ICAO implemented a mandatory requirement in 2009 for all airlines to have a safety management system (SMS). The purpose is for airlines to identify hazards, and then implement changes to operational procedures to mitigate the risk of these hazards resulting in an incident.

The principles of safety management systems (SMS), and their use

The International Civil Aviation Organisation (ICAO) has had a mandatory requirement since 2009 for airlines to have a safety management system (SMS) in place. The SMS was an amalgamation of various hazard identification and safety auditing processes. ICAO put all safety management requirements in ICAO Annex 19 in November 2013.

Hazard identification had been in place since the 1970s, while recording, processing and analysing flight operations data evolved in the 1990s.

The core of the SMS process is identification of operational hazards and risks by collecting, processing and analysing safety-related flight operations data, as well as conducting safety audits, filing reports of incidences during operations, and assessing operational risks. The findings are processed, and an assessment made as to whether or not changes to standard operating procedures (SOPs) are required to improve operational risks and safety.

There needs to be clarity on the definition of hazards and risks. A hazard is a real or potential event or incident that leads to an incident and an undesirable consequence. Examples are birdstrikes, or a hard landing caused by severe weather. A potential hazard exists on a route an airline does not currently operate. A risk is the probability of the undesirable consequence.

After procedures and SOPs have been updated to reduce the risks of an incident occurring, the collection, processing and analysis of flight operations data continues, with further changes made to operational procedures as required. The SMS process is a cycle of data collection, analysis and process improvement.

An SMS involves the following four elements: the implementation of a safety policy; identification of operational hazards and risks; having a safety assurance scheme in place; and a safety promotion process.

Safety policy

This first section of an SMS has five main elements. The first is management commitment to a safety policy.

Airlines have to create a safety policy manual. This includes details of management commitment and responsibility, safety accountabilities of managers, appointment of key safety personnel, an SMS implementation programme, and coordination of emergency response planning.

There are also safety accountabilities. These are clearly defined for managers and employees at all organisational levels.

The SMS also requires the airline to establish a safety and quality services department, with a dedicated team.

Ultimately, the airline must aim to manage all risks and hazards to 'as low as reasonably practical' (ALARP) principles. This involves the safety and quality services department recognising all inherent risks, and optimising safety performance by proactively identifying and assessing hazards and safety risks, and taking the appropriate action to mitigate them.

Airlines must appoint safety personnel and establish a safety committee staffed by senior managers, to deal with strategic issues related to safety policies and monitoring performance, and to monitor the effectiveness of the airline's SMS.

Finally, the airline should have an emergency response planning (ERP) team to integrate at airports, within airlines, and air traffic services.

Airlines are required to document all issues related to its safety policy. These relate to management responsibility, safety accountability, appointment of key safety personnel, and the coordination of its emergency response plan.

Hazard identification

The second section of an SMS identifies and assesses operational hazards, and then puts in place improved or new operational procedures to mitigate them. "This is a process with a lot of human interaction where the question: 'Are we aware of all the hazards and risks in our operation?' is continually asked," explains Eddie Rogan, aviation solutions director at OSyS, a wholly-owned subsidiary of Rolls-Royce.

Hazards are captured in various ways within an organisation. For example in an airline they can be reported by staff, discovered as audit findings or automatically generated as an event from a flight data monitoring (FDM) programme. These data are then processed and analysed to identify the underlying causes. Example of hazards are an aircraft not being stable at an altitude of 1,000 feet when on the glideslope on approach to landing, when SOP requires the aircraft to be stable at this point, and an abundance of birds that could lead to a birdstrike.

One of the main elements of a SMS is for airlines to identify operational hazards. Hazards are defined as real or potential events that could lead to an incident or undesirable consequence. Examples of hazards are the frequent occurrence of extreme weather at particular airports.

FDM/FOQA data analysis

Several systems have evolved for identifying and quantifying operational hazards and risks. In the case of many airlines, this comes from analysing flight operations quality audit (FOQA) and FDM data.

"The United Kingdom Civil Aviation Authority (CAA) was the first to mandate the need for airlines to identify and quantify operational hazards and risks through the collection and processing of flight operational data," explains Rogan. "The European Aviation Safety Agency (EASA) also mandated the need for airlines under its jurisdiction to have the same process, termed FDM. The UK CAA name is operations flight data monitoring (OFDM).

"Hazard identification and quantification through the collection and processing of flight operational data is non-mandatory in the US," adds Rogan. "US airlines nevertheless have such systems in place, referred to as FOQA."

FDM and FOQA basically involve the monitoring of an aircraft's operational parameters. Examples are airspeed, altitude, pitch angle, various engine speeds and pressures, and fuel flow in each engine.

The operational parameter data are then processed to find undesirable trends in the aircraft's operation.

"The aircraft's quick access recorder (QAR) records these parameters. These can be just a few dozen for the simpler aircraft types, up to several hundred or even thousands in the modern complex airliners," says Rogan. "The data of monitored parameters are downloaded, processed and analysed using specialist software packages. Processing and analysing data may involve using algorithms.

Raw FDM/FOQA data is downloaded from the aircraft via USB drives, or wirelessly using connectivity systems such as WiFi or cellular. "The raw data are basically in binary format," says Peter Clapp, director at Flightdatapeople.com. "FDM software first converts the data into meaningful units. The data are then analysed by the software and split into flights, flight phases, and then particular events. These are incidences such as engine starts, take-off, climb, and landing.

The analysed data are compared with the minimum and maximum standards for each monitored parameter defined by the aircraft operating manual and the airline. Events are revealed by spikes or deviations from the norm. Examples are instability at 1,000 feet on the approach, heavy landings, long and short landings, overspeeds, and many others relating to the pilots' operation of the aircraft.

"All flights for all fleet types are analysed in the case of most airlines, although US regulations allow a sampling of flights," says Clapp. "The FDM/FOQA is downloaded everyday, and analysed shortly after, sometimes within minutes.

"Airlines can perform FDM/FOQA themselves, or get a third-party specialist to do it for them," continues Clapp.

Several airlines have developed their own in-house FDM processes. British Airways' own FDM process, for example, was SESMA and BAFDA. BAFDA is now marketed by Flightdatapeople.com.

Another example of an FDM system is Teledyne Controls' AirFASE system. This records virtually every operating parameter on the aircraft.

"Airlines that do all their FDM processes themselves need a dedicated team in the flight operations department to perform the analysis," says Clapp. "There are differences in the effectiveness of FDM software. Some software packages are able to identify false positives. That is, an event that the flight operations department is actually interested in. Further to this, there is a need to look at trends to get core information so that the causes behind the most problematic events are fully understood. This is made possible by filters in the software, which allow causal factors to be identified."

Incident reports

A second way that hazards get identified is through incident reports made by airline staff members, such as flight and cabin crew, ground crew, and line mechanics. Such incidents get reported in operations reports.

"Flight safety incident reports primarily come from flight crew, since that is where most incidents are picked up, although they also occur in ground operations and in maintenance," says Rogan. "Some of the more serious incidents have to be reported via a mandatory occurrence report (MOR), which is a form that has to be completed by flight crew, to the airline's regulatory authority. Flight crew can now submit MORs and non-MOR safety reports via mobile devices such as iPads. There is guidance from the aviation authority on which incidents are deemed an MOR.

Typical examples that result in a MOR are in-flight shutdowns of engines, flightdeck instrument failures, and system-related problems. A MOR has to be filed every time that there is a safety-significant occurrence. The general rule is that all hazards have to be reported, and in turn some of these have to be reported to the airline's regulatory authority. While in the past only major occurrences were reported, the modern attitude is that all incidences, including low-level hazards, should be reported."

Safety & quality audits

"A third way of identifying hazards is through safety and quality audits," continues Rogan. "Airlines have auditing processes for assessing the safety of the

Severity	Likelihood				
	Extremely Improbable	Improbable	Remote	Occasional	Frequent
Catastrophic	5.00	10.00	15.00	20.00	25.00
Hazardous	4.00	8.00	12.00	16.00	20.00
Major	3.00	6.00	9.00	12.00	15.00
Minor	2.00	4.00	6.00	8.00	10.00
Negligible	1.10	2.20	3.30	4.40	6.50

Acceptable Tolerable Intolerable

A risk matrix is used to assess a range of parameters and potential risks. A risk matrix is generated for each hazard following the processing and analysis of FDM data, incident reports, and safety audits.

workplace of operations-related airline activities, SOPs, operating and work practices, and safety compliance. "The overall objective of safety auditing is to ask whether the organisation is doing things correctly, or in a way that opens it up to risk," explains Rogan. "This auditing process is very rigid, and examines whether an airline is compliant with all the operating procedures and SOPs at all levels. This will be in its flight operations, maintenance control, flight dispatch, and pilot operations."

The standards for a safety audit come from the IATA operational safety audit (IOSA). Many airlines use this standard. "IOSA approves safety auditors, who visit airlines when conducting an audit," explains Rogan. "There is an ICAO SMS manual, and this generates a checklist of how to perform a safety audit. This is based on IOSA standards and recommended practices. Audits take place every one or two years.

Risk management

A fourth method of hazard and risk identification is risk assessment, associated with management-of-change. "This is a proactive process, where an attempt is made to identify hazards and risks before incidents occur. This is different from a reactive process, where actions are taken after an incident," says Rogan. "The proactive risk assessment system is used by an airline for any management-of-change exercise. This can include any type of change in the airline's operation, such as: flying to new destinations; taking delivery of a new aircraft or engine type; moving to a new main terminal; and adopting a new operational procedure, such as using a new fuel type or electronic flight bag."

An airline is required to document that it did a proper risk assessment, and it can use specialist software for this purpose. The ICAO SMS manual describes the process of assessing risk and filing a report. "Risk assessment and filing reports is done internally, but an airline's regulatory authority will oversee the identified risks to ensure the mitigation actions are completed and effective," explains Rogan.

Analysed results

The findings of all incident reports, safety and quality audits, and risk management and assessment have to be quantified in terms of the level of risk, likelihood of occurrence and severity in the event of an incident. This is achieved through the use of a risk matrix.

The ICAO recommended risk matrix *(see picture, this page)* is used to assess a range of parameters and potential risks. It can be used, for example, as a guide for performing the risk assessment of management change. The system is not only used for SOPs and on-going incidences, but assessing new styles of management or products. An example is the use of a new biofuel. In the case of management changes, incidences may become more frequent, thereby raising the level of risk. An example is the change of aircraft types on a particular route. The switch from a four-engined 747 to a twin-engined 777 on a route into an Indian airport, for example, would raise the likelihood of the total loss of an aircraft due to birdstrike. This is quite a common incident at Indian airports, and is especially hazardous because large birds and vultures can often be ingested into engines. While the probability of a birdstrike is not affected by the change of aircraft type, the change from a four-engined to a twin-engined aircraft increases the risk of total aircraft loss.

The matrix can be generated manually, but is also an integral part of some SMS software providers.

A risk matrix illustrates the combination of the probability and the severity of an incident occurring.

The risk matrix will have five levels of likelihood of a hazard or safety issue happening along the horizontal axis of the matrix, as well as five levels of severity if the incident actually occurs along the vertical axis of the matrix.

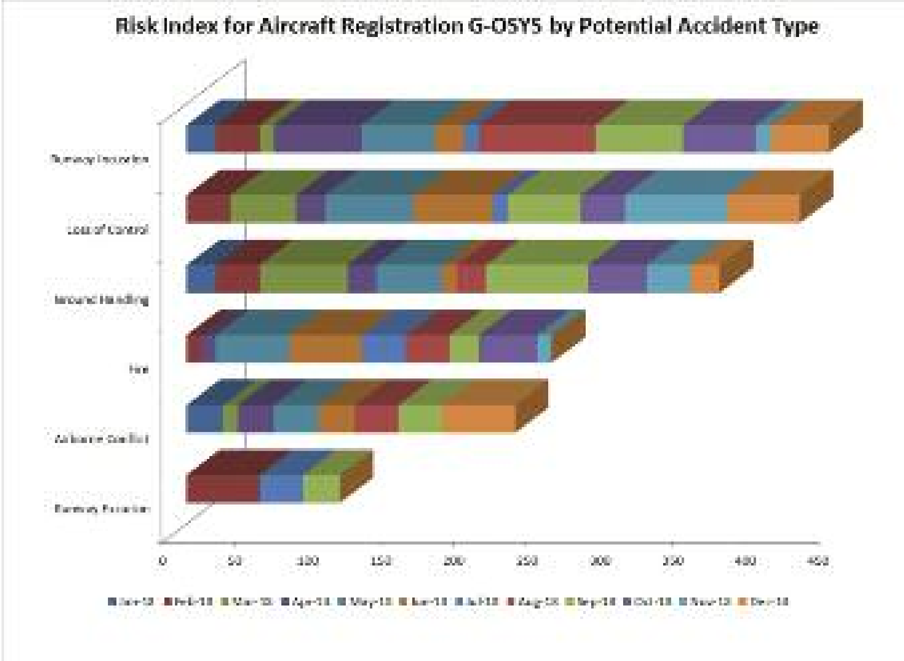
The five levels of likelihood or risk are: rare, unlikely, possible, likely, and almost certain. The 'almost certain' category will have the highest score and be to the right of the horizontal axis, while the 'rare' category will have the lowest score and be at the left end.

The five levels of severity are catastrophic, major, moderate, minor, and negligible *(see picture, this page)*. The 'catastrophic' category will have the highest score, and is at the top end of vertical axis; while the negligible category will have the lowest score, and be at the bottom of the vertical axis.

The matrix grid therefore assesses each risk with one of five levels of likelihood and severity. It thus creates 25 cells with a corresponding total score that is a product of the assessed risk and severity of an incident occurring. If, for example, the likelihood of a risk is assessed as almost certain it may be given a score of five. If the severity of an event happening is assessed as catastrophic, it would also have a score of 5. This event would have an overall score of 25. It would correspond to the cell at the top-right corner of the matrix and be coloured red.

At the other end of spectrum, a particular issue with a rare likelihood of happening is given a score of one, and an issue that is regarded as having a negligible effect or consequences if it were to happen, would also have a score of one. The overall score would therefore be one. This would correspond to the cell in the bottom-left corner of the matrix, and be coloured green.

Each parameter would have a final score or matrix value. The objective would be for each parameter to be as close to the bottom-left corner of the matrix as possible, or in the green cells.



Once all analysis has been completed, SMS software applications can generate reports to indicate an airline's largest hazards or most frequent incidents.

Risk value then indicates if something needs to be done to reduce either the likelihood of an occurrence or an incident if possible, or to reduce the severity.

"This means that, rather than looking at the incidences which occurred the highest number of times in a year, the airline will actually achieve a better level of risk management if it focuses on those incidences with the highest risk and severity values," explains Rogan.

The severity of an event or incident cannot be changed in some cases. Some hazards have a higher severity than others. The only way to improve a parameter's overall matrix score, therefore, in these circumstances is to reduce the likelihood of it occurring.

Each parameter needs to have this matrix and overall score generated or assessed each time flight operations data has been processed and assessed, and the various audits completed. If a parameter's matrix score was in the red or orange cells, then procedures and changes would have to be put in place to reduce the likelihood of an event happening.

"Once the matrix score for each parameter is determined, the airline's SMS team has to decide if it is acceptable. Its decision is based on ALARP principles," explains Rogan.

Safety assurance scheme

Safety assurance is an important component of an SMS. It is the means of recording and demonstrating the safety performance, and ultimately how effective the SMS is.

The main way of achieving this is by continuously monitoring and measuring the outcomes of operational activities. This means that the appropriate and relevant safety metrics and achievable targets are agreed and put in place.

Each organisation could have different and perhaps unique risks associated with its operation and, therefore, these agreed metrics and targets will normally be focused on the current high risk areas. The data for these metrics are normally provided by the various SMS software systems, using built-in analysis and reporting tools.

Finally, a formal continuous improvement process needs to be established to identify the causes of any sub-standard performance of the SMS, determine any implications and eliminate such causes. Often this is achieved by regular independent reviews and surveys of the various operational areas.

Safety promotion

Safety promotion is the ICAO term used to positively influence the individual and organisational behaviour to support SMS concepts and practices. It reinforces the main messages prescribed in the SMS policies, procedures and processes, and seeks to create a positive safety culture through continual safety education and awareness programmes. This is done by using consistent and regular communications channels.

SMS systems

In addition to software tools for analysing FDM and FOQA data for identifying and quantifying hazards, there are also software tools for managing the entire SMS process.

One tool available is OSyS's VisiumAQD. VisiumAQD has more than 100 customers, many of which are first-tier airlines.

VisiumAQD does not perform FDM itself, but does interface with FDM systems. VisiumAQD therefore gets the required stream of processed and analysed data from FDM/FOQA systems. This data is then processed in VisiumAQD and managed in the same way as incidents reported by flight crew.

"VisiumAQD will use the identification of FDM events generated by FDM and FOQA analysis and match these to incidents from incident reports," says Rogan. "An example can be a heavy landing, revealed by the analysis of FDM data, and which should also have been reported by flight crew as an incident."

VisiumAQD uses safety management and quality assurance principles to get a continuous cycle of improvement. This is basically achieved through a process of data feedback, which allows an airline to implement actions to reduce safety risks. "This data is from an interfaced FDM/FOQA system, from incident reports, from safety and risk audits, and from risk assessments," says Rogan. "VisiumAQD uses a risk matrix to determine the risks associated with flight data events, incidents and audit findings.

"The benefit of any SMS software product is that the more airlines that use it, the larger the volume of data that is processed. More improvements are then made as a result," adds Rogan. "A risk matrix for a particular hazard, such as a heavy birdstrike or windshear at a particular airport, can be generated using the data from several airlines."

As in the general SMS process, VisiumAQD continually monitors the airline's operation, collects flight operations and safety-related data, processes and assesses it, and then implements fixes.

The success of SMS relies on a healthy safety culture, robust processes and good software tools to process the wealth of hazard data. "VisiumAQD will generate a range of results to indicate the findings of data analysis," says Rogan. "One example is the generation of a bar chart to illustrate the risk level of all the categories of parameters that are monitored, as well as indicate which are the parameters with the highest risks. VisiumAQD also generates standard reports that trend the risk level or number of actions taken for each parameter over time. AC