Key elements to avoid drifting out of the safety space

Ivonne Andrade Herrera[1] and Ranveig Kviseth Tinmannsvik[2]

[1] The Norwegian University of Science and Technology (NTNU), Department of Production and Quality Engineering, NO-7491 Trondheim, Norway
Ivonne.A.Herrera@ntnu.no
[2] SINTEF Technology and Society, Department of Safety and Reliability, NO-7465 Trondheim, Norway
Ranveig.K.Tinmannsvik@sintef.no

Abstract. The paper is based on the experience from the development and application of safety performance indicators made in cooperation with the Norwegian and Swedish Civil Aviation Authorities. The following, two main categories of safety performance indicators are discussed: outcome-based indicators (reactive indicators; measuring the outcome/ result after a loss has happened) and activity-based indicators (proactive indicators; measuring efforts to prevent accidents). The paper presents a summary of the application of safety performance indicators to assess the management of safety in aviation maintenance. Lessons learned regarding the utilization of these safety performance indicators are presented. The paper looks critically into how the indicators are used and the conclusions that may be achieved. The paper will look into safety performance indicators and how they can contribute as indicators for resilience.

1 INTRODUCTION

The Accident Investigation Board/Norway (AIBN) has presented a study regarding the relation between concurrent organizational changes and safety (AIBN, 2005). The paper discusses the following question: How do we identify when we are drifting out of the safety space? The main objective is to discuss how performance indicators can contribute to control safety and resilience.

Recent development of the aviation industry regarding deregulation, cost reduction and increase of low cost carriers, demands the industry to be more effective and save costs. Another aspect is the tendency to subcontract activities, and the airlines may face the challenge of having to take decisions based on fragmented information. Even if the aviation industry is very safe, there is a general concern regarding cost reduction and safety. Aviation safety records show a stable accident rate while there is a concurrent increase in the number of passengers. The forecast accident rate worldwide for commercial aviation is one aircraft accident per week by 2010. In this context, maintenance errors are estimated to contribute 12% to major airline aircraft accidents and 50% to engine-related flight delays (Patankar, 2004).

The AIBN study recommended to develop more risk based supervision sustained by personnel with the relevant expertise (AIBN, 2005). In aviation, risk analyses are performed mainly by the manufacturer during the development phase of the aircraft, and this is the basis for the initial aircraft maintenance program. The initial maintenance program is delivered to the operators who are responsible for the development and update of this program in close cooperation with the manufacturer. Even if experience from the operators is taken into account in the definition phase, aviation still suffers from little research regarding risk informed operations.

As a consequence of a continuous conflict between safety and production, resilience has emerged as a new field to develop tools that include human and organizations factors to manage risk proactively. In the context of resilience engineering, it has been pointed out a need to develop resilience indicators. The paper is based on the experience from the development and application of safety performance indicators made in cooperation with the Norwegian and Swedish Civil Aviation Authorities. Lessons learned regarding the utilization of these safety performance indicators is presented. The paper looks critically into how the indicators were used, on the conclusions that can be achieved and it ends with a discussion regarding safety performance indicators and their contribution to risk informed organizations and resilience.

2 MONITORING RESILIENCE

Resilience is defined as the ability of an organization (system) to keep, or recover quickly to, a stable state, allowing it to continue operations during and after a major mishap or in presence of continuous significant stresses (Wreathall, 2006). Another definition of resilience is the ability of the systems to prevent or adapt to changing conditions in order to maintain a system property (Leveson et al, 2006). Application of resilience definition to aviation: "The capacity of the airline to continue safe operations in the face of unexpected threats or hazards including the occurrence of human errors and violations" (Wood and Dannatt, 2006). Resilience definitions include looking into the past, looking into the present (learning about normal operations) and be mindful to be able to cope with the next hazard.

Characteristic of resilience relates to how the organization acts in relation to safety-production goal conflict. Monitoring resilience involves properties such as kinds of disruptions that the system can adapt without a breakdown, systems abilities to restrict itself to response to external changes or conditions or pressures, how closely the system operates to the performance boundary, and how the system behaves near such a boundary (Woods, 2006).

Aviation maintenance could illustrate these characteristics; we could have an aircraft on ground due to technical problems, then the maintenance organization expertise from different areas work together to solve this problem, together taking the appropriate decisions to return the aircraft into operation. Due to organizational changes, the maintenance organization sometimes comprises various subcontractors; in this case the decisions involve several actors in the decision-making process, which complicates the dynamics and affects the organizations ability to maintain a normal situation. So there is a risk that the decision making process is based on a fragmented picture.

The monitoring of resilience requires both reactive and proactive parameters (indicators), which help the decision makers to detect and monitor changes in an organization which experience continuous pressure for production and safety. These indicators should describe e.g. how the organization deals with safety/production conflict, its management commitment, reporting culture, learning culture, preparedness/anticipation and flexibility.

There are tools already developed that could be applied or are applied to assess resilience. The Accident Risk Assessment Methodology for Industries in the context of Seveso II (ARAMIS) project developed a method to audit the Safety Management System and a questionnaire to measure the safety culture of an organization. It has been expressed that these two subjects are the main contribution of ARAMIS to resilience (Hale, 2006). Reason & Hobbs (2003) developed a check list for Transport Canada based on Check List for Assessing Institutional Resilience (CAIR) to assess safety culture, and the Australian Safety Bureau performed an assessment of resilience in 12 airlines, and recommendations are provided to improve the assessment of institutional resilience. The audits and check lists provide "snapshots" of the status of the organization, while the use of indicators could provide monitoring of changes and trends in the organization. Thus, these two approaches complement each other.

To address the fact that there are changes in risk with time, the Organizational Risk Influence Model (ORIM) presents a framework for the establishment of risk indicators including a risk control tool that measure the risk level of an offshore installation (Øien, 2001). This tool covers the technical, operational and organizational factors important to risk.

3 INDICATORS AS A NAVIGATION AID FOR FLIGHT SAFETY

3.1 Development of safety performance indicators

The development of performance based indicators for flight safety was done as part of the AIBN study in Norway (AIBN, 2005). The main focus of the work was flight safety, i.e. safety for passengers. SHE (Safety, Health and Environment) conditions for the employees in aviation were considered as relevant only if they were supposed to have a direct influence on passenger safety. Neither was *security* problems included in the study.

Safety performance indicators are usually established in order to monitor changes in factors influencing safety over a specific period of time. Another use of performance indicators is to estimate changes in risk level. The present study had, however, no ambitions for the latter application. Kjellén (2000) presents an overview of different SHE performance indicators, based on a framework for accident analysis:

1. *Loss*-based SHE performance indicators (e.g. the lost-time injury frequency rate, LTI-rate)

2. *Process*-based SHE performance indicators (e.g. the number of near accidents per year)
3. *Causal factor*-based SHE performance indicators (e.g. indicators based on information about contributing factors and root causes; similar to questions in safety audits).

It may be difficult to distinguish between indicators of category 1 and 2, as well as between category 2 and 3. An alternative categorization is therefore between (a) *outcome*-based indicators and (b) *activity*-based indicators:

In the following, two main categories of safety indicators have been discussed:

a) *Outcome*-based indicators (***reactive indicators***; measuring the outcome/ result after a loss has happened)
b) *Activity*-based indicators (***proactive indicators***; measuring efforts to prevent accidents).

Outcome-based indicators measure the frequency of injuries/near accidents (injury frequency rate, FAR – fatal accident rate); while activity-based indicators measure efforts to reduce injuries/losses (e.g. backlog in implementing safety measures, frequency of emergency response drills). In the AIBN study, 43 performance indicators for flight safety were put forward; 5 outcome-based and 38 activity-based indicators, respectively. The activity-based indicators were defined within the following main groups: (1) external audits (by authorities); (2) internal audits (company level); (3) emergency; (4) competence, training and experience; (5) work load; (6) maintenance; and (7) economy/ investments (Tinmannsvik, 2005). Examples of safety performance indicators for maintenance operations are shown in chapter 3.2.

The full list of 43 performance indicators were too much to handle in the project, therefore there was a need to distinguish between indicators that were supposed to be (1) very important in monitoring trends in flight safety (*dark grey colored*), (2) of average importance (*light grey colored*) and (3 no color) of minor importance for flight safety monitoring (*no color*).

The development of indicators, as well as the splitting in three groups according to their expected importance for flight safety monitoring, were based on safety audit checklists and discussions with experienced people in the civil aviation authorities in Norway, as well as in Sweden.

3.2 Indicators in practice – a maintenance case

A combination of performance indicators (proactive and reactive) was applied (AIBN, 2005) to assess the management of safety in five maintenance organizations. Table 1 gives a subset of the reactive indicators (R) and the proactive (A) indicators that are very important and on average importance in monitoring maintenance trends related to flight safety.

Table 1. Indicators for monitoring trends in maintenance organizations

Nr	Indicator	Comment
Reactive indicators (R)		
R1	Accident rate: Number of accidents per 100.000 Flight Hours (FH)	This is in accordance to ICAO Annex 13 accident definition
R2	Serious incidents rate: Number of serious incidents per 100.000 (FH)	This is in accordance to ICAO Annex 13 accident definition
R3	Deviations rate: Number of reported deviations, disturbances per year	This indicator should be careful interpreted, it could say something about improvements related to reporting culture
R4	Loss time injury frequency rate (LTI-rate): Number of injuries per 1 million working hours	It is recommended to divide per group of employees, Line Maintenance, Heavy Maintenance, Planning, Engineering, Logistics etc
R5	Sick leave (%): Number of days off (due to illness) per year in relation to total number of working days * 100%	
Proactive indicators (A)		
Internal and external audits		
A1	Number of internal and external audits per year	Different types of audits, management audits, system audits, inspections
A2	Number of deviations identified during audits per year	This indicator should be careful interpreted, it could say something about: a) organization safety level b) audit quality and effectively
A3	Number of dispensations requested to the authorities per year	
Competence, training & experience		
A4	Number of continuation or recurrent training per technician per year	This indicator need to be interpreted in relation to aviation requirements
A5	Number of certified personal per type of certificate per station per year	
Maintenance program		
A6	Part of maintenance program that is based on in service experience, internal company requirements (in addition to manufacturer recommended maintenance program)	It includes collection of information regarding development of maintenance intervals
A7	Back-log (Hold Item List) per aircraft type per 100.000 FH	This indicator should be analyzed together with the amount of dispensations requested per year
Corrective Maintenance		
A8	Minimum Equipment List (MEL) reports per aircraft type per 100.000 FH	This indicator should be analyzed together with the amount of dispensations requested per year

Nr	Indicator	Comment
Economy		
A9	Fleet age per aircraft type	Indicates where the airline is located in relation to the technological development and safety equipment installed
A10	Number of aircraft types	Aircraft type diversity implies more resources for equipment, spares, training and competence
A11	Number of implemented safety measures per year	Indicates the organization commitment to accomplish safety recommendations

Information was gathered from three airlines and two helicopter operators for a 2000-2004 period (Herrera et al, 2006). One of the problems while collecting the information is that even some definitions are standard in the aviation industry, the different operators may have different interpretations for the same term; e.g. it was not possible to gather data regarding trends in maintenance costs. It was also noticed that the operators mainly collect and analyze information that is required by the regulators. Information not required by regulators, even if available, was not used proactively in the management of safety. Indicator A3 "Number of dispensations requested to the authorities per year" illustrates this aspect. The operator requests a dispensation to the Civil Aviation Authority to continue operations when an abnormal situation occurred and the operator have to prove that the airworthiness of the aircraft is not affected to continue operation. In our case operators archived information about dispensations but did not use the information to monitor trends.

After the information was gathered and analyzed, there were discussions with maintenance personnel to verify the validity of the results. Indicators showed changes in staff, movements between companies, changes in levels of qualification and training and changes related to the maintenance program.

The indicators in our case study showed that the recurrent maintenance training has been reduced. They also showed that the constant pressure to reduce costs without affecting safety had an impact in reducing the maintenance program to the minimum acceptable level in some cases.

Conclusions from the AIBN study confirmed that the operators have systems in place to follow-up and analyze reactive indicators, but there is still a need to gather information and analyze proactive indicators.

4 DISCUSSIONS AND FURTHER WORK

Based on experience from the current study, it is evident that aviation is very strong regarding reactive indicators. To achieve robust conclusions regarding trends in safety performance indicators, data collection should be run for a long period of time; AIBN study demonstrated that 5 years is not sufficient. Conclusions concerning a potential drifting towards safety boundaries should however not be based only on performance indicators, but on a combination of quantitative and qualitative approaches.

The innovative aspect of the indicators proposed in this paper is the use of reactive, as well as proactive indicators to monitor trends related to normal operations in the aviation industry. Regarding the relationship between indicators used in the AIBN study and resilience, we could conclude that indicators such as Minimum Equipment List and Backlog have direct relation to how the organization handles the conflicts between safety and production. Indicators related to economy and implementing safety measures have direct relation to the management commitment to safety. For the future development of resilience indicators, we suggest indicators measuring the organization's ability to recover from serious deviations into stable state. Information from near misses, incidents that were overcome and ended up successfully, would be valuable data for such indicators.

A further work could include adaptation of indicators into the maintenance process, ensuring that indicators are embedded in the maintenance management system; (1) maintenance policy; (2) maintenance concept; (3) corrective maintenance; (4) preventive maintenance; (5) maintenance tasks, engineering orders; (5) planning, resource allocation; (6) scheduling work; (7) execution of work (including safety job analysis prior to perform the task); (8) inspection; (9) reporting, analysis and improvements (adapted from Hale et al., 1998). This adaptation should take into account the safety boundaries and from a resilience perspective be able to identify small changes that could affect safety.

ABBREVIATIONS

AIBN	Accident Investigation Board / Norway
ARAMIS	Accident Risk Assessment Methodology for Industries in the context of Seveso II
CAIR	Checklist for Assessing Institutional Resilience
FAR	Fatal Accident Rate
ICAO	International Civil Aviation Organization
LTI	Lost-Time Injury
ORIM	Organizational Risk Influence Model
SHE	Safety, Health and Environment

ACKNOWLEDGEMENT

The authors would like to thank the contribution from the Norwegian and Swedish Aviation Authorities to develop the safety performance indicators.

The authors acknowledge senior research scientist Per Hokstad at SINTEF and professor Jørn Vatn at NTNU for their valuable comments during the elaboration of the paper.

REFERENCES

AIBN, Accident Investigation Board / Norway (2005). Safety in Nowegian Aviation during the Process of Change. Lillestrøm, Norway

ARAMIS Project – Fifth Framework Program of the European Community, Energy, Environment and Sustainable development. Contract number: EVG1-CT-2001-0039. December 2004 (pp 47-52) http://aramis.jrc.it

Hale, A., Guldenmund, F. & Goossens, L (2006). Auditing Resilience in Risk Control and Safety Management Systems Resilience Engineering Concepts and Precepts, edited by Hollnagel, E. et al. (pp. 199-325). Ashgate, Alsershot, USA

Hale, A., Heming, B., Smit, K., Rodenburg, F. & Leuwen, N. (1998). Evaluating safety in the management of maintenance activities in the chemical process industries, Delft University of Technology, Netherlands

Herrera, I.A. (2006). Aviation safety and maintenance under major organizational changes, investigating a non existing accident. ESREL conference 2006 September 18-21, Estoril, Portugal

Kjellén, U. (2000). Prevention of Accidents Through Experience Feedback (pp. 226-261). Taylor & Francis, London, UK

Leveson N. et al. (2006). Engineering Resilience into Safety-Critical Systems, Resilience Engineering Concepts and Precepts, edited by Hollnagel, E. et al. (pp. 95-122). Ashgate, Aldershot, USA

Reason, J. & Hobbs, A. (2003). Managing Maintenance Error (pp. 159-175) Ashgate, Aldershot, USA

Tinmannsvik, R.K. (2005). Ytelsesindikatorer for flysikkerhet - noen resultater fra svensk luftfart, (Performance based indicators for flight safety - some results from Swedish aviation). SINTEF, Trondheim, Norway

Patankar, S. & Taylor, J. (2004). Risk Management and Error Reduction in Aviation Maintenance (pp. 2-25) Ashgate, Aldershot, USA

Wood, M & Dannatt, R. (2006). Assessing Institutional Resilience, A useful guide for airline safety managers? (pp. 35-45). Canberra, Australia

Woods, D. (2006). Essential Characteristics of Resilience, Resilience Engineering Concepts and Precepts, edited by Hollnagel, E. et al. (pp. 21-35). Ashgate, Aldershot, USA

Wreathall, J. (2006). Property of Resilient Organization: An Initial View, Resilience Engineering Concepts and Precepts, edited by Hollnagel, E. et al. (pp. 275-285). Ashgate, Aldershot, USA

Øien, K. (2001). Risk Control of Offshore Installations. A Framework for the Establishment of Risk Indicators, NTNU report 200104, Norway (pp.1-48)