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AGA/AOP/SG/6-WP/24

13/05/08

Agenda Item 3: Review of AGA Deficiencies

3.5 Aerodromes Certification/Safety Management Systems (SMS)

AIRPORT SAFETY MANAGEMENT SYSTEMS AND PERFORMANCE INDICATORS

(Presented by the Secretariat)

SUMMARY

This working paper presents a methodology to estimate Individual and Overall Performance Indicators to evaluate the “health” of airport SMS.

The development of this approach was based on surveys carried out with the SAM States and airport operators of this Region and it was presented at the 87th Annual Meeting of the Transportation Research Board, carried out from 13 to 17 January 2008, in Washington, D.C. A copy of this paper is in the Appendix to this WP.

References:

- Annex 14, Volume I, Aerodromes - Aerodrome Design and Operations, Fourth Edition, July 2004;
- Doc 9774-AN/969, Manual on Certification of Aerodromes, 1st Edition, 2001;
- Doc 9589, AN/460, Safety Management Manual (SMM), 1st Edition, 2006;
- State Letter AN 12/46-06/52, of 30 June 2006; and
- Surveys through State Letters from ICAO Regional Offices.

1. Introduction

1.1 Chapter 1 of Annex 14, Volume I, 4th Edition, in its Section 1.4, “Certification of Aerodromes”, requires as a standard, as of 27 November 2003, that States shall certify aerodromes used for international operations in accordance with the specifications contained in this Annex, as well as other relevant ICAO specifications, through an appropriate regulatory framework. In addition, the same Section establishes that, as of 24 November 2005, a certified aerodrome shall have in operation a safety management system.

1.2 Since then, ICAO has been preparing guidance material on SMS implementation, such as the Doc 9589-AN/460 published in 2006 and the 11 editions (versions) of its official SMS course. A remarkable progress has been achieved in this sense.

1.3 One of the aspects that still need to be addressed is how to evaluate the performance of an airport SMS. This working paper aims at presenting a very simple and flexible methodology to be used by the States/Territories and airport operators, as it is discussed in the next item.

2. Discussion

2.1 Based on the ICAO guidance material, the States/territories shall require, as part of their safety programme, that a certified aerodrome operator implements a safety management system acceptable to the State that, as a minimum:

- a) identifies safety hazards;
- b) ensures that remedial action necessary to maintain an acceptable level of safety is implemented;
- c) provides for continuous monitoring and regular assessment of the safety level achieved; and
- d) aims to make continuous improvement to the overall level of safety.

2.2 In addition, a safety management system shall clearly define lines of safety accountability throughout a certified aerodrome operator, including a direct accountability for safety on the part of senior management.

2.3 Over fifty countries have already received the ICAO official SMS course. Between 2006 and 2007, fourteen courses and one regional course were delivered in South America. In addition, three other courses are planned to be delivered until the end of 2008. ICAO, through the SAM Regional Office, started training the States/Territories and the airport industry on SMS implementation since March 2005. As a consequence of this initiative, among others, five international airports have already implemented SMS: three in Bolivia in November 2005, one in Peru and one in Ecuador in March and August 2006, respectively.

2.4 As indicated in item c) of paragraph 2.1, the SMS should be continuously monitored and assessed in order to check the safety level achieved. The only and best way to accomplish this task is the application of performance indicators.

2.5 The **Appendix** to this working paper provides the methodology developed in the SAM Region through several surveys carried out with the States/Territories and airport operators. Thirty individual performance indicators are presented. The appendix also presents a very simple and straightforward approach to estimate the overall performance indicator based on the individual performance indicators for a particular airport.

3. Suggested action

3.1 The Meeting is invited to take note, review and comment on the information provided in the Appendix to this working paper.

APPENDIX
TRANSPORTATION RESEARCH BOARD
2008 TRB 87th Annual Meeting

**Methodology to Estimate Individual and Overall Performance Indicators for Airport
Safety Management Systems (SMS)**
(Paper Number 08-0197)
(6209 words, 4 figures and 2 tables)

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Methodology to Estimate Individual and Overall Performance Indicators for Airport Safety Management Systems (SMS)

Abstract

Safety is an intrinsic component of Civil Aviation. Besides the key aspects of technical and human performance, the concept of organizational accidents, developed in the 90's, should also be taken into consideration in contemporary safety endeavors. This concept considers not only the active failures of individuals involved in the front line operations (the triggers of accidents) but also the latent conditions inevitably present in any business. Since November 2005, ICAO (International Civil Aviation Organization) requires that a certified airport have a Safety Management System (SMS) in operation. It is recognized that any airport SMS performance needs to be monitored not only by outcome measures (i.e., number of accidents and loss of life) but also by its potential to identify and address latent conditions. This paper presents a methodology to estimate Individual Performance Indicators (IPIs) and Overall Performance Indicators (OPIs) for airport SMS focusing on the latent conditions and "near-miss" events at/on airports. Based on the information on airport operations and aviation safety gathered by the authors, a list of potential IPIs was developed and validated by airport operators in South America according to ten priority groups. Weights from 10 to 1 were assigned to each group from the highest to the lowest priority. This methodology assumes that the IPIs should be limited to one-year periods, but averaged/estimated for 10,000 aircraft operations. The calculation of the OPI for a particular year is 10^{-2} times the sum of the IPIs measured/established for that year multiplied by their respective weights.

Introduction

Many industries around the world have been implementing Safety Management Systems (SMS) during the last three decades. Recently, it has been recognized that SMS is also a powerful tool to improve airport/aircraft safety. In this regard, ICAO (1) considered the implementation of SMS by airport operators as a standard since November 2005. Initiatives in this direction have already been taken by several State Agencies, such as, among others, CASA (Civil Aviation Safety Authority) in Australia (2), FAA (Federal Aviation Administration/ACRP - Airport Council Research Program/Transportation Research Board) in the United States (3, 4), Transport Canada (5), United Kingdom Civil Aviation Authority (6, 7).

In 2006, ICAO published its Safety Management Manual (SMM) (8) and developed a one-week SMS Training Course to be delivered to all of its contracting States that may wish so. Over fifty countries have already received this course. Between 2006 and 2007, thirteen courses and one Regional Course were delivered in South America.

The SMS implementation by airport operators in this Region has advanced quite well. ICAO, through its Regional Office in Lima, Peru, started training the States and the airport industry on SMS implementation since March 2005 (9, 10). As a consequence of this initiative, among others, seven out of fourteen countries of the Region have already developed basic documentation for the SMS implementation and five international airports implemented SMS: three in Bolivia in November 2005, one in Peru and one in Ecuador in March and August 2006, respectively.

Not much can be found in the literature for the evaluation of airport SMS performance. Furthermore, this is an issue that needs to be urgently addressed.

The ICAO SMS framework (11) encompasses four main components: Safety Policy and Objectives, Safety Risk Management, Safety Assurance and Safety Promotion. Safety Performance Monitoring and Measurement are the main elements of the Safety Assurance component.

According to the European Transport Safety Council (12), there is a tendency to consider number of crashes or causalities as performance indicators in aviation. However, modern approaches consider not only the result of accidents or fatalities as indications of the level of safety in any industry branch but the latent conditions existent in any system, as described by Reason (13) and lately by Hansen and McAndrews (14).

Besides the latent conditions, Reason (13) also considers important and advantageous to collect and analyze “near-miss” events, defined as “any event that could have had bad consequences, but did not”. According to the same author, the term “near-miss” encompasses “near-miss” and incident events. Furthermore, it becomes clear that “near-miss” events are an indirect way to measure the organizational processes performance.

One of the main objectives of this paper is to focus on the SMS performance taking into consideration the latent conditions and the “near-miss” events that may exist at/on the airports. In this sense, it is assumed that individual and overall performance indicators are the main tool to be considered for monitoring and measuring the performance of any airport SMS.

The final objective of this paper was to develop a methodology to estimate Individual Performance Indicators (IPIs) and Overall Performance Indicators (OPIs) for airport SMS by using simple tools as a spreadsheet. To better understand the context of performance indicators, next item presents a very short overview on SMS for airports.

To accomplish this goal, the information systematically gathered on airport operations/safety by the first author since 2000, on aviation safety around the world by the second author and on safety at the interface airport/air traffic control by the third author, in South America, was the basis for the development of this investigation. This information was refined through the results of surveys carried out with States and airport operators in the South American Region.

SHORT OVERVIEW ON AIRPORT SMS

A SMS, as its name implies, must operate in a systemic way. Thus, it must encompass a series of consistent, integrated and documented policies, procedures and practices for the effective management of safety of any type of business (2).

According to ICAO (15), “Safety Management Systems are systems for the management of safety at aerodromes including the organizational structure, responsibilities, procedures, processes and provisions for the implementation of aerodrome safety policies by an aerodrome operator, which provides for the control of safety at, and the safe use of, aerodrome”.

More recently, ICAO (11) officially defined SMS as “a systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures”.

The wide spectrum of these definitions is represented by Figure 01, which suggests a structure for developing a SMS with nine sub-systems (9, 10), which are:

- SMS Policy and Philosophy;
- Definition of Responsibilities;
- Risk Management;
- Investigation and Adjustment of Activities with Risk above the target level;
- Training and Qualification of Personnel;
- Data Documentation and Control;
- Hazard/Risks Notification and Reporting of Actions Taken;
- Auditing of System Operation and Assessment of Incidents/Accidents; and
- Assessment of System Operation.

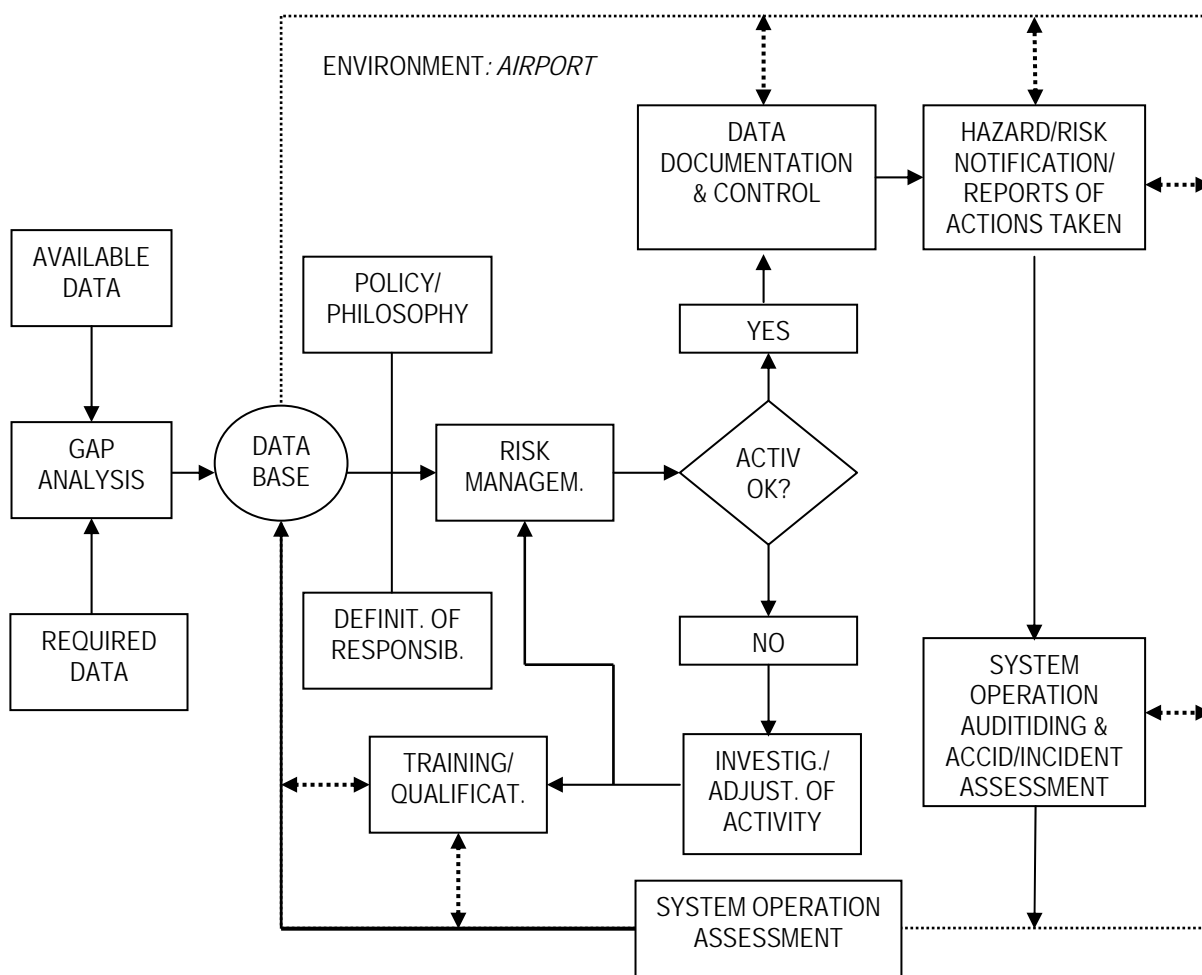


FIGURE 1 SMS implementation and its subsystems (9, 10).

Operation of a SMS as Indicated by Figure 1

In general and very simple terms, the SMS for a given airport, as described in Figure 01, should work as follows:

- The first step is to carry out a gap analysis by checking the airport available information against the international and national safety requirements. This information will allow the development of the SMS database. According to the reference (3), “Gap Analysis is the identification of existing safety components, compared to SMS requirements. Gap Analysis provides an airport operator an initial SMS development plan and roadmap for compliance”;
- Using the database as a reference, verify if each aerodrome activity, physical characteristic, process or procedure and the like has an acceptable level of risk (“Risk Management” sub-system);
- If the level of risk is not acceptable, the information is sent to the “Investigation and Adjustment of Activity with Inappropriate Level of Risk” sub-system;
- Once the causes have been identified and the level of risk for the activity, physical characteristic, process or procedure and the like has been adjusted, the complete information must be sent to the “Data Documentation/Control” and “Training and Qualification” sub-systems;
- If the level of risk is acceptable, the documentation concerning the respective activity, physical characteristic, process or procedure and the like must be completely ready and available in the “Data Documentation/Control” sub-system;
- The “Data Documentation/Control” sub-system acts as the SMS library. All its documentation, including the objectives, policy, definition of responsibilities, and each activity, physical characteristic, process or procedure and the like must be ready and available to be used or implemented. Likewise, all documentation control must take place in this sub-system; and
- All information on hazards and risks should be recorded using the forms and guidance available in the “Data Documentation/Control” sub-system.

More information on these subsystems can be found in the ICAO Safety Management Manual (SMM) (8) and elsewhere (2, 9, 10). These subsystems are also implicitly included in the four SMS components recommended by the ICAO SMS Training Course (11).

The first two subsystems indicated by Figure 01, the SMS Policy and Philosophy and Definition of Responsibilities and/or the first ICAO component (Safety Policy and Objectives) are tasks that must be developed by the highest airport authority. In this regard, the “Safety Policy and Objectives” component recommended by ICAO (11) establishes that the senior management must:

- Develop the **safety policy**, signed by the accountable executive, in accordance to national and international standards and organizational priorities;
- Communicate, with visible endorsement, the safety policy to all staff;
- Provide necessary human and financial resources;
- Establish **safety objectives** and **performance standards** for the SMS;
- The safety objectives and performance standards should be linked to the **safety performance indicators**, **safety performance targets** and **safety requirements** of the SMS; and,

- Identify the accountable executive, who must be an identifiable person, with full responsibility for the organization's SMS. He/She could be: Chief Executive Officer (CEO)/Chairman Board of Directors, a partner or the proprietor.

The following basic concepts are fundamental for the development of the methodology described in this paper:

- Hazard: "Condition, object or activity with the potential of causing injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function". (11);
- Risk: "The likelihood of injury to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function, measured in terms of probability and severity". (11);
- Latent conditions: existent conditions in the system that can be triggered by an event or a set of events (11) or "latent errors, whose adverse consequences may lie dormant within the system for a long time" (16);
- Near-miss events: Reason's (13) definition is: "any event that could have had bad consequences, but did not".
- Safety objectives: a set of safety objectives established by the senior management in accordance with the Safety Policy;
- Safety requirements: the tools used to guarantee the safety performance. They are, for example, procedures, technology, training, etc.;
- Safety performance: the change of the tendency over time of any business safety level. In other words, it is the frequency of occurrence of some events, incidents, reports, etc., related to safety;
- Safety Performance Indicators: parameters that reflect the measurement of the safety performance of any business at a particular time;
- Safety performance goals (targets): quantified objectives established by the top management level. They are tied up with the safety objectives and should be monitored by the safety performance indicators;
- Individual Performance Indicators: each one of the parameters used to point out how well or bad particular aspects of the SMS are working over time; and
- Overall performance indicator: the combined response of all of the IPIs considered in one SMS. Its function is to give a broad view of how safety, as a whole, is going on. It does not replace the information that each IPI can give.

As reported by Reason (16), performance is goal-oriented. Furthermore, we can assume that performance indicators are the "bridge" between the safety policy (defined by the accountable executive) and the safety requirements and targets (goals). This relationship is indicated in Figure 2. As being so, good identification, measurement and quantification of the performance indicators are mandatory tasks for the success of any SMS.

According to Reason (13), latent conditions reflect the consequences of top-level decisions that provoke a delayed-action effect on the SMS. In this regard, the performance indicators are the most important tools to quickly show to the top level of management (accountable executive) the need to redirect/readjust the SMS safety policy, safety objectives

and performance standards. The methodology developed in this study to estimate individual and overall performance indicators is discussed in the following item.

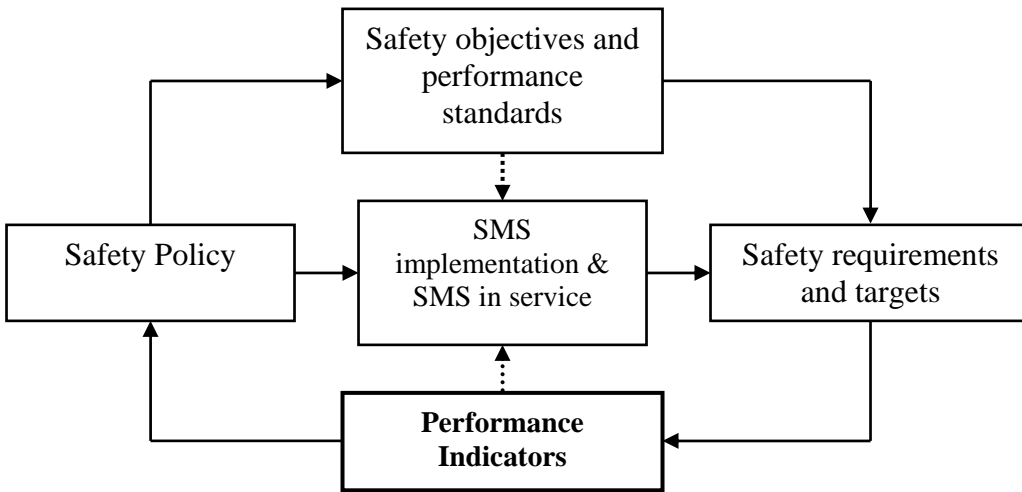


FIGURE 2 Role and importance of performance indicators.

METHODOLOGY TO ESTIMATE INDIVIDUAL AND OVERALL PERFORMANCE INDICATORS

This investigation has focused on two objectives. The first one was to identify Individual Performance Indicators (IPIs) that could reasonably indicate safety trend of an airport SMS. The second one was to obtain airport SMS Overall Performance Indicators (OPIs) that could be able to reflect the safety trend of an entire airport SMS.

Fortunately, aviation accidents are rare events. For this reason, the data base resulted from them are unreliable for monitoring safety performance of the entire aviation system or for a single aviation system component such as an airport. As being so, indicators that are able to reflect the events that occur more frequently or conditions that can be monitored on an on-going basis are necessary.

Furthermore, rather than considering the performance indicators related with active failures (triggers of accidents), this paper looked for Reason’s concept of organizational accidents and “near-miss” events (13), which have multiple causes encompassing many people operating at different levels of the organization. In addition, Reason recalls that “near-miss” events happens with more frequency than bad outcomes and “they provide a powerful reminder of the hazards confronting the system”.

In this regard, the European Transport Safety Council (12) considers that the number of accidents does not explain much about the processes that originate accidents because it is a question of chance whether a hazardous situation results in an accident or not. In order words, it is reasonable to suppose that, by luck, very risky conditions do not always end up in accidents. For this reason, the number of accidents or loss of life needs to be complemented by other safety indicators. According to the same reference, a criterion for aviation safety performance indicators should encompass:

- Identification of the performance indicators to be measured;

- Development of the methodology to monitor performance indicators; and
- Quantification of the performance indicators

This criterion was adopted for the development of this investigation and the first step was the identification of the performance indicators to be measured.

Preliminary Identification of the Individual Performance Indicators

As mentioned before, the information gathered by the authors during several years was analyzed aiming at identifying IPIs with the following characteristics:

- Able to reflect a link between a latent condition and possible outcomes/accidents;
- Easy to be quantified;
- Not subjective;
- Consistent across time; and
- Possibility to be combined with other IPIs to obtain Overall Performance Indicators (OPIs);

In addition, the IPIs should represent the same contributory factors to ramp accidents, reported by Ashford *et al* (17): “failure to follow regulations and standard procedures, problems with equipment, organizational problems, behavior-related factors and physical circumstances”.

The following potential IPIs for airports SMS selected with these characteristics were:

- Obstacles* that do not comply with standards
- Markings* that do not comply with standards
- Lights* that do not comply with standards
- Signs* that do not comply with standards
- Runway incursions**
- Incidents on each apron
- Incidents on each runway
- Incidents on each taxiway
- Deficiencies/Failures observed during a full-scale aerodrome emergency drill
- FOD*** found on each apron
- FOD found on each runway
- FOD found on each taxiway
- Aircraft bird/wildlife strikes
- Reports on the presence of birds/wildlife
- Air navigation aids equipments out of service*
- Reports on surface distresses on each apron
- Reports on surface distresses on each runway
- Reports on surface distresses on each taxiway
- Reports on slippery runway
- Driver infractions on each apron
- Driver infractions on each runway

- Driver infractions on each taxiway
- Infractions during aircraft refueling in each apron
- Unauthorized vehicles on each apron
- Unauthorized vehicles on each taxiway
- Unauthorized persons on each apron
- Unauthorized persons on each taxiway

ICAO definition (1); ** ICAO definition (18) and * Reference (6) definition: “Foreign object damage’ or ‘foreign object debris’, both abbreviated to FOD, are a potential source of catastrophic damage to aircraft - particularly engines. FOD can also be a tripping or slipping hazard resulting in injury to personnel and passengers”.*

To validate these IPIs, they were sent to all of the South American Civil Aviation Authorities (CAA) and ACI/LAC (Airports Council International/Latin American and the Caribbean Region), during the first semester of 2007, to be submitted to the airport operators under their administrations or influence to take the following actions: indicate the order of priority of the IPIs, classify them as optimum, good, fair or bad and suggest other possible IPIs with respective priority and classification. They were also required not to include number of accidents, loss of equipment or lives.

Difficulties to Carry Out and Interpret the Surveys

The initial idea of this investigation was to conduct just one survey as stated before. However, additional surveys, applied in phases, were necessary to overcome some difficulties faced, as follows:

- Phase 1: Survey sent to the South American CAAs and also ACI/LAC to submit it to airport operators;
- Phase 2: Survey applied to 30 representatives of Argentinean airport operators during an ICAO SMS course;
- Phase 3: Discussions of the IPI list obtained in phase 2 during a plenary session of the same course;
- Phase 4: Application of a new survey with the improved results obtained in phases 2 and 3 to 30 Chilean CAA high executives during another ICAO SMS course; and,
- Phase 5: Discussions of the results generated in phase 4 during a plenary session of the same course and preparation of the final IPI list with the priority groups.

A few answers were received from the airport operators and it became the main difficulty to carry out phase 1. Another difficulty faced was the interpretation of the answers obtained in phases 2 and 4, due to inconsistencies verified. It was found that the different backgrounds of the participants such as academic and technical experience, location of their responsibilities and duties at the airside, etc., interfered in their answers. Some examples of these inconsistencies were:

- a lawyer tends to prioritize IPIs related to non compliance with standards;
- a fire fighter considers the number of deficiencies/failures observed during a full-scale aerodrome emergency drill more important than other stronger IPIs;

- who works in apron area tends to consider IPIs related to aprons more important than those related to runways; and, etc.

There was an exception for this behaviour when the participants selected the IPIs for Group 1 (see Table 1) in phases 1, 2 and 4, all of them considered as “near-miss” events. In this sense, there was almost 100 % consensus that runway incursions were the most powerful IPI. Another very interesting observation was that the results became much more consistent when the ICAO Instructors interacted with the audience in phases 3 and 5 and explained to them the background about performance indicators in more detail and the purpose of the investigation.

Although these surveys pointed out that these IPIs are reasonable tools to indicate the “health” of any airport SMS, they will be submitted to a deeper statistical analysis to better understand their behaviour in the near future.

Development of the Methodology to Monitor the Performance Indicators

Individual Performance Indicators (IPIs)

Based on the information gathered during the field investigation in phases 2 to 4, decreasing weights were assigned to the IPIs, starting from 10 to 1 and from the highest to the lowest priority group, as shown in Table 1. The final classification obtained in those phases was slightly adjusted in phase 5. It has to be pointed out that the authors did not introduce any opinion or changes in this table in order to avoid the addition of more subjectivity in the results and to express what was really found in the survey.

The number of FOD ingestions was suggested during the survey and incorporated subsequently in Table 1.

For considering the IPIs, the following aspects should be taken into consideration:

- The obstacles, markings, signs, and lights that do not comply with standards, as well as air navigation aids equipments out of service, should be monitored in percentage of serviceability. All of the other IPIs should be monitored in terms of number of occurrences. This task can be facilitated by following the index of Annex 14, Volume I (1).
- Any type of incidents on aprons should be considered as “incidents on each apron”, except those due to tower/apron miscommunication while aircraft are parked. They should be considered in the ATS (Air Traffic Services) SMS;
- Incidents on each runway or taxiway are those not related to ATS and/or aircraft operation. An aircraft hitting an animal would be a good example of an incident in a runway. According to reference (18), the presence of an animal in runways is not considered a runway incursion.
- For monitoring (counting) the number of FOD found on each runway, taxiway and apron it is suggested to use the same sections and sample units delineated for the airports that run Pavement Condition Index Survey (PCI Method) according to ASTM D 5340-04 standard (19). The objective to use this procedure is to keep a

record where the presence of FOD occurs more frequently. Furthermore, all the sample units must be considered. Other approaches should be used for those airports that do not have the PCI Method in place and they should be able to allow the possibility of keeping track of the presence of FOD over time.

TABLE 1 Selected IPIs and respective groups, priority and weights for Airports SMS

Group/Priority	Individual Performance Indicators for Airports SMS	Weight
1	Runway incursions* Aircraft bird/wildlife strikes Incidents on each runway FOD*** ingestions	10
2	FOD found on each runway Incidents on each apron Incidents on each taxiway	9
3	Reports on slippery runway	8
4	FOD found on each taxiway FOD found on each apron	7
5	Air navigation aids equipments out of service** Non authorized vehicles on each runway Driver infractions on each runway Infractions during aircraft refueling on each apron	6
6	Obstacles** that do not comply with standards Reports on surface distresses on each runway Lights** that do not comply with standards Non authorized persons on each runway Markings** that do not comply with standards Signs** that do not comply with standards	5
7	Reports on the presence of birds/wildlife	4
8	Failures observed during a full-scale aerodrome emergency drill Non authorized vehicles on each taxiway Non authorized vehicles on each apron Driver infractions on each apron	3
9	Non authorized persons on each taxiway Non authorized persons on each apron Driver infractions on each taxiway	2
10	Reports on surface distresses on each taxiway Reports on surface distresses on each apron	1

According to * ICAO definition (18), ** ICAO (1) and *** Reference (6)

This paper does not have the intention to cover all the particular aspects of all the airports and/or airport operations.

Overall Performance Indicators (OPIs)

The IPIs indicated in Table 1 became the basis for the OPIs calculation, as it will be indicated later on.

Quantification of the Performance Indicators

This section discusses how to quantify the Individual Performance Indicators and the Overall Performance Indicators.

Individual Performance Indicators (IPIs)

All of the IPIs should be referred to one-year periods but averaged/estimated for 10,000 aircraft operations. As an example, two scenarios are proposed: a) a small airport with two runway incursions during 3,650 operations/one year; b) a large airport with three runway incursions during 100,000 operations/one year. The IPI values for both situations, for that particular year, would be 5.48 ($2 \times 10,000 \div 3,650$) and 0.30 ($3 \times 10,000 \div 100,000$) runway incursions, respectively.

Overall Performance Indicators (OPIs)

Once estimated the IPIs, the OPIs can easily be calculated by Equation 1.

$$OPI_{year} = \sum_{i=1}^n W_i (IPIvalue)_i \quad (1)$$

where:

OPI_{year} = OPI for a particular year

W_i = weight for the i-th performance indicator (Table 1)

$IPIvalue_i$ = value measured for the i-th IPIvalue

n = total number of individual performance indicators

Equation 2 is the result of Equation 1 multiplied by 10^{-2} . The application of this new equation allows a manageable capture of any change in the values of all of the IPI priority groups and an easier interpretation of the final OPI results. The only requirement to use this new equation is to express the final results with two decimals.

$$OPI_{year} = 10^{-2} \left[\sum_{i=1}^n W_i (IPIvalue)_i \right] \quad (2)$$

PRACTICAL APPLICATION OF THE METHODOLOGY

Because the implementation of airport SMS is relatively recent, no systematic data is available to be used for the estimation of IPIs and OPIs. In benefit of showing the practical application of the methodology, let's assume the scenario indicated by the Table 2 columns for a de-identified airport SMS (airport with single runway, taxiway and apron):

Column 1: groups of IPIs;

Column 2: IPIs considered;

Column 3: IPI values measured in 2007 and referred to 10,000 aircraft operations; and,

Columns 4 to 10: safety performance targets referred to 10,000 aircraft operations and established/endorsed by the airport senior management for the period between 2008 and 2014.

Estimation of IPIs

Basically, no calculation is needed to estimate the IPIs. However, each IPI should be plotted in order to be better analyzed. A good example of these plots is the performance curves shown, in Figure 3, for the “runway incursions” IPI (related to 10,000 aircraft operations). For this particular example, two additional and possible situations to occur were assumed:

- a) Runway incursions from 2008 to 2014: 2; 1.9; 1.8; 1.5; 1; 0.8 and 0.5, respectively
- b) Runway incursions from 2008 to 2014: 1.8; 1.6; 1.2; 1; 0.4; 0.1 and 0, respectively

The middle curve (data from Table 2) in Figure 3 represents the safety target values established/endorsed by the airport top level administration for this IPI. The upper curve shows that the performance would be below the expected level. Furthermore, the designed safety standard was not accomplished and complementary actions need to be taken to improve the SMS performance for this IPI. On the other hand, the lower curve shows that the performance was above the expected level, which means that the results of the actions taken to reduce runway incursions were effective and the established safety requirements and safety standard were adequate.

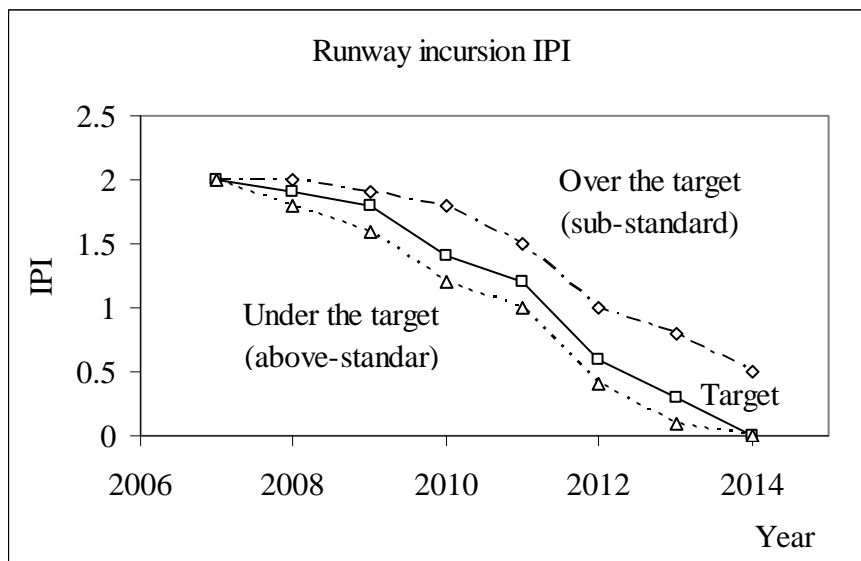


FIGURE 3 Performance curves for “runway incursion” IPI.

TABLE 2 Measured and Target IPI Values for an Hypothetical Airport SMS

Group	Individual Performance Indicators for Airports SMS	Measured	Target values						
		2007	2008	2009	2010	2011	2012	2013	2014
1	Runway incursions*	2	1.9	1.8	1.4	1.2	0.6	0.3	0
	Aircraft bird/wildlife strikes	2	1.9	1.8	1.4	1.3	1.2	0.5	0
	Incidents on each runway	2	2	2	2	2	0	0	0
	FOD*** ingestions	3	3	2	2	2	2	1	0
2	FOD found on each runway	10	10	10	8	5	4	3	0
	Incidents on each apron	5	4.5	4.5	3	3	1	1	0
	Incidents on each taxiway	4	4	4	3.2	3	1.5	1	0
3	Reports on slippery runway	3	2.8	2	1.6	1.5	1	0	0
4	FOD found on each taxiway	15	15	14	14	12	6	5	3
	FOD found on each apron	20	20	18	12	10	5	4	3
5	Air navigation aids equipments out of service**	50	45	40	25	20	12	5	0
	Unauthorized vehicles on each runway	2	2	2	1.5	1.3	1	0.8	0
	Driver infractions on each runway	3	3	2	2	1	1	1	0
	Infractions during aircraft refueling on each apron	2	2	2	1	1	1	0	0
6	Obstacles** that do not comply with standards	100	90	80	60	40	20	10	0
	Reports on surface distresses on each runway	4	2	2	2	2	1	0	0
	Lights** that do not comply with standards	30	20	20	15	10	0	0	0
	Unauthorized persons on each runway	2	2	2	1	1	0	0	0
	Markings** that do not comply with standards	40	30	20	15	10	0	0	0
	Signs** that do not comply with standards	35	30	30	25	20	10	0	0
7	Reports on the presence of birds/wildlife	5	5	5	4	4	3	2	1
8	Failures observed during a full-scale aerodrome emergency drill	10	10	8	6	3	3	2	1
	Unauthorized vehicles on each taxiway	4	3	2	2	1	1	1	1
	Unauthorized vehicles on each apron	3	2	2	2	1	1	0	0
	Driver infractions on each apron	5	4	3	3	2	2	1	0
	Unauthorized persons on each taxiway	3	3	3	2	2	1	0	0
9	Unauthorized persons on each apron	5	5	4	3	3	2	1	0
	Driver infractions on each taxiway	4	4	4	3	3	2	1	0
	Reports on surface distresses on each taxiway	5	5	5	4	4	2	1	0
10	Reports on surface distresses on each apron	3	3	3	3	2	1	1	0

* According to ICAO definition (18), ** ICAO (1) and *** Reference (6)

Estimation of OPIs

The objective to estimate OPIs is to have an overall reference of an airport SMS performance curve. The following steps are necessary to calculate the OPIs:

- Classify the IPIs according to the 10 priority groups set in Table 1;
- Multiply the IPI values measured in 2007 and the target values (2008 to 2014) by their respective weights, according to Table 1; and
- Apply Equation 2 (sum up these products for each year and multiply by 10^{-2}).

The final results estimated for the OPIs, for this particular example, are presented in Figure 4.

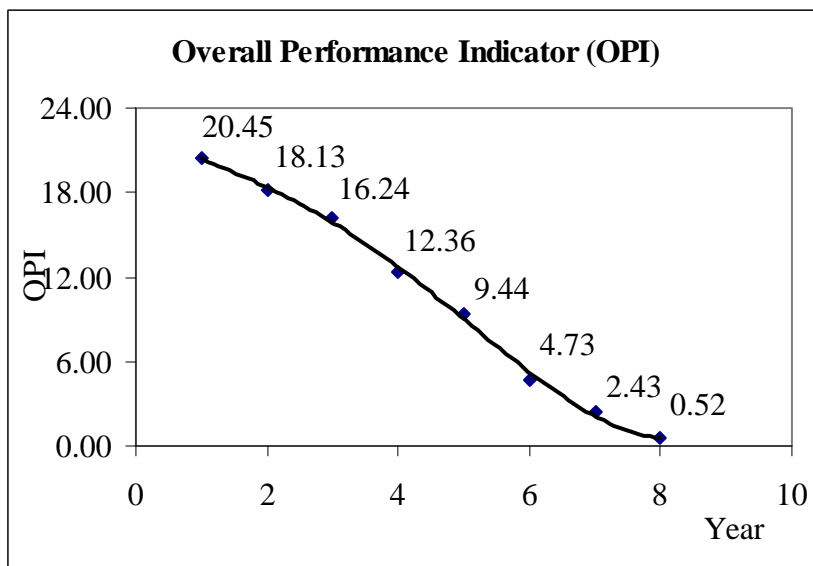


FIGURE 4 Performance curve for the OPIs.

It is important to recall that the OPIs do not replace the IPIs. In other words, even if a particular OPI is better than the target value, the IPIs must be checked one by one because an OPI is the result of different IPI combinations.

Finally, this paper does not have the intention to consider all the possible airport safety indicators because this methodology is completely flexible to allow the incorporation of other IPIs according to the needs and reality of each airport. The only necessary step to add IPIs is to classify and insert them in one of the 10 groups suggested in Table 1.

CONCLUSIONS AND FUTURE RESEARCH

This paper has initially provided an overview on SMS and recalled that the SMS implementation by certified airport operators has been an ICAO requirement since November 2005.

It has been recalled that the airport senior management and accountable executive have the responsibility to establish/endorse the Safety Policy and Objectives, performance standards, safety performance indicators, safety performance targets and safety requirements.

It has also been shown that the performance indicators are the “bridge” between the Safety Policy and the Safety Requirements and Targets established/endorsed by the top level administration and that they are the most powerful tool to help the senior management in the decision-making process to adjust/redirect the SMS policy and objectives.

The methodology to estimate Individual and Overall Performance Indicators developed in this paper focus on the latent conditions and “near-miss” events at/on airports instead of active failures. The general scope followed to develop the methodology was the identification of the individual performance indicators (IPIs) to be measured, the development of procedures to monitor them and how to quantify them.

The identification of the preliminary potential IPIs was based on the information accumulated by the authors on airport operations and aviation safety during several years and validated through surveys carried out with South American airport operators. Then, the IPIs were classified in 10 groups according to the priorities indicated by the surveys and decreasing weights were assigned to them, starting from 10 to 1 and from the highest to the lowest priority group.

The proposed procedure to monitor the IPIs consists of the number of occurrences found for each IPI, except obstacles, markings, signs, lights that do not comply with standards, as well as air navigation aids equipment out of service, that should be considered in percentage of serviceability.

The IPIs should be quantified and referred to one-year periods, but averaged/estimated to 10,000 aircraft operations. For obtaining the OPIs, also on one-year basis, the IPIs should be multiplied by their respective weights. The OPI for a particular year is the sum of the products “IPI values x IPI respective weights” multiplied by 10^{-2} for that particular year. It is recalled that the objective to estimate OPIs is to have an overall reference of an airport SMS performance curve. They do not replace the IPIs, which should be checked one by one.

Practical examples were also presented in this paper to clarify the application of the methodology.

Finally, it is important to stress that this methodology is flexible enough to consider IPIs according to the needs and reality of any particular airport SMS just by classifying and inserting them in those groups suggested by this paper in Table 1.

Future research will consist on a deeper statistical analysis of the data already accumulated in order to better understand the behavior of the IPIs considered in this study and to incorporate new potential IPIs as well.

Disclaimer

The contents of this paper are the results of many years of observation and experience of the authors on airport operations and safety and do not necessarily reflect the official views and policies of the International Civil Aviation Organization. Furthermore, the opinions, findings and conclusions of this paper do not constitute an ICAO standard, recommendation, specification or regulation.

REFERENCES

1. International Civil Aviation Organization. *Aerodromes, Aerodrome Design and Operations*. ICAO, International Standards and Recommended Practices, Annex 14 to the Convention on International Civil Aviation, Volume I, 4th Edition, July, 2004.
2. Australian Civil Aviation Safety Authority. *Developing a Safety Management System at your Aerodrome*. CASA, Advisory Circular, AC 139-16(0), Australia, March 2005, 11 pp.
3. U. S. Department of Transportation. *Introduction to Safety Management Systems (SMS) for Airport Operators*. Advisory Circular 150/5200-37, Federal Aviation Administration, February 28, 2007, 16 pp.
4. ACRP Report 1. *Safety Management Systems for Airports, Volume I: Overview*. Transportation Research Board of the National Academies, Washington, D.C., 2007.
5. Transport Canada. *Introduction to Safety Management Systems*. Document TP 13739, April 2001, 19 pp.
6. United Kingdom Civil Aviation Authority. *Airside Safety Management*. Safety Regulation Group, Document CAP 642, May 2003, 52 pp.
7. United Kingdom Civil Aviation Authority. *The Management of Safety – Guidance to Aerodromes and Air Traffic Service Units on the Development of Safety Management Systems*. Safety Regulation Group, Document CAP 728, March, 2003, 19 pp.
8. International Civil Aviation Organization. *Safety Management Manual (SMM)*. ICAO, Doc 9859-AN/460, First Edition, 2006.
9. Cardoso, S.H. Basic Concepts on Safety Management Systems for Airports. Presented at ICAO Workshop on Safety Management Systems for Airports for the NAM/CAR/SAM Regions -Spanish Speaking Countries, www.lima.icao.int, Buenos Aires, April, 04-08, 2005.
10. International Civil Aviation Organization. *Guide for the Implementation of Airport Safety Management Systems (SMS)*. ICAO, South American Office, www.lima.icao.int, Lima, Peru, May, 2005, pp. 01-23.
11. *ICAO Safety Management (SMS) Course*. International Civil Aviation Organization, ICAO, www.icao.int/anb/safetymanagement, Revision N° 10, October/2007, Accessed November 05, 2007.
12. European Transport Safety Council. *Transport Safety Performance Indicators*. ETSC, Brussels, Belgium, 2001, 56 pp.
13. Reason, J. *Managing the Risks of Organizational Accidents*. Ashgate Publishing Limited, England, 2006.
14. Hansen, M., and C. McAndrews. Challenges of Measuring Performance for FAA's Safety Oversight System. In *Transportation Research Record: Journal of the Transportation Research Board, No 1937*, TRB, National Research Council, Washington, D.C., 2005, pp. 31-36.
15. International Civil Aviation Organization. *Manual on Certification of Aerodromes*. ICAO, Doc 9774-AN/969, 1st Edition, 2001.
16. Reason, J. *Human Error*, Cambridge University Press, 17th Printing, USA, 2006.
17. Ashford, N.J., N. N. Ndoh, and A.S. Brooke. Airport Ramp Analysis and Management System. In *Transportation Research Record: Journal of the Transportation Research Board, No 1562*, TRB, National Research Council, Washington, D.C., 1996, pp. 8-18.

18. International Civil Aviation Organization. *Procedures for Air Navigation Services – Air Traffic Management*, ICAO, Doc 4444-ATM/501, 14th Edition, 2001, 323 pp.
19. Annual Book of ASTM Standards. *Standard Test Method for Airport Pavement Condition Index Surveys*. ASTM, D 5340-04, Section Four - Construction, Volume 04.03, Road and Paving Materials, Vehicle-Pavement Systems, 2007, pp. 552-606.