of obtaining the results; a proper balance needs to be found. It is recommended to determine if the SPI introduced in this paper comply with the European guidance material on safety Key Performance Indicators.

A baseline risk picture can be obtained by expanding the safety performance indicators into a causal risk model that formally represents the causal and statistical associations between the safety performance indicators and accident probabilities for various accident scenarios. The system of safety performance indicators and the causal risk model only provide a snapshot view of safety. In order to be useful in support of continued operational safety there must also be a process for continuous safety monitoring.

Ref: Safety Performance Indicators in Aviation
Issue: 1.0

Page: 24
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