Cross Domain Within EASA Safety Management Systems Environment

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July 2018

Abstract

Aviation is safe critical industry with the goal of delivering a service. However, it is impossible to guarantee that one finds an environment, specially in a a system with human input, completely free of hazards and risks. Therefore, safety has to be a dynamic characteristic of the system where risks to safety need to be constantly mitigated.

Provided safety risks are kept under an appropriate level, the aviation system can be expected to maintain the appropriate balance between production and protection. Organizations that have SMS implemented have significantly lower accident rates. As such it is interesting to see SMS in action.

The purpose of this research is to determine the impact of SMS on a commercial aviation operation using a case study. This study starts with the definition of safety and its evolution in aviation as well as its implementation. Then, a review of the status of the SMS with EASA is made and a case study which actively involves different organizations is presented.

The results showed how organizations, ANSP, Operators and Airport authorities have indeed recognized the importance of the SMS and that each organization has customized their SMS to fit their needs. Furthermore, variations were identified between the ICAO SMS model and the models adopted by EASA. In addition, it also concluded that, safety assessments will always be a subjective methodology, highly dependent of the expertise of those participating in it.
Keywords: Safety; SMS; Risk assessment; Hazard identification.

1. Introduction

The rapid worldwide increase of air traffic and aircraft technological development demands a rapidly changing and adaptation of aviation operational environments, which boundaries are rarely limited to single organizations or countries.

The prestige of this industry is deeply affected by safety. Any accident becomes the centerpiece of the media, filling the headlines of newspapers and TV news segments. The public expects nothing short of immaculate safety records. Thus, safety is paramount. According to ICAO, Safety “is the state in which the risk of harm to persons or property damage is, reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and risk management. [1]

We can therefore, infer that absolute safety does not exist, because failures will always occur, despite the most diligent prevention efforts, as it is impossible to completely eliminate all risks. No human-made system/technology can be free from risk and error.

Nonetheless, risk and error are acceptable if controlled in an inherently safe system. In order to further improve the already good safety record obtained in the civil aviation industry, ICAO has promoted the principles of safety management. These principles revolve around the implementation of a SMS in industry organizations and a SSP in Contracting States.

Furthermore, there has been a paradigm shift regarding safety, from a traditional reactive approach, to a proactive and innovative implementation of Safety Management Systems.

The implementation of a safety management system should lead to an overall improvement of the processes of a company, and should contribute to one of civil aviation’s key business goals: enhanced safety performance, aiming at best practices and moving beyond full compliance with regulatory requirements.

In this way, following ICAO’s signing of the international standard for SMS in aviation, EASA started to draft regulations in the SSP and SMS. This led to the development of a distinct set of regulations for both authorities and organizations. The authorities requirements focus on specific critical elements of a safety oversight system defined by ICAO namely:

- State civil aviation system and safety oversight functions
- Technical personnel qualification and training
- Technical guidance, tools and the provision of safety-critical information
- Licensing, certification, authorization and/or approval obligations
- Surveillance obligations
- Resolution of safety concerns.

Organization Requirements include consolidated general requirements for management systems, designed to embed the SARP in a way as to ensure compatibility with existing management systems and to encourage integrated management. These requirements and related AMC/GM set out what is needed in terms of the organization's management system. Together with the relevant provisions of the Basic Regulation 216/2008 [2], these fully cover the existing ICAO SMS Standards and encourage integrated management.

The scope of this research is to analyze an hazard, foreign object debris from the perspective of how the SMS from the different organizations act showcasing its differences and parallels. It aims to present a clear, coherent, complete and integrated approach to aviation organizations of SMS and how it can manage hazards and provide an inherently safe environment for operations to take place.

The methodology applied for the risk assessment focuses on the human reliability analysis evaluated through the application of TESEO.

In order to achieve this goal a top down approach was used, constituted by the following parts:

- Role and definition of safety and SMS state of the art analysis;
- Clarification of the differences between a hazard and a risk ;
- Assessment of existing risk assessment methods;
- EASA regulatory SMS framework;
- Application of the TESEO methodology in a FOD case which involves the different organizations.

2. Literature review

2.1. Role and definition of safety

Defining what safety is could be the topic of a thesis and many discussions are currently held concerning the topic. This is due to a shift between what has become coined as Safety I and Safety II that is underway.

Traditionally, safety has been defined as a condition where there is absence of harm [3]. Or, more precisely, since we know that ensuring that nothing goes wrong is impossible, as a condition where the number of things that go wrong is acceptably small. This is an indirect definition, defining safety by what happens when it is missing. Subsequently, safety is also measured indirectly, by the consequences of its absences instead as of a quality in itself.

Safety I is usually described as of the design of safe system that is able to eliminate, adequately control or mitigate all the adverse outcomes [4]. When in normal functioning, everything works as it should and the outcomes will be acceptable. The number of adverse events is small and acceptable. When something goes wrong, when there is a malfunction, human or otherwise, this will lead to an unacceptable outcome. The key question lies in how the transition from normal to abnormal occurs. If this transformation can be blocked, safety and efficiency can be achieved.

The view held by Safety II is that "Safety is more than the negation of risk" and "Safety is a dynamic non-event and non-events cannot be characterized or counted"[5]. It recognizes that these systems are in fact intractable and proposes a definition shift in safety from avoiding unacceptable outcomes to ensuring things go right.

Therefore, Safety II, sees the human factor as an asset because people can adjust their performance accordingly to match the conditions of work. This performance variability is seen by Safety II as positive factor since it represents adjustments necessary for safety, instead of a deviation from standards, as per Safety I.

These different safety concepts lead to different types of safety management. Reactive safety management, which is based in the Safety I definition, is often equated with the "fly-fix-fly". This approach is reactive because it tries to respond to adverse events by trying to understand the relevant factors that originated it, or by improving detection and recovery from these events.

From Safety II's perspective, the goal of safety management is to reduce failures and ensure acceptable outcomes. Proactive risk management deals with issues before they come up and therefore affecting how they happen or even prevent them from happening. More specifically, proactive safety management, tends to use history patterns to make policy/procedure decisions based on anticipation.

Emerging from reactive and proactive safety management, predictive safety goes a step further when comparing it with proactive safety. It uses normal operational data, and not only significant, accident data, to determine the potential risk and avert an accident that has not happened (yet). Making use of the multitude of normal operational data available coupled with today's data analysis capabilities we can identify hazards previously only discovered by an accident or a serious incident. In order to be predictive we must be able to use this normal day to day operational data and modern data processing tools to show the potential risks and what the current risk trends are.

Figure 1: The spectrum of safety [6]

Figure 4 depicts a scale of how the definitions presented in the previous subsections may be viewed with reactive at one end and predictive at the other.

2.2. Safety management systems

A SMS is a term used to refer to a system that deals with safety characteristics throughout an organization. The system offers a systematic way of categorizing hazards and managing risks guaranteeing that these controls are effective. A SMS is expected to be assimilated into an organization and becomes part of the culture; the manner people do their job.

A SMS can be defined as:

" (...) a businesslike approach to safety. It is a systematic, explicit and comprehensive process for managing safety risks. As with all management systems, a safety management system provides for goal setting, planning, and measuring performance. A safety management system is woven into the fabric of an organization. It becomes part of the culture, the way people do their jobs." [7]

There are four components of a SMS that represent its two core operational processes as well as the organizational arrangements that are necessary to support it. These four pillars are:

- Safety policy;
- Safety risk management;
- Safety assurance;
- Safety promotion.

The main activities are safety risk management and safety assurance, but they can only be in place under a set of declared policies which have in turn to be supported by safety promotion.

By extending the responsibility for safety, through these four pillars, across all levels of the organizations the chance of a threat endangering the organization is greatly reduced. This follows Reason's Swiss Cheese Model Fig. 6 which likens human-machine systems to multiple slices of swiss cheese. [8] These layers stacked side by side, in which the risk of a threat becoming a reality is mitigated by the differing layers and types of defenses which are "layered" behind each other. Therefore, in theory, lapses and weaknesses in one defense do not allow a risk to materialize, since other defenses also exist, to prevent a single point of weakness.

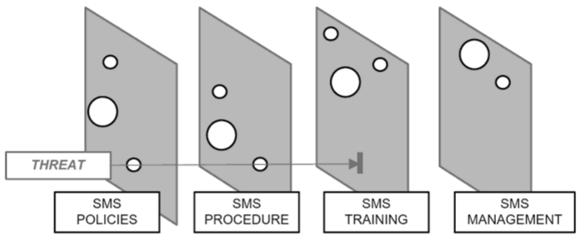

Figure 2: Example of successive layers of safety in a proactive SMS, with a threat affecting policy and procedures but being blocked by proper safety training.[9]

2.3. Risk Assessment

The official definition of safety risk by ICAO takes into consideration the identified hazard and classifies it into two categories "probability" and "severity". Safety risk is thus the scenario that follows when a hazard is accepted.

"Safety risk as the assessment, expressed in terms of predicted probability and severity, of the consequences of a hazard, taking as reference the worst foreseeable situation". [10]

Risk assessment is an evaluation in terms of criticality of their harmful effect and ranked in order of their risk-bearing potential. In other words, it determines the probability and consequences of a negative impact and then estimates the level of risk by combining the probability and consequences. If the risk is considered acceptable, operation continues without further intervention. If it is not acceptable, the risk mitigation process is initiated.

In order to interpret the combination of risk probability and risk severity, the data is usually presented in a risk matrix. This matrix is custom created for the organization, encompassing the company's objectives, its environment, its production processes and its possible hazards. Both the probability and severity columns are divided into a number of levels, each one of them characterized either by a range of values of probability, or by the description of the damages that can occur.

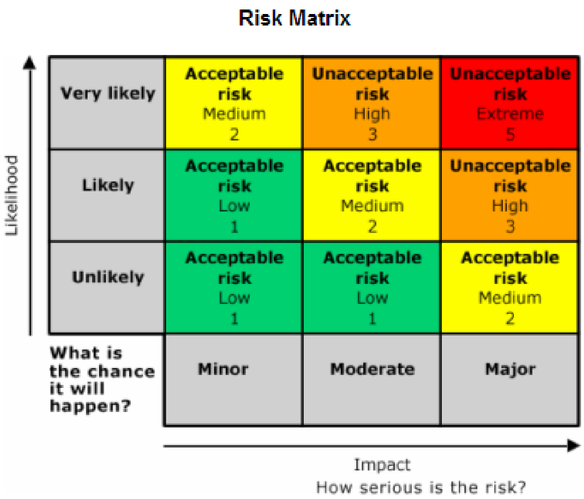

Figure 3: The risk matrix

If the risk is falls in the red, orange or yellow areas, then control measures have to be taken to increase the level of defenses against that risk or to avoid or remove the risk. In the unacceptable area immediate action is required. In the case of the acceptable region, it is important to do a cost benefits analysis so the best compromise between safety, costs, and production can be found. This is important since it helps management establishing a balance between resources allocated to production and protection efficiency and safety.

The competition for the allocation of resources may lead to a management dilemma named the "dilemma of the two Ps". The "dilemma of the two Ps" can be described as the conflict that arises at the management level due to the perception that resources must be allocated on an "either basis" to what are believed to be conflicting goals: production goals (delivery of services) or protection goals (safety).

2.4. TESEO

When doing a risk assessment, there is the constant need of expert judgments and technical discussions for understanding how an hazard can generate and develop. This results in the collaboration of experts to seek mitigation strategies. The need to implement more consolidated technical approaches for probability evaluation, other than Expert Judgment, as led to the implementation of the TESEO (Tecnica Empirica per la Stima degli Errori degli Operatori) approach for assessing the probability of human error.

In this thesis, the TESEO method is used to give a quantitative analysis to the case study. This method was developed in 1980 by Bello and Colombari [11]. The Human Reliability (HR) calculates the probability of an operator successfully completing the action in question. HR is calculated as:

$$HR = 1 - HU \tag{1}$$

where HU stands for Human Unreliability.

Two other important concepts to introduce are the Human Error (HE) and the Probability of Recovery (PR). HE is the probability that the person makes a mistake, while PR is the probability to correct it. HE and PR are correlated using the following equation:

$$HU = HE(1 - PR) \tag{2}$$

using the hypothesis that HE and PR can be represented as a function of the operator skills, the operator's failure probability can be computed as a multiplicative function of five parameters linked to:

- The type of activity to be carried out (K1);
- The time available to carry out this activity (K2);
- The human operator's characteristics (K3);
- The operator emotional state (K4);
- The environmental ergonomics characteristics (K5).

$$HU = K1.K2.K3.K4.K5 \tag{3}$$

If the value of HU is more than one, it will be assumed that $HU = 1$. This means that the likelihood of the operator successfully accomplishing the task is zero.

The values of each parameter can be obtained by consulting standard tables. [11]

The table below was built to detail the HU calculation for each event.

Table 1: Barrier failure table

Interaction type	Human factor	K1	K2	K3	K4	K5	Failure probability
L							
L-E							
L-S							
L-L							
Subtotal							

Where:

- L : liveware, the operator himself/herself;

- L-E : interaction between the operator and his/her work environment;
- L-L : interaction between operators working on the same task;
- L-S : interaction between the operator and all the non- tangible components involved in his/her job;
- L-H : interaction between the operator and tools used for the task;
- Human Factor: one or more human factors from the Dirty Dozen correlated to the operator's interaction
- K1, K2, K3, K4, K5: TESEO parameters;
- Failure probability : equals to HU
- Subtotal : the causal barrier/initial event final failure probability;

In order to decide the most adequate K factor, one should keep in mind how this specific human factor affects each k factor in order to make the barrier fail. It is important to recognize that events or human factor contributions can simultaneously occur. Therefore, they are non-mutually exclusive and independent.

Once that the probability of the initiating event and the success and failure probability of each causal barrier have been calculated, it is possible to evaluate the overall probability of occurrence of the incident sequence. since this sequence is composed by multiple elements, the interaction among them has to be classified. In this case, we simply consider the events as independent, being the final probability value given by:

$$p_t = \sum_{i=1}^{n} p_i \qquad (4)$$

Where:

- p_t : overall probability;
- p_t : probability each single event
- n : number of causal barriers

3. EASA Regulatory Framework

3.1. Current rule-making status regarding SMS

EASA is creating a performance based regulatory environment with common standards across all regulations which are enabled by EASA BR 216/2008 [2]. Specific Focus on Management and Safety Systems is evident.

The current EU Regulations that mandate SMS assessment are as follows:

- Commission Regulation 290/2012 [12] ”Aircrew”;
- Commission Regulation 965/2012 [13] ”Air operations”
- Commission Regulation 139/2014 [14] ”Aerodromes”;
- Commission Regulation 2015/340 [15] ”Air traffic controllers' licenses and certificates”;
- Commission Regulation 2016/1377 [16] ” for ANSP and the oversight in ATM/ANS” require competent authorities to assess how organizations identify aviation safety hazards and how they manage the associated risks and to consider the effectiveness of the SMS as part of their oversight.
- Commission Regulation No 1216/2011 [17] and Regulation 390/2013 [18] ”Performance Scheme Regulation, for air navigation services and network function” require ANSP to periodically answer Effectiveness of Safety Management and Just Culture questionnaires.

In addition to the ANS Performance based IR requirements, EU Regulations will require (for those domains where SMS requirements have not yet been issued) organizations to monitor the effectiveness of their risk management and authorities to consider the effectiveness of the SMS as part of their oversight.

	Airworthiness	Flight Standards	ATM/ANS	Aerodromes
Implemented	x	✓	✓	✓
Currently applies	x	✓	✓	x
Applies by the end of 2017	x	-	✓	✓

Figure 4: Status of SMS requirements for the different organizations

4. Cross domain assessment

4.1. Foreign Object Debris

A foreign object debris is basically a foreign object, a substance, debris or article alien to the aircraft equipment that if ingested into the engine or lodged in a mechanism can potentially cause damage which may render the system unsafe for operation.

For years, foreign object debris has represented a safety hazard for the aviation industry and it has contributed to a number of incidents and accidents. The proportion of serious incidents is approximately 4 per 10 000 takeoffs or landings. Furthermore, a conservative approach made by Insight SRI estimates the direct costs of FOD at 1,1 billion USD per year, rising to a total of 12,4 billion USD if indirect costs are accounted for [19].

Examples of foreign object debris include:

- Aircraft parts, rocks, broken pavement, ramp equipment.
- Hail, birds
- Garbage, maintenance tools, etc.

The case study in which the assessment is based took place in 2010 in Helsinki-Vantaa airport. Flight BLF639, suffered severe damage to the outer left engine during the take-off run which led to a rejected takeoff at 100 knots. After the aircraft vacated the runway, at ATC request, a runway inspection was performed. This inspection found the runway to be clear of obstacles and thus, safe to operate. As such, 2 transport aircraft were cleared to take-off from that runway. Minutes later, the pilot in command of BLF639 called ATC and recommended the runway to be reinspected. This second inspection disclosed a significant amount of engine pieces on the runway and they were removed. Neither of the aircraft which used the runway prior to debris removal were subsequently found to have suffered any damage but both were advised of the situation en route.

In this case the hazard can be classified as below.

System	Subsystem	Activity	Hazard description	How was it identified
Air side	Movement area	Runway operations	FOD	Subsequent runway inspection

Figure 5: Foreign object debris hazard classification

In the end, since the hazard distinguishes itself from the initial event, one can indicate as triggering event, the non detection of debris on the runway while conducting a runway inspection.

4.2. Analysis

In order to prevent the incident sequence from taking place and to reduce the likelihood of the hazard developing its damage potential to the fullest, it is important to look for casual barriers which may already be in place. Some of these barriers are can prevent the consequences from happening while others can delay the activation of the initial event.

In this case, there are causal barriers intrinsic in the air side areas against foreign object debris and in the training backgrounds of airport staff and crews. The operators training and the air side infrastructure characteristics preventing foreign object debris will affect the choice of the K3 and K5 parameters respectively.

Finally, given that the vehicle driver has missed debris during the first runway inspection, two causal barriers were identified:

- The vehicle driver, knowing that parts are missing from the airplane, conducts a second inspection;
- Aircraft pilot notices that the runway is contaminated and rejects the take off.

Once reasonable causal barriers are found for the hazard, this methodology suggest to build a "classical" event tree: starting from the initiating event, coinciding with the tree root, each barrier represents a tree branch; specifically, the bottom one stands for the probability of failure of the barrier, while upper ramification stands for the probability of success, equals to one minus the probability of failure, considering one the optimum. The tree ends expresses the various consequences linked to the same hazard.

Below are calculated the probabilities of failure of the barriers.

Table 2: Non detection of the reported debris

Interaction type	Human factor	K1	K2	K3	K4	K5	Failure probability
L	Distractions	0.01	0.5	1	1	1	0.005
L-E	Pressure (to open the runway)	0.01	0.5	1	1	1	0.005
L-S	Norms (established procedures)	0.01	0.5	1	1	1	0.005
L-L	Lack communication (pilot - airport services)	0.01	0.5	3	2	3	0.09
Subtotal							0.105

Table 3: Conduction of a second runway inspection without finding debris

Interaction type	Human factor	K1	K2	K3	K4	K5	Failure probability
Universal	Complacency (a first inspection had already been conducted)	0.1	0.1	1	1	1	0.01
L-E	Pressure (to open the runway)	0.1	0.1	1	1	1	0.01
L-S	Norms (established procedures)	0.1	0.1	0.5	1	1	0.005
L-L	Lack communication (between airport staff)	0.1	0.1	1	2	1	0.02
Subtotal							0.045

Table 4: Pilots do not notice that the runway is contaminated

Interaction type	Human factor	K1	K2	K3	K4	K5	Failure probability
L	Distractions	0.01	10	0.5	2	1	0.05
L-E	Fatigue	0.01	10	0.5	1	1	0.1
L-S	Norms (established procedures)	0.01	10	0.5	1	1	0.05
L-L	Lack communication (between PF and PNF)	0.01	10	0.5	1	1	0.05
Subtotal							0.25

Table 5: Event tree

Initial Event	First Barrier	Second Barrier	Consequence	Probability
	0.75		Review	0.07875
0.105				
		0.955	Unacceptable	0.02506875
	0.025			
		0.045	Unacceptable	0.00118125

4.3. Managing Risk

The operation of flying an aircraft from A to B has always an underlying risk.

Therefore, in order to manage risks, the operator of the system, people with explicit control responsibility, must be able to influence the scenario, probability and consequences of an event.

In the case of foreign object debris, the interaction between the operator, air traffic control and the aerodrome is crucial.

The effectiveness of co-operation between ATC and the airport is paramount. This largely depends on communication practices and these should be continuously performed across all levels and not only between senior staff and supervisors. The likelihood that a certain scenario takes place is, in this case, governed by the flight deck, air traffic control and aerodrome operator decisions.

The aircraft operator is the one facing the harshest consequences. It has not only to endure the damage to the airplane but also the possible loss of human lives. The ANSP and aerodrome have less exposure to consequences, the damage to its assets is limited. In the case of a heavier aircraft, the magnitude of losses is greater as the kinetic and potential energy of an aircraft is positively correlated with the damage it can inflict. It is however possible that an aircraft, after ingesting foreign object debris, could damage the airport tower and terminal.

Table 6: Incident sequence risk index

Incident sequence	Probability	Probability level	Severity	Risk index
1	0.100275	Occasional	Minor	8 - Review
2	0.00354375	Occasional	Major	12 - Unacceptable
3	0.00118125	Remote	Catastrophic	15 - Unacceptable

Obviously, the incident chain ending into an accident, thus combining the failure of both boundaries, is not acceptable. Indeed, it is mandatory to further analyze it and put in place all necessary boundaries in order to move its risk index into the yellow area, or, even better, into the green one.

In this case, all sequences seek mitigation actions that will bring them to the green zone, the one of full tolerability.

4.4. Mitigation action

In order to try the incident sequences to the green, safe zone, there are foreign object debris prevention programs issued by the aviation authorities which provide standards and guidelines eliminating and reducing consequences of this hazard.

They are usually composed by 3 elements [20]:

- FO designation / sensitive area;
- Awareness;
- FOD air side activities preventive measure.

Foreign objects designation area consists on identifying areas that are particularly sensitive to foreign object damage. However, it is possible that debris are not controlled or found in this area. Foreign object damage sensitive areas should be designed by combining two risk factors: probability and consequences as shown in Figure 6. Good practices include a clean-as-you-go policy and physical segregation of the different areas.

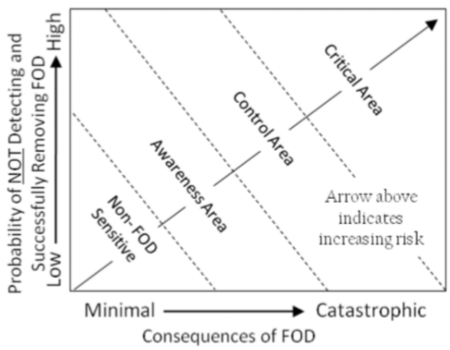

Figure 6: FOD sensitive areas by the combination of probability and consequences [20]

Another important pillar is raising awareness for this issue. It is important that the FOD program is properly disseminated throughout the organization with proper communication methods such as advertisement and visual tools, which are used to remind all employees about the foreign object debris hazard.

Most foreign objects are found in airport apron, service roads, baggage area and areas near the aircraft galley usually come from aircraft servicing activities. In order to avoid any unwanted incidents due to these objects, these areas should be monitored and cleaned. Additionally, it is important to set up procedures to check ground servicing equipment for any signs of wear and tear that have tendency to create foreign object hazard.

5. Conclusions and future work

SMS is which contains the tools that an aviation organization needs to control the safety risks of the hazard's consequences it must face during the delivery of the services.

Aviation safety issues are neither inherent to, nor a condition of aviation operations, but a byproduct of the need for the delivery of a service. Therefore, SMS must start with senior management allocating resources in a way which supports the overall service delivery needs of the organization. It is important to identify and involve all the aviation stakeholders to ensure that their input and knowledge, relevant to safety risk decisions, are taken into consideration.

Each service provider defines its roles, responsibilities, and relationships. Even though the organizations are not under a regulatory imperative, they should take a proactive action facilitating the dissemination of SMS activities and safety information.

It is important to stress the importance of promoting airport safety committees where each individually operated SMS assists on identifying hazards that might impact other entities and to create a common understanding of hazards, risks, incidents, etc. Furthermore, SMS related voluntary agreements at local, regional and international levels should exist among stakeholders to share safety information and improve SMS activities.

Considering the Portuguese SMS scenario, it is immediately clear how advanced these organization's SMS are. They have well organized structures, planned activities in order to reach their safety goals and a built-up approach for developing tasks.

Finally as the sizes, complexity and core business of organizations vary greatly, it is important that the SMS is adjusted for each organization's needs. Theses differences lead to different responses to changes. The introduction of mitigation actions is also different across organizations both in feedback and time needed for them to be implemented. Nonetheless, the proactive nature of SMS means that service providers that are lagging behind can learn from other organizations' experiences and continuously improve.

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