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RESEARCH PROJECT EASA.2022.HVP.04

REPORT ON SAFETY MECHANISMS, METHODS AND TOOLS THAT MIGHT CONTRIBUTE TO THE EFFECTIVE IMPLEMENTATION OF SECURITY MEASURES D-4.1

Impact of Security Measures on Safety

Research conducted by:

UK Civil Aviation Authority International

apave Aeroservices

CASRA

An Agency of the European Union

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Apave's core business is to help companies and government services managing their technical, environmental and human risks in the areas of Oil & Gas / Nuclear / Industry / Transportation. In aviation, Apave is committed to offering a range of civil and military aviation safety services, covering oversight authority tasks, audits, technical control, training and consulting services, through specialized and dedicated entities. Apave's staff in aviation enjoy extensive knowledge of the International and European regulatory framework, with a focus on Airworthiness, Flight Operations and Safety Management Systems In 2022 Apave has strengthened its portfolio through the acquisition of Oppida a cyber-security specialist in many highly regulated domains and safety and security exposed businesses. Apave has organised its civil and military aviation risk management consulting services around a unique value proposition with a dedicated entity: Apave Aeroservices (hereafter referred to as ''Apave") has been designated in 2009 as the Group centre of excellence to provide risk management solutions to the Aviation community, including aviation authorities, Air Operators, Industry, Maintenance Organisations (MROs - Maintenance, Repair & Overhaul) and Training Organisations.

APSS Software & Services Ltd is part of the Center for Adaptive Security Research and Applications (CASRA), which was founded in 2008. CASRA emerged from the Visual Cognition Research Group of the University of Zurich, which was founded by Adrian Schwaninger in 1999. Today, CASRA APSS has a workforce of around 35 people, comprising of psychologists, economists, computer scientists, imaging specialists, software developers, aviation security experts, and more, most of which have an academic degree. The main objective of CASRA is to increase security and facilitation at airports and other environments involving people and technology. Through their studies and research on human – machine interaction, it was identified that visual abilities and training determine largely screeners' performance. As such CASRA has been working with a number of aviation security authorities and airports on selection, training and competency assessment processes providing advisory and research as well as their solutions globally.

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ABBREVIATIONS

ACRONYM	DESCRIPTION
ADS	Aircraft Design Standards
AMM	Aircraft Maintenance Manual
ASC-IT	Aviation Safety Culture Inquiry Tool
ASRS	Aviation Safety Reporting System
BEIS	Department for Business, Energy & Industrial Strategy
CAA	Civil Aviation Authority
CAMO	Continuing Airworthiness Management Organisations
CANSO	Civil Air Navigation Services Organisation
CBTA	Competency-Based Training and Assessment
CHIRP	Confidential Human Factors Incident Reporting Programme
CRM	Crew Resource Management
CS	Certification Specifications
CVR	Cockpit Voice Recorder
DANS	Dubai Air Navigation Services
EBT	Evidence Based Training
EU	European Union
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis
GASeP	Global Aviation Security Plan
HAZOPS	Hazard and Operability Studies
HF	Human Factors
HIRA	Hazard Identification and Risk Assessment
HP	Human Performance
HPM	Human Performance Modelling
IASHIM	Intelligent Aviation Safety Hazard Identification Method
IATA	International Air Transport Association
ICAO	Internation Civil Aviation Organisation
IFALPA	The International Federation of Air Line Pilots' Associations
IOSA	IATA Operational Safety Audit
IQSMS	Integrated Quality and Safety Management Software
IRM	Internal Review Meeting
MCDA	Multi-Criteria Decision Analysis
MoC	Management of Change
MOR	Mandatory Occurrence Reporting
MSAT	Management System Assessment Tool

NASA	National Aeronautics and Space Administration
NCASP	National Civil Aviation Security Programme
PBO	Performance Based Oversight
RBO	Risk Based Oversight
RCA	Root Cause Analysis
SA	Safety Architecture
SeMS	Security Management System
SMART	SMS Maturity and Refinement Tool
SME	Subject Matter Expert
SMICG	Safety Management International Collaboration Group
SMS	Safety Management System
SRM	Safety Risk Management
SSO	State Safety Oversight
SSP	State Safety Programme
STPA	Systems Theoretic Process Analysis
STPA-SEC	Systems Theoretic Process Analysis for Security
SWIFT	Structured What-if
TEM	Threat and Error Management
UK	United Kingdom
UK CAA	United Kingdom Civil Aviation Authority
US	United States
USAP-CMA	Universal Security Audit Programme – Continuous Monitoring Approach
USOAP-CMA	Universal Safety Oversight Audit – Continuous Monitoring Approach
WP	Working Paper

1. Executive summary

Security and safety have evolved side by side in aviation, with both overlapping and conflicting priorities. Safety is often described as the more mature of the two areas, and this presents the opportunity for security to draw on existing safety knowledge. To this end, this task report examines methods, mechanisms, and tools (collectively referred to herein as "tools" or "safety tools") in aviation safety that have the potential to enhance aviation security measures.

The report describes and assesses specific deployed solutions in safety, identified through stakeholder consultation and a literature review. An introductory analysis is conducted that highlights the current debate and issues around the applicability of safety tools to security contexts, and a list of definitions is provided that aids understanding of their utilisation.

Safety Management System (SMS) as outlined in ICAO Annex 19, provided a useful structure for reviewing and categorising proposed tools, methods and mechanisms. The 26 presented solutions and tools are organised into four main categories, corresponding to the four pillars of SMS: Safety Policy, Safety Risk Management, Safety Assurance and Safety Promotion. Each pillar includes specific elements that lists a number of tools, processes or methods that are required under SMS.

Safety Management and Policy

- SMS
- Annex 13 – Aircraft Accident and Incident Investigation
- Descriptive analysis

Risk management tools, methods and mechanisms

- Hazard Identification
    - HIRA
    - Intelligent Aviation Safety Hazard Identification Method
    - Systems Theoretic Process Analysis (STPA)
- Risk Management
    - Bowtie
    - Fault Tree Analysis
    - Fishbone

Safety assurance tools, methods and mechanisms

- Performance Monitoring and Measurement
    - Occurrence Reporting
    - Root Cause Analysis methods
    - Risk Based Oversight (RBO)
    - Performance Based Oversight (PBO)
    - Diagnostic Statistical Analysis
    - Aviation Safety Data Mining Workbench
    - Natural Language Processing
    - Multi Criteria Decision Analysis (MCDA)
    - Human Performance Modelling (HPM)
- Management of Change
    - Change Management process
    - Safety Case

- Continuous Improvement
    - Management System Assessment Tool – EASA
    - Aviation Safety Culture Inquiry Tool (ASC-IT)

Safety promotion tools, methods and mechanisms

- Training and Education
    - Competency Base Training and Assessment
    - Evidence Based Training
    - Crew Resource Management (CRM)
    - Human Factors Training

The overview of each presented tool, method or mechanism includes a description and its potential value within security domain. Each tool was assessed with based on its complexity, accessibility to security managers, scalability to different domains, impact its introduction would have on operation, what value it would add to security domain and its overall maturity. Additional resources and reading material for further exploration of each tool are also included in each section.

The presented tools vary in complexity, scalability, added value, maturity or the operational impact they would have if implemented. How these tools are utilised and implemented would highly depend on a specific area of application - whether it be an airport, an air operator, air traffic services or a cargo company. Some tools are low complexity and could be introduced with minimal disruption, whilst others, such as risk or performance-based oversight, are complex system that would require potential regulatory changes, a solid implementation strategy and establishment of a project team.

Implementing any tool would necessitate an impact assessment and a change management approach. As such, recommendations for implementation must be tailored to the specific context. This report does not provide specific recommendations for implementation but serves as a knowledge base for security professionals for security professionals to better understand available tools and assess what could add value in their local context.

2. Problem area

Over the past two decades, particularly in the aftermath of the 9/11 attacks, the landscape of aviation safety and security has undergone significant transformation. While both safety and security have evolved in parallel, this simultaneous development has sometimes led to overlapping requirements and, at times, conflicting priorities. Each domain has independently crafted and implemented risk management strategies tailored to its specific needs and challenges. The goal of Task 4 in this research project is to explore and propose solutions for a more integrated approach to risk management, one that harmonizes the strengths of both aviation safety and security tools to enhance overall resilience.

Task 4.1 is a first subtask of task 4 and its objective is to examine safety tools (including methods and mechanisms) that can contribute to the implementation of security measures. Safety tools have been successfully adapted for the security domain in the past, with Security Management Systems (SeMS) being a prime example. Developed based on Safety Management Systems (SMS), SeMS has been recognised for its value by both industry and regulators in enhancing security. The aviation industry frequently employs safety risk assessment and management methodologies when implementing security measures. Risk management tools such as Bowtie have proven effective in both safety and security contexts. These safety tools and mechanisms share a common goal – identification and monitoring of risk and achievement of the state in which risks associated with aviation activities, are reduced, and controlled to an acceptable level.

Examined safety tools, methods and mechanisms included:

- Tools, methods and mechanisms that are commonly utilised in aviation safety and security without the need for adaptation for example most root cause analysis methods
- Tools, methods and mechanisms that could be used in aviation security domain but are underutilised or utilised in less structured and less standardised way
- Tools, methods and mechanisms that could be adapted to aviation security domain adding value to the overall safety of aviation
- Tools, methods and mechanisms that are utilised exclusively for specific areas of aviation safety and are neither easily adaptable nor add value in other contexts
- Tools, methods and mechanisms that are not easily accessible, that are complex or at early stages of maturity is safety area

The applicability of safety tools to security contexts is a subject of debate, given the distinct paradigms of safety and security. While safety tools are widely used and well-integrated across various areas, their effectiveness in security is less certain, particularly due to concerns about data protection and data sharing in security environments. Tools like CHIRP, which are effective in safety reporting, may face challenges when adapted for security due to these concerns.

Although many safety tools have security counterparts, such as checklists and questionnaires, these are often used in a more fragmented and less researched manner in security contexts. There is a notable lack of academic literature evaluating aviation security tools, with most studies focusing on risk assessment rather than the broader range of tools employed in aviation security. This gap highlights the need for further research, particularly case studies exploring the use of specific safety tools within security systems.

3. Methodology

The following steps outline the methodology implemented in this task to identify safety tools and mechanisms that can contribute to the effective implementation of security measures:

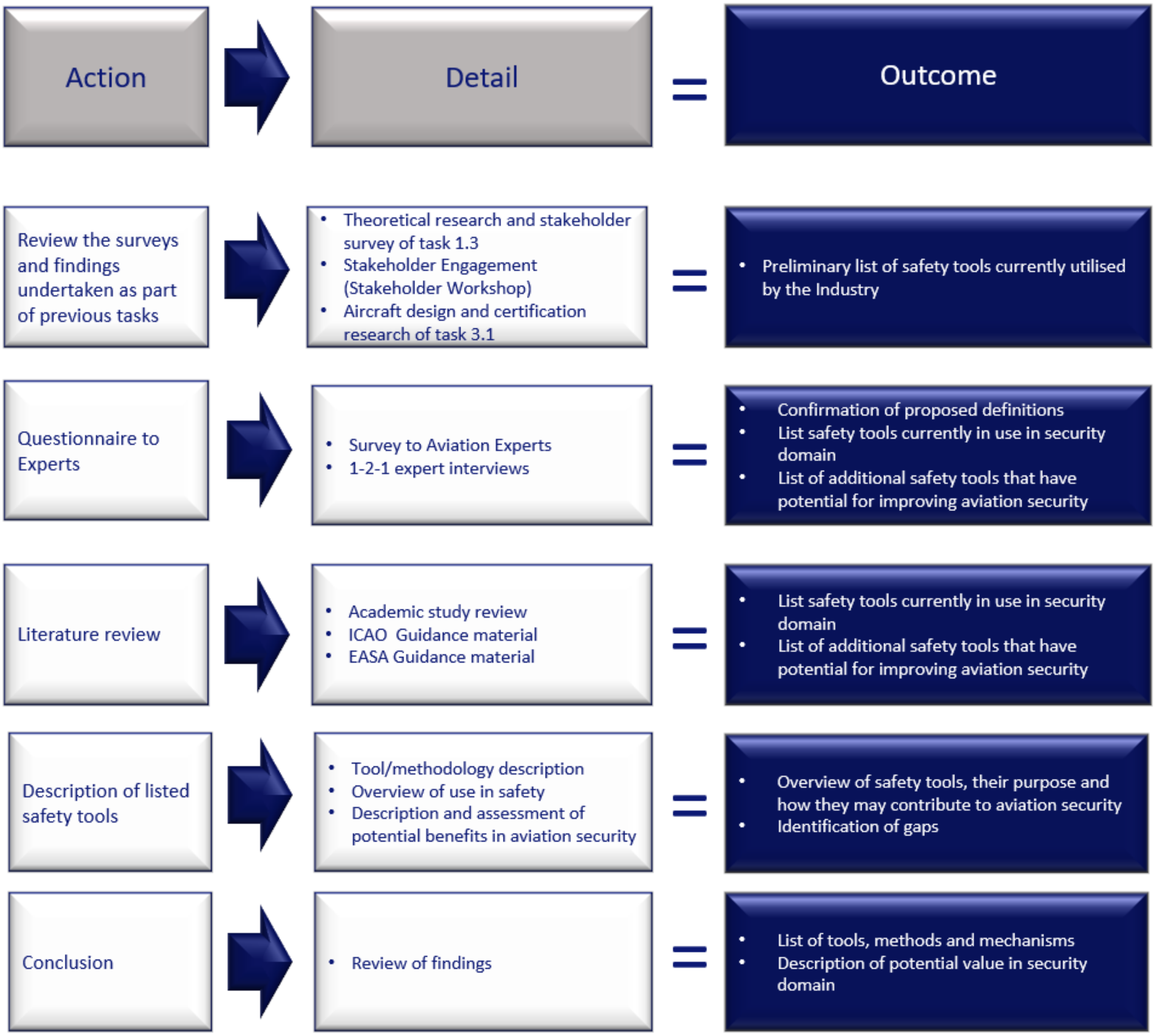

Figure 1. Task 4.1 methodology.

4. Context

The European Union Aviation Safety Agency (hereinafter "EASA") is an agency of the European Union, which has been given specific regulatory and executive tasks in the field of aviation safety. The Agency constitutes a key part of the European Union's strategy to establish and maintain a high uniform standard of safety and environmental protection in civil aviation at European level.

As part of the Horizon Europe Work Programme 2021-2022 on Cluster 5 Climate, Energy and Mobility, the European Commission has entrusted EASA with the management of one specific research action entitled "impact of security measures on safety".

As a result, EASA has awarded a public contract to a consortium of 3 companies:

- CAA International
- Apave Aéroservices
- CASRA

The contract details the four main tasks which are specified in order to achieve the expected outcome which is to understand the nature and extent of the interdependencies between safety and security in order to assess the impact of security measures on safety. In doing so, the research project should identify which processes and job roles are affected by safety–security interdependencies and which certification requirements and licensing activities are affected. In the medium term, safety risk management techniques that can be applied to security will produce harmonised risk assessment methods and support integrated policy and decision-making processes at national and EU level.

The project aims to develop a comprehensive knowledge base for the evaluation of the potential impact of security measures on the safety performances of aviation systems, personnel and operations, including the leading indicators for measuring such an impact (positive or negative) as well as the main factors playing a role in such security-safety dependencies.

The four main tasks are:

- Task 1: Identify the interdependencies between security and safety
- Task 2: Assessment of the impact of security measures on safety
- Task 3: Analysis of certification standards
- Task 4: Integrated risk management

5. Objective of the document

Scope

This report represents deliverable 'D 4.1' of the Impact of Security Measures on Safety (EASA.2022.HVP.04). The aim of this task is to identify the safety mechanisms and tools that contribute to the effective implementation of security measures. The work presented here represents the first output from 'Task 4' which objective is to identify a recommended practices and solutions for the implementation of integrated risk management concept while considering the key differences as well as the main limitations resulting from existing national or EU regulatory frameworks.

Scope context

The following outline represents a simplified context of this research.

The initial three tasks facilitated the establishment of a foundation for the knowledge base. This included an initial exploration of the interdependencies between safety and security, along with the compilation of a list of safety domains potentially affected by security measures. Additionally, a comprehensive list of security threats that may impact the aircraft safety was also developed.

D1.1
List of safety areas affected by security

D1.2
List of job roles with safety and security functions

D2.1
List of threats to the aircraft safety

The subsequent phase involves formulating the methodology for evaluating the impact of security measures on safety. Task 1.1 has catalogued 64 safety – security interdependencies where the effects on safety may occur, whether positive or negative. To pinpoint the actual nature and severity of these impacts (assessment undertaken in Task 2.3), in Task 1.3 the methodology to assess the impact of security measure on safety was developed.

D1.3
Methodology to assess the impact of security measures on safety

Upon the completion of the methodology development, the assessment phase commenced. This involved the practical evaluation of the impact of security measures on safety, as well as a direct assessment of certification standards.

D2.2 D2.3
Assessment of the actual impact of security measures on safety

D3.1 D3.2 D3.3
Detailed assessment of aircraft design, safety and security certification processes

Recommendations for integrated approach to safety – security risk assessment and management will be provided in the final tasks of this study.

D4.1
Safety tools that contribute to implementation of security measures

D4.2.1 D4.2.2 D4.2.3
Provisions for integrated risk assessment and management

D4.3
Recommendations for integrated policy and decision-making process at national and EU level

Figure 2. Context of task 4.1 and this research framework.

6. Definitions

For the purpose of this task the following definitions had to be established:

Safety - the state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level[1].

Safety Management System (SMS) – a systematic approach to managing safety, including the necessary organisational structures, accountability, responsibilities, policies and procedures[2].

Safety measures – international, regional and national standards and recommended practices, including legally binding regulations, best practice, national rules, processes and individual SOPs that are implemented to control and reduce safety risks associated with aviation activities to an acceptable level. In this context EASA regulatory framework provides a collection of safety measures that shall be implemented by States and industry in the European Union.

Safety tool – a mechanism, process, practice, or technology designed to ensure the effective implementation, continuous monitoring, and ongoing improvement of safety measures. It encompasses international standards and regulations, communication methods, accountability frameworks, and tools for raising awareness, all of which contribute to the proactive management and enhancement of safety in various environments.

Aviation security - the combination of measures and human and material resources intended to safeguard civil aviation against acts of unlawful interference that jeopardise the security of civil aviation[3].

Security measures - include international, regional, national and local standards and recommended practices, including legally binding regulations, best practice, national rules, processes and individual SOPs established in order to protect civil aviation from acts of unlawful interference. Legal framework for aviation security constitutes a collection of security measures.

Method: A systematic way of doing something, which describes an approach or process used to achieve a goal. Can be conceptual or applied.

Mechanism: An established route by which something takes place, that is part of a wider system, machine, or behaviour.

Tool: A practice or technology that aids in the execution of a method; a means to carry out a process. Is generally something practical and applied.

*There is often overlap in the definitions – e.g. a Bow Tie Methodology could be defined as a method and a tool, as it is both **way** of doing something in order to achieve a goal and is the **means** to carry out the process. Similarly, some tools will also be mechanisms. Whilst the semantic boundaries between these solutions is somewhat subjective, there is a common goal in that they all aim to facilitate improvements in safety. Understanding the category into which each technique fits can help security professionals to use them appropriately, hence a categorisation has taken place as part of this study – this categorisation should be viewed as an aid to understanding, rather than a bound on the applicability of a method or tool.*

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[1] ICAO, Annex 19, Second Edition, July 2016
[2] Ibid
[3] EC300/2008, Article 3

Worked Example – Reporting Systems

Method – the concept of reporting and the process of making a report, the goal of which could be defined as gathering information on safety incidents to inform future analysis.

Mechanism – the specific reporting system, an established route through which the process of making a report is conducted.

Tool – the technology that enables the reporting to take place, such as a specific online platform.

7. Introduction

Although safety and security have largely developed in parallel and often in isolation, safety tools and mechanisms that attained higher level of maturity, have frequently supported the security domain. The industry, more so than the regulatory environment, seeks to utilise well-established tools that, with some adaptation, can be applied in both domains. This allows, in some cases, for integrated management of safety and security, reducing required human and financial resources, also allowing for more centralised oversight and overview of risks and potential conflicting priorities. Problem of integration and possible solutions in the field of risk management, policy and decision making on a national and EU level will be investigated in Tasks 4.2 and 4.3.

In researching safety tools that could support the effective implementation of security measures, it is necessary to explore those tools that have been successfully utilised in security domain up to date with main example being SMS and how it influenced development of an SeMS. The examination of safety tools, methods and mechanisms in this paper starts by a high-level description of SMS and a case study where the route from SMS to SeMS is described. SMS also provides a useful framework for classification of tools, methods and mechanisms in this report, dividing them in four main categories: policy, risk management, assurance and promotion tools. Specific elements under each pillar are also used to present proposed tools, methods and mechanisms that could contribute to the effective implementation of security measures. For example, the SMS pillar of safety assurance includes tools related to safety performance monitoring and measurement, the management of change and continuous improvement, therefore the tools that could contribute in a similar way in security domain are contained within this section.

Other concepts like 'security culture' also stem from 'safety culture' concept where elements of security culture reflect what was previously done in safety. Within this, Just Culture, reporting or management commitment are equally important and applicable to both safety and security. When ICAO announced 2021 as the Year of Security Culture, a number of tools, videos and materials were produced by ICAO and a number of ICAO Member States. As this concept is now maturing and a number of tools and materials are available on ICAO website Security Culture this concept was not analysed in this report.

ICAO Annex 19 – Safety Management outlines a high-level safety tools, methods and mechanisms which were also reviewed for the purpose of this research. Primarily these include State Safety Programme (SSP), SMS framework, data collection and analysis, State Safety Oversight (SSO) and elements covered under SSO. Out of these tools and mechanisms SMS is described and SMS to SeMS case study is included. SMS also provides a useful framework for classification of tools, methods and mechanisms in this report.

The security equivalent to an SSP is a NCASP. NCASP details security responsibilities, outlines detailed security measures applicable for entities, describes certification, training and oversight requirements and its application in State is verified through ICAO USAP-CMA audit, equivalent to USOAP-CMA in safety. As the NCASP structure, processes and alignment with regional regulations are well established and mature in the European Union, an SSP as a framework was not evaluated in this report.

Other tools in Annex 19 relate to data collection, analysis, protection, sharing and exchange. This was examined and a number of tools are presented in safety assurance section. The mature and robust reporting system and policies are in most cases the prerequisite for a successful use of data analysis tools and methods. Currently security reporting, available data and analysis of it in security domain is much less mature and remains the main point for improvement and development. Data sharing in security domain is difficult due to sensitivity of security information. Presented tools would add value to security domain, however development of appropriate reporting standards and building a security database would need to be addressed first.

Surveillance obligations described in Annex 19 require taking into consideration the entity performance, size, and complexity and it requires priotisation of inspections, audits and surveys towards the areas of greater concern. These are the essential elements of Risk Based Oversight in aviation safety. Both risk and performance-based approaches are described in this report. The process of moving from standard compliance-based oversight and direct-and-inspect approach to a more mature RBO or PBO in aviation security has already started, however both of these approaches require access to performance data and higher degree of maturity within both the regulators and the industry.

Stakeholder engagement and research conducted to date have identified safety risk assessment and management as tools that contribute to the implementation of security measures. Consequently, the risk assessment methodology used in safety is relevant to this task. However, Task 4.3 will provide an in-depth examination and comparative analysis of various risk management methodologies.

8. Summary of previous engagement

Attendees of the Introduction Webinar held on July 5, 2023, were surveyed to establish an initial understanding of the current methodologies employed in assessing the impact of security measures on safety. Among the 150 stakeholders contacted, 55 provided responses to the survey. The aim of this survey was to engage with those who are dealing with the safety-security interdependency on a daily basis and to investigate if the impact of security measures on safety is currently being undertaken. Additionally, this survey aimed to identify the level of integration of safety and security and methodologies that allow to identify risks to safety when new security measures are implemented.

Among the 55 respondents, 10 indicated that safety and security management is fully integrated, while the majority confirmed the separate management of safety and security. Notably, entities such as airports, Aircraft Design Organisations, air carriers, airport supplies organisations, and independent training organisations were identified among those fully integrating safety and security management.

Entities investigating potential safety risks when introducing security measures primarily rely on standard safety risk assessments or risk management procedures. Hazard identification is another common approach, with several entities indicating that they gather information on potential risks through relevant department meetings where the overall impact is assessed. Following answers were provided by the stakeholders:

What methods are used by your organisation to determine and mitigate the level of risk to safety if a new security measure is proposed?

Figure 3. Stakeholder survey conducted in task 1.3.

During the project update webinar of 22nd May 2024 similar question was presented to the audience of the webinar. *What safety tools are you currently using when implementing security measures?* Following answers were provided by the attendees:

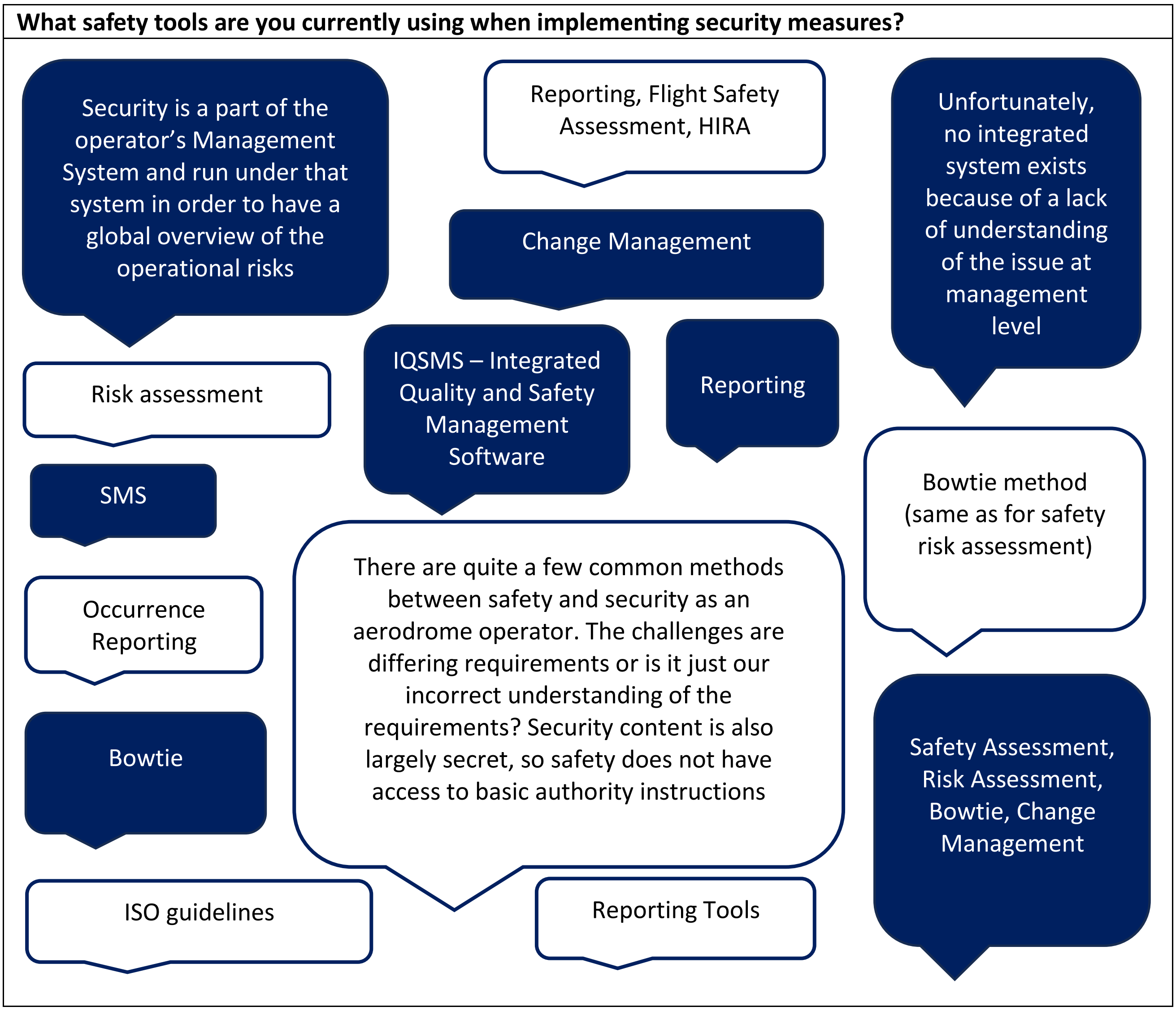

Figure 4. Stakeholder survey conducted during informative webinar on 22nd May 2024

As part of Task 3.1 of this study, research was conducted to investigate existing safety models suitable for analysing aircraft design standards (ADS) against security threats to aircraft safety. The findings and conclusions of Task 3.1 are also relevant to the current task.

The research team identified several risk assessment methodologies and, after thorough analysis and feasibility assessment, selected the bowtie method as the preferred tool for the required analysis. Bowtie methodology or adapted bowtie methodology was also listed by the stakeholders in previous engagement and as such it shall be further analysed in this task as a safety tool that contributes to the implementation of security measures. Other frequently utilised methods were also listed in report 3.1 of this research study[4]:

- Risk matrix
- Decision tree
- Failure modes and effects analysis
- Bowtie model / analysis

[4] Troczynski A., Impact of Security Measures on Safety, D-3.1

- What-if analysis
- Fault Tree Analysis
- Hazard operability analysis

In conclusion, previous engagement and research have already identified a number of safety tools that are currently used by the industry to implement and manage security measures. The most common examples include:

- Safety risk assessment
- Safety Management System
- Management of change
- Occurrence reporting
- Bowtie methodology
- Flight safety assessment

Experts interviewed/surveys for the purposes of this report also raised following points:

- All SeMS components are already in place at the organisational level but require integration into a cohesive system. Achieving this integration should be a key focus of future security policies and regulations.
- There is a strong need for the rapid development of an integrated safety and security system, leading to a unified airport management framework.
- Industry guidelines such as the ACI World's Management of Security Handbook and Eurocontrol's Security Management Handbook offer valuable frameworks for implementation.
- Current Key Risk Areas (KRAs) primarily focus on safety factors. Incorporating security perspectives into KRAs, such as through the use of bowtie diagrams, would help identify potential security failures that could result in safety events, thereby reducing siloed approaches.
- The security sector tends to lag behind safety in terms of integration, largely due to the secretive nature of security operations. Allowing a vetted aviation safety professional to observe and assess security practices could offer valuable insights or assurance.
- Unlike in safety, there is a noticeable lack of detailed documentation and analysis of security incidents, their precursors, and outcomes.
- Security training should not rely solely on eLearning; it must include both theoretical and practical assessments. Additionally, practical security training should be integrated into existing safety training cycles, such as triennial safety training.
- When adopting new tools, it is essential to standardise their application to ensure consistency and effectiveness.
- Existing information-sharing platforms, such as the Aviation Information Sharing and Analysis Centre (A-ISAC) for cybersecurity and EASA's European Information Sharing and Cooperation Platform on Conflict Zones, provide valuable resources.
- The overlap between safety and security functions can create structural challenges, often resulting in siloed practices. To address this, increased regulatory collaboration, including joint audits and inspections, is recommended.

9. Aviation Safety Tools and their Applicability to Aviation Security - Literature Review

Methodology of the literature review

A high-level review of the existing literature was undertaken as part of EASA's research study. This review aimed to broadly evaluate academic research into aviation tools, and their use in the aviation security sphere.

The review looked at a sample of the literature and assembled the findings into a table. An initial evaluation of the emergent themes has been completed, with key points for discussion. Owing to the scope of the overarching project, and the extensive nature of the safety literature, the approach of sampling the literature and indicating significant topics and tools was employed. This naturally limits the extent of the research but does not compromise the validity of the findings.

The nature of a literature review such as this is to use exclusively secondary data sources, allowing the broadest possible field of information to be explored. Credible academic journals and sources were used to ensure validity of findings whilst meeting this aim.

The work was undertaken in an exploratory review style, incorporating some systematic elements for searching (including specific search terms as outlined below). This is not as rigid as a fully systematic review but is more well defined than a fully narrative review, enabling the research to be directed, efficient, and replicable but retaining the flexibility necessary for such emergent themes and exploratory research.

An initial analysis is made of the potential applicability of each of the discovered tools to aviation security – this is limited in its depth but provides an indication of areas of interest to prioritise for further examination.

The literature search strategy below was drafted before conducting the review and was followed during the inspection of the literature.

Literature Search Strategy

Key Themes and Search Terms:
Aviation safety tools
Aviation security tools
Aviation safety mechanisms
Aviation security mechanisms
Aviation safety methods
Aviation security methods
Aviation safety management
Aviation security management

Specific Questions

- What is an aviation safety tool/mechanism/method?
- Which aviation safety tools/mechanisms/methods are available to manage safety risks?
- Which aviation safety tools/mechanisms/methods are widely used?
- Which aviation safety tools/mechanisms/methods are effective?
- In what contexts and business areas are aviation safety tools/mechanisms/methods used?
- What aviation safety tools/mechanisms/methods are currently used in (managing) security (risks)?
- What aviation safety tools/mechanisms/methods have the potential to be applied to aviation security?

- What are the considerations or constraints on using aviation safety tools/mechanisms/methods in aviation security?

Timescale

Aviation safety management is a decades-old concept, evolved from industrial health and safety contexts – hence no older literature will be excluded. However, owing to more recent developments in aviation safety management (such as ICAO's publication of SARPs for State Safety Programmes in 2009, and the development and mandating of Safety Management Systems for aviation) there is likely to be a more relevant subsection of literature from the 2000s and onwards.
The literature search itself was conducted in August 2024.

Suggested Bibliographic Databases

ACM Digital Library - https://dl.acm.org/
Aviation Safety and Security Commons - https://network.bepress.com/engineering/aviation/aviation-safety-and-security/
Flight Safety Foundation - https://flightsafety.org/
Google scholar - https://scholar.google.com/
Science Direct - https://www.sciencedirect.com/
Taylor and Francis - https://taylorandfrancis.com/journals/
Transport Research International Documentation (TRID) - https://trid.trb.org/
Wiley - https://onlinelibrary.wiley.com/

Suggested Journals

Aviation Safety Magazine
Aviation Security International
Computers and Security
The Computer Journal
Human Factors and Aerospace Safety Journal
Information Management and Computer Security
Journal of Air Transport Management
Journal of Applied Security Research
Journal of Transportation Security
Safety Science

Websites

CAA - UK specialist aviation regulator - https://www.caa.co.uk/home/
EASA - European authority for aviation safety - https://www.easa.europa.eu/
IATA - supports aviation with global standards - https://www.iata.org/
ICAO - United Nations specialised agency - https://www.icao.int/Pages/default.aspx

Summary of findings

There are myriad safety tools present within the academic literature. This literature review broadly examines a sample of the existing research in order to firstly, define themes for additional focus, and secondly, to identify specific aviation safety tools. Three main emerging themes are uncovered:

- Tools developed in the safety space that may have direct application in security.
- Existing tools that already apply to security but that require further research or are underutilised.
- Findings on limitations and applicability around the implementation of tools, which could provide learnings for security.

The tools examined fall into the following types or categories (noting that many of these categories can overlap in their definitions):

- Statistical methods, data analysis
- Data mining techniques
- Computer modelling
- General modelling
- Evaluation toolkits (ranking, rating scales, surveys)
- Questionnaires (also as part of toolkits)
- Natural language processing
- Reporting tools / data gathering tools
- Methodological approaches (to incident investigation)
- Machine learning and artificial intelligence
- Information sharing

Discussion points

- There is a question as to the broad applicability of safety tools as security tools, given the different paradigms of safety and security.
- There is more apparent ubiquity in safety tools. Hence tool utilisation should be evaluated for security, (including those tools with cross applicability between safety and security), specifically with respect to reporting tools e.g. CHIRP. One problem could arise in that there are distinct concerns about data protection and data sharing in security.
- Lots of safety tools already have security counterparts (e.g. checklists and questionnaires) but are used in less 'joined up' ways and less well researched.
- Further research in the form of case studies into use of specific safety tools in a security system would be valuable.
- Lots of this research/lots of the literature relates to an *evaluation* of tools as applied to aviation safety – the main points in these evaluations should be considered when applying such tools to aviation security, i.e. what can security learn from the routes safety has already travelled?
- There are many aviation safety tools within the literature, however, a search for "aviation security tools" produces much fewer academic reviews, mostly centred around risk assessment (e.g. Tamasi & Demichela, 2011 [https://doi.org/10.1016/j.ress.2011.03.009]). However, tools *are* widely used in AvSec (e.g. security culture questionnaire, reporting tools (e.g. iPad app at Stansted), demand matrix in UK CAA compliance, SeMS, ICAO security culture toolkit). This points to a lack of research.
- Most of the tools require access to vast amounts of data. This is not available in security (there are fewer incidents, near misses are impossible to measure, data is not shared).
- Potential tools of interest for further exploration include Systems Theoretic Process Analysis (STPA), Data Mining Workbench, SMS Maturity and Refinement Tool, Natural Language Processing.
- Some tools analysed were found to apply methods (e.g. management system assessments) that are already mature in the security space (for example, SeMS frameworks have already established complex methods for assessment within entities). In these areas – where security and safety methods show similar levels of advancement and maturity – it is important that there is continuing collaboration across the spheres, such that there may be continuous learning and improvement.

Operational Feedback

The literature review enabled signposting of a sample of relevant tools, some of which are evaluated in more detail within this report. Additionally, it was prudent to examine the practical, operational feedback within the research.

Generally, **all safety tools have some value for security.** Safety and security are very closely related in how they manage risk. As safety is generally seen as more mature than security, security can continue to learn from safety's pathway. As already highlighted in this paper, there have been strong historical examples of tools transferring successfully from safety to security (e.g. SMS to SeMS). Current examples include competency based training.

Some novel or advanced tools and concepts will provide a high delta for added security value (e.g. performance or risk-based oversight, statistical analysis, data mining) – here the value comes from *first order developments*, defined as new insights, data, and assessments. And some tools are currently already used in security (e.g. root cause analysis, reporting systems) – here the value comes from *second order developments* such as process change or improvements to functionality. It is clear that **culture underpins effective tool use**, with safety and security culture sharing many of the same values and goals, as discussed in this FAA report into Safety Culture Assessment.

The following feedback has been identified within the literature:

- Wilke et al. (2013) report on implementation of data mining in security: A common reporting methodology and language needs to be developed for security reporting, otherwise there is a danger that incomparable data are aggregated, which could lead to inaccuracies in risk assessments and security mitigation strategies based upon them. Furthermore, additional "security promotion" activity must be conducted to improve the level (quantity and quality) of reporting. This includes operational staff, management, and regulators. Stakeholders need to go beyond their current thinking by analysing the bigger picture and collect data that reflects the security of the whole system rather than their particular area of responsibility. This shift in reporting culture will enable collection of comprehensive and comparable datasets to conduct robust security analysis and develop effective mitigation methods (Wilke et al., 2013).
- Nazeri (2003) reports on American Airlines' trial of a data mining approach and found the tool useful – it highlighted areas that needed further investigation, and moreover produced outputs in seconds that would have taken days of manual work. They reported: *"(the tools) will greatly enhance our responsiveness to analyze and report significant concerns, deviations, and correlations."* This is an old paper that explores basic data techniques, however given the infancy of such techniques as applied specifically to aviation security, the insights are still valuable (Nazeri, 2003).
- Stroeve et al., (2022) comment on integrating culture data and SMS data. Feedback on what they call "The Safety (Culture) Stack" approach shows that using results of safety culture surveys as a basis for workshop interactions gives an additional perspective. A safety culture survey provides a broad overview about the safety attitudes of a large part of the personnel and about their perceptions on the way safety is handled in operations. An SMS maturity survey provides views on the effectiveness of approaches in the organisation's SMS according to a group of experts on SMS topics (such as safety managers, staff of a safety department, other managers). Attitudes and perceptions throughout the organisations can best be understood in combination with knowledge on safety performance and SMS details to arrive at organisational measures that support advancing the level of safety (Stroeve et al., 2022).

Literature review with list of sources, summary description and comments can be found in Annex A of this paper.

10. Safety tools that may contribute to Aviation Security

There are a number of tools and mechanisms primarily used in safety that are also common in security domain and are often listed by the industry as contributors to the overall aviation safety. Academic reviews explore additional areas and tools. Presented tools vary in their maturity, complexity and scalability. This section lists, describes and provides assessment of safety tools. Additionally, each described tool includes list of further guidance that may be explored to gain further understanding of given tool.

The assessment criteria are defined by six values: complexity, accessibility, scalability, impact on operation, added value, and maturity – each with a score from 1-5 stars. There are many criteria that can be used to define the overall competency of a tool, however the six below represent the key areas that control success, and to a sufficiently high level to allow evaluation and comparison across a broad range of tools.

Criteria	
Complexity	**The level of sophistication in a tool and how straight-forward it is to use and understand.** A low score here indicates a basic tool without complex features, whereas a high score indicates a very complicated tool, perhaps using advanced computer modelling techniques and artificial intelligence.
Accessibility	**The level of effort, resources, and technical challenge associated with implementing a tool.** A low score indicates that a tool that requires a lot of resource and specialist knowledge to implement, whereas a high score indicates that a tool can be implemented easily by the average security operation.
Scalability	**The capacity of the tool's usage to be expanded, both within and across operational areas.** A low score indicates a tool that is difficult to expand, either for reasons of specificity or resource, whereas a high score indicates a tool that can apply in multiple operational areas and/or can be expanded without excessive resource cost.
Impact on operation	**The degree of negative impact a tool has on operational process, or how disruptive the use is to standard operating procedures.** A low score indicates a limited impact on standard operating procedures and easy integration, whereas a high score indicates a large degree of change required to use the tool effectively.
Added value	**The level of positive impact a tool has on the end-users or the business, specifically in enhancing security standards, but also in efficiency and user experience.** A low score indicates that a tool will potentially add little value to the security process, whereas a high score will add significant improvements to the standard. Low value also indicates that the method or tool may not be entirely suitable, whilst some specific elements could add value. A number of tools could be assessed as low in current security environment, however with future developments and improvements the given tool may provide more significant additional value.
Maturity	**How widely used and well-developed a tool is.** A low score shows that a tool is relatively novel and under-utilised or under-developed, whereas a high score shows that a tool is widely used and has been developed over a longer time period, hence there is better data available on its implementation and use.

Table 1. Assessment criteria.

There are numerous tools that can be implemented within aviation safety and security. Some may bring significant value and advances in security standards, whilst others may not have any significant impact.

Additionally, the complexity and accessibility can vary greatly – some tools may require minimal effort, whilst others are more challenging. The scoring system utilised in this report aims to set up consistent criteria to enable objective comparison between tools for different values. The goal is to list mechanisms, methods, and tools that can be useful for security, but also to serve as a decision-making tool for industry. Where tools with adverse scores are listed - although these may not be recommended as useful – the aim is to demonstrate the full scoring and evaluation process and to allow industry to wholly comprehend the scoring, so that they may make their own evaluations of potential tools and mechanisms.

The scoring system has the advantage of applying a consistent and comparable standard, which allows stakeholders to leverage the insights herein to make plans about which to use, which are most appropriate to their specific areas of operation, and also to identify risk management aspects. The criteria will assist in evaluation and prioritisation of the features based on whichever score has local importance and provides a clear understanding of the trade-offs involved in implementing different tools; it allows stakeholders to assess the potential impact of a feature against the effort required to implement it.

Although any numerical scoring system applied to qualitative criteria (e.g. complexity) necessarily has some degree of subjectivity, it is the value in *comparing* the tools that stands-out – users must remember that this scoring is a guide and allows industry to adapt and iterate.

10.1 Safety policy and management tools, methods and mechanisms

This chapter introduces and explores tools and methodologies crucial for the effective management of aviation safety that are part of the first pillar of SMS – *Safety Policy* and include general management of safety but also emergency response and planning. Central to this discussion is the Safety Management System (SMS), which serves as a comprehensive framework for identifying, assessing, and mitigating risks within aviation operations.

SMS	**Regulators & Industry**

ICAO Annex 19 defines Safety Management System (SMS) as *"a systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies and procedures.*[5]*"* EASA expands further on this definition: "*'safety management system' means a systematic approach to managing aviation safety including the necessary organisational structures, accountabilities, policies and procedures, and includes any management system that, independently or integrated with other management systems of the organisation, addresses the management of safety*[6]*".*

An SMS is a framework comprising of processes designed to facilitate proactive, risk-based decision-making in daily operations. The primary focus of an SMS is to continuously enhance the overall safety of the aviation system by proactively identifying safety issues and ensuring corrective actions to reduce the risk of those issues becoming unwanted events are undertaken. Through proactive risk management and continuous monitoring, an SMS aims to prevent incidents and accidents, ensuring the highest safety standards in all aspects of aviation operations[7].

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[5] ICAO Annex 19 – Safety Management, July 2016.
[6] Easy Access Rules for Occurrence Reporting (Regulation (EU) No 376/2014), Published December 2022.
[7] SMICG, 10 THINGS YOU SHOULD KNOW ABOUT SAFETY MANAGEMENT SYSTEMS (SMS) at: sms-docs-Safety-Management-International-Collaboration-Group-(SM-ICG)-phamphlet-A4--v4.pdf (europa.eu)

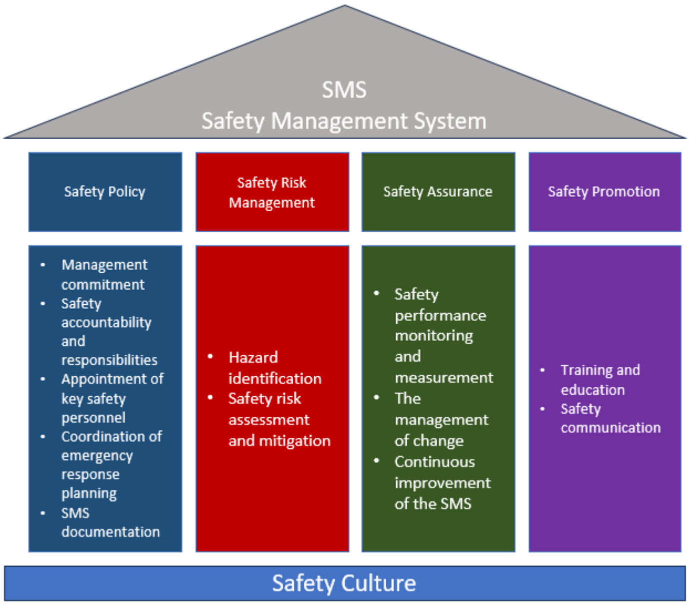

Figure 5. SMS Framework - 4 pillars and 12 elements as described in ICAO Annex 19

Under each element of the 4 pillars there are specific processes or policies that enable effective management of risk. ICAO Annex 19 in Appendix 2 provides below a framework for SMS.

1. Safety policy and objectives
1.1 Management commitment
1.2 Safety accountability and responsibilities
1.3 Appointment of key safety personnel
1.4 Coordination of emergency response planning
1.5 SMS documentation

2. Safety risk management
2.1 Hazard identification
2.2 Safety risk assessment and mitigation

3. Safety assurance
3.1 Safety performance monitoring and measurement
3.2 The management of change
3.3 Continuous improvement of the SMS

4. Safety promotion
4.1 Training and education
4.2 Safety communication

For effective implementation of these processes, the organisation must have an effective system to collect, process and analyse safety data. Safety data can be obtained through accident and incident investigations, mandatory, voluntary and self-disclosure reporting systems. Effective root cause analysis and implementation of Just Culture are essential for encouraging safety reporting and ensuring a substantial database.

Stakeholder engagement indicates that entities that are mandated to implement and maintain SMS may also use it for implementation of security measures. SMS is a complex but mature system of which different elements are also suitable or already utilised in the security domain.

CASE STUDY – From SMS to SeMS

Safety Management Systems in aviation was developed as a systematic approach to managing safety, aiming to enhance safety performance through proactive risk management. The development of SMS was influenced by several key factors. First, the aviation industry's expanding complexity and the increasing number of flights highlighted the need for a more structured and proactive approach to safety. The introduction of concepts like James Reason's "Swiss Cheese" model of accident causation, which emphasised the importance of understanding and managing latent failures within systems, also played a significant role.

In the 1990s, ICAO began advocating for a formalised safety management framework, recognising the need for an approach that could be integrated into all aspects of aviation operations, from airlines to air traffic control and maintenance. ICAO's efforts culminated in the inclusion of SMS requirements in ICAO Annex 19, which was specifically dedicated to Safety Management and became effective in 2013.

SMS was developed around four key components: safety policy, safety risk management, safety assurance, and safety promotion. These components work together to ensure that safety is managed systematically and that risks are identified, assessed, and mitigated before they lead to incidents. SMS requires the active involvement of all levels of an organisation, from frontline employees to senior management, ensuring that safety is ingrained in the organisation's culture.

Over time, SMS has become a global standard in aviation safety, adopted by airlines, airports, maintenance organisations, and air traffic service providers. It represents a shift from reactive to proactive and predictive safety management, focusing on continuous improvement and the prevention of accidents before they occur.

SMS became mandated in aviation through a gradual process led by ICAO, culminating in the adoption of SMS requirements into global and national regulations. The formalisation of SMS in ICAO Annex 19 marked the standardisation of safety management practices across the aviation industry, making SMS an essential component of aviation safety worldwide.

The initial EASA SMS requirements were introduced through Regulation (EU) 290/2012, covering authority and organisation requirements in the areas of flight and cabin crew, and Regulation (EU) 965/2012, addressing air operations. These requirements have since been gradually extended to other parts of the aviation system, including Air Traffic Management and Aerodromes, and will eventually be integrated into regulations for Initial and Continuous Airworthiness[8].

The development of Security Management Systems (SeMS) in aviation emerged as a response to the evolving and increasingly complex security threats facing the industry. The need for SeMS arose from a growing recognition that traditional, reactive security measures were insufficient to address the evolving threats faced by the aviation industry. There was a clear gap in the systematic management of security risks, similar to the gap SMS addressed in safety management. SeMS replicated SMS route to develop standardised approach to security management. Much like SMS, SeMS was established to provide a systematic, proactive approach to managing security risks, with the goal of preventing security breaches and ensuring the safety of passengers, crew, and aircraft.

Key elements of SMS, such as a proactive approach to identifying hazards, risk management processes, and the establishment of safety culture, were adapted to the security context. This involved identifying potential security threats, assessing vulnerabilities, and implementing measures to mitigate risks.

Just as SMS gained support from ICAO and national aviation authorities, SeMS also garnered similar backing. In 2002 IATA established SeMS that currently forms part of IOSA requirements. In 2009 SeMS was incorporated as guidance material in ICAO Doc 9873 – Security Manual building foundation for international

[8] EASA, *SMS – Europe* at: SMS - Europe | EASA (europa.eu)

recognition. In the UK DfT and CAA published SeMS framework (CAP 1223) for UK industry after 18 months industry consultation period. SeMS was then rolled out on a voluntary basis, not as a regulatory requirement and in 2020 Phase 2B of implementation was launched - this is a phase where an entity has developed an operating and effective SeMS and provides ongoing continuing assurance in the form of regular data submissions and an annual assurance assessment.

Essential elements SMS vs SeMS (UK and ICAO models)

	SMS	SeMS
Safety Policy	Management commitment	Management commitment (ICAO model, UK model)
	Accountability and responsibilities	Part of Management commitment (ICAO model) Accountability and responsibilities (UK model)
	Coordination of emergency response planning	Incident response (ICAO model, UK model)
	SMS documentation	Part of Management commitment – Security Policy Statement (UK model)
Risk Management	Hazard identification	Threat and risk management (ICAO model, UK model)
	Safety risk assessment and mitigation	Threat and risk management (ICAO model, UK model)
Safety Assurance	Safety performance monitoring and measurement	Performance monitoring and continuous improvement (ICAO model) Performance monitoring, assessment and reporting (UK model)
	The management of change	Threat and risk management (ICAO model) Management of change (UK model)
	Continuous improvement of the SMS	Performance monitoring and continuous improvement (ICAO model) Continuous improvement (UK model)
Safety Promotion	Training and education	SeMS training programme (ICAO model) Security education (UK model)
	Safety communication	Communication (ICAO model, UK model)

Approach to SMS assessment vs SeMS assessment

SMS UK assessment	SMS EASA tool	SeMS UK assessment
Present: There is evidence that the 'marker' is clearly visible and is documented within the organisation's SMS Documentation	Present: there is evidence that the relevant item is documented within the organisation's Management System Documentation	Phase 1 SeMS Assessment is to establish if SeMS is "Present and Suitable". The organisation should be able to clearly describe or demonstrate how SeMS requirements will be met
Suitable: The marker is suitable based on the size, nature, complexity and the inherent risk in the activity	Suitable: the relevant item is suitable based on the size, nature, complexity of the organisation and the inherent risk in the activity	
Operating: There is evidence that the marker is in use and an output is being produced	Operating: there is evidence that the relevant item is in use and an output is being produced	At the Phase 2 Assessment the organisation will be asked to evidence the processes

Effective: There is evidence that the element or component is effectively achieving the desired outcome	Effective: there is evidence that the relevant item is achieving the desired outcome and has a positive safety impact	described within Phase 1 Assessment, and provide assurance that the SeMS is "Operating and Effective"

A number of tools, methods and mechanisms deriving from SMS are already present and utilised in aviation security including risk assessment and management, safety culture, performance monitoring or management of change. The structure of SMS provided a foundation for categorisation of tools, methods and mechanisms in this report.

Safety Management System (SMS) – Management tool	
Complexity	★ ★ ★ ☆ ☆
Accessibility	★ ★ ★ ★ ★
Scalability	★ ★ ★ ★ ★
Impact on operation	★ ★ ☆ ☆ ☆
Added value	★ ★ ★ ★ ★
Maturity	★ ★ ★ ★ ★
SMS is an approach to safety management that comprises a number of elements that can be considered safety tools. Implementation of an SMS requires consideration of all the required elements under the framework; however, it does not necessitate the use of specific software solutions and may therefore be assessed as moderately complex. There is an abundance of literature on this topic, and the framework is widely accessible. The case study of SeMS development further demonstrates the high scalability and significant value of an SMS framework in security domain.	

Table 2. SMS Assessment.

SMS Guidance

- EASA ICG. 10 Things You Should Know About Safety Management Systems (SMS) at: sms-docs-Safety-Management-International-Collaboration-Group-(SM-ICG)-phamphlet-A4--v4.pdf (europa.eu)
- CAA, Safety and Airspace Regulation Group. CAP795 - Safety Management Systems (SMS) guidance for organisations, at: cap795_sms_guidance_to_organisations.pdf (caa.co.uk)
- ACI World. Management of Security Handbook, First Edition 2020
- Eurocontrol. Security Management Handbook, A Framework, Edition 1.0, 2008

ICAO Annex 13 – Aircraft Accident and Incident Investigation — Regulator

ICAO Annex 13 - Aircraft Accident and Incident Investigation which deals with the investigation of aircraft accidents and incidents, is primarily focused on safety-related occurrences. Its main objective is to improve aviation safety by determining the causes of accidents and incidents without apportioning blame or liability. However, while Annex 13 is specifically designed for safety investigations, some of its principles and methodologies could be adapted to the aviation security context[9].

[9] ICAO Annex 13 – Aircraft Accident and Incident Investigation. Twelfth Edition, July 2020.

Annex 13 outlines a systematic approach to investigating accidents and incidents, which includes gathering evidence, analysing information, and identifying causes. This systematic approach can be valuable in aviation security investigations, such as examining security breaches or terrorist attacks. The thorough, objective investigation process helps in understanding how and why a security event occurred.

The processes of collecting data, interviewing witnesses, and analysing findings in Annex 13 can be adapted to security incidents. This might involve gathering information from security personnel, analysing surveillance footage, and reviewing security procedures and their effectiveness.

Just as Annex 13 seeks to identify contributing factors to accidents, a similar approach could be used in security investigations to understand the vulnerabilities that were exploited in a security breach. This could include identifying lapses in security protocols, human factors, or weaknesses in security infrastructure.

One of the key outputs of Annex 13 investigations is the issuance of safety recommendations to prevent future occurrences. Similarly, security investigations could lead to recommendations aimed at strengthening security measures, improving training, or enhancing response protocols to prevent similar incidents in the future.

While Annex 13 can provide a useful framework, there are important limitations when it comes to aviation security. Unlike safety investigations, security incidents often involve criminal intent. This requires a legal and possibly punitive approach, which differs from the non-punitive focus of safety investigations. The threat is external to the organisation unless it is an insider attack and investigation will be carried out by relevant national authorities including law enforcement. Security investigations might require different protocols, particularly in terms of handling sensitive or classified information, which is not typically a consideration in safety investigations.

Some aspects of the investigative approach in aviation safety, such as those outlined in Annex 13, could be beneficial to aviation security. For example, Annex 13, Standard 6.5, states that "*In the interest of accident prevention, the State conducting the investigation of an accident or incident shall make the Final Report publicly available as soon as possible and, if possible, within twelve months.*" While security investigation reports may contain sensitive or confidential information, the principles of information sharing and cooperation, which are foundational to a strong safety culture, could be better applied to security. By making security investigation reports publicly available in a redacted form that protects confidential details, the aviation community could benefit from shared lessons and insights, enhancing overall security practices.

<u>Security Value</u>

Security attacks, given their criminal nature and intent, often require collaboration with law enforcement or military organisations during investigations. Consequently, the findings and final reports of such investigations are typically classified and not made publicly available. However, despite the confidential nature of security investigations, certain tools and methodologies from safety investigations can still be beneficial. For instance, the use of structured investigation checklists can ensure thorough and consistent examination of incidents, while guidance on the development of final reports can help standardise documentation and facilitate internal learning. Adapting these approaches could enhance the rigor and effectiveness of security investigations, even if the full details remain confidential.

Annex 13 requires public release of the final report of accident. Revisiting approach to report sharing and assessment of how the security accident reports can be shared or what elements of the reports can be shared without compromising sensitive information, could drive improvement and learning.

Annex 13 – Accident Investigation tool	
Complexity	★ ★ ★ ☆ ☆
Accessibility	★ ★ ★ ★ ★
Scalability	★ ☆ ☆ ☆ ☆
Impact on operation	★ ★ ★ ★ ★
Added value	★ ☆ ☆ ☆ ☆
Maturity	★ ★ ★ ★ ★
This method is of moderate complexity, requiring specialised knowledge and substantial practical experience in the field. The established nature of Annex 13 makes it highly accessible, with standardised processes widely recognised and consistently applied across aviation. However, scalability is limited, as security investigations often involve coordination with multiple government agencies, including law enforcement or intelligence services which operate within highly developed systems often linked to national security policies. These systems are mature and well-integrated, making the introduction of a different model potentially impractical and likely to significantly impact operations. Consequently, the added value of adapting this method for security is assessed as low. Nevertheless, certain elements from safety investigations, such as improved information sharing and broader access to investigation reports, could offer potential value if incorporated into the security domain.	

Table 3. ICAO Annex 13 accident investigation tool assessment.

Descriptive Analysis — Regulator & Industry

Descriptive analysis in data analysis is a statistical method that involves summarising and organising data to make it easier to understand. It focuses on describing the basic features of the data, providing simple summaries and visualisations that highlight patterns, trends, and relationships within the dataset. Descriptive analysis does not make predictions or test hypotheses but rather offers an overview of what the data shows. This safety tool was identified through literature review undertaken for this task.

Applying the descriptive analysis method used by Barroso and Munoz-Marron (2023) to aviation security could offer potential benefits, particularly in understanding the evolution of global security culture and improving security incident investigations. This method involves analysing historical data and incidents to identify patterns and trends, which could help trace the development of a global security culture, similar to how aviation safety culture has evolved. By examining different eras of aviation security, this approach could highlight how security measures and incident responses have changed over time, and how they have contributed to a broader, more cohesive security framework.

It may be argued that an extensive literature on past security attacks already exists and more detailed analysis and information sharing of current attacks would be more beneficial for the security domain. Security incidents often involve sensitive or classified information that cannot be publicly shared. Unlike safety incidents, which can be openly analysed and reported, security investigations may be constrained by confidentiality requirements, limiting the availability of comprehensive data for analysis.

Security threats can be multifaceted and evolve rapidly, making it challenging to categorise and analyse incidents in a systematic way. The dynamic nature of security risks requires continual updates to methods and models, which may not be as straightforward as those applied to safety incidents. Security investigations may involve multiple agencies (e.g., law enforcement, intelligence, and aviation authorities) with different data formats and standards. Integrating these diverse sources into a cohesive analysis framework can be complex and time-consuming.

The culture and operational practices surrounding security and safety can differ significantly. Applying methods developed for safety to security may require adjustments to account for these differences, including variations in investigative approaches and reporting standards. Organisations and agencies involved in security may be resistant to adopting more open approach, especially if they require significant changes to existing practices or if they challenge established norms.

Security Value

One benefit of this method would be the ability to pinpoint when significant shifts in security culture occurred, particularly in response to major incidents. Understanding these shifts could help security professionals anticipate future challenges and adapt more effectively. Additionally, this analysis could enhance root cause analysis in security investigations by relating security incidents to the specific cultural and operational factors that were prevalent at the time. This would not only improve the accuracy of investigations but also lead to more targeted and effective security measures in the future.

Furthermore, just as the air transport industry's evolution has been marked by significant advances in safety due to the knowledge gained from accident investigations, a similar approach in security could lead to substantial improvements. By systematically analysing past security incidents, the industry could develop a deeper understanding of the factors that contribute to security breaches and use this knowledge to prevent future occurrences. This could also foster a more proactive and informed security culture, where lessons learned from past incidents are continuously integrated into current practices, ultimately leading to a safer and more secure aviation environment.

Implementing descriptive analysis methods and integrating them into security practices may require additional resources, including trained personnel, advanced analytical tools, and time. Organisations may face constraints in terms of budget, personnel, and technological capabilities.

Descriptive Analysis – accident investigation tool	
Complexity	★★★☆☆
Accessibility	★★★★★
Scalability	★★★★★
Impact on operation	★☆☆☆☆
Added value	★★★★★
Maturity	★★★★★
Descriptive analysis is a medium complexity method; the approach is simple to understand but may require some advanced analysis in part. It remains broadly accessible and scalable and is a very high level method that can be picked up and applied in any area. It does not require any change to operational process, as is focused entirely on existing (past) data. As a mature approach, it represents high potential value in security that could be applied locally by security managers in their specific areas, or internationally by regulators when assessing global risk.	

Table 4. Descriptive Analysis – investigation tool assessment.

Descriptive Analysis Guidance

- Barroso and Munoz-Marron (2023). Major Air Disasters: Accident Investigation as a Tool for Defining Eras in Commercial Aviation Safety Culture. [View of Major air disasters: accident investigation as a tool for defining eras in commercial aviation safety culture (vilniustech.lt)]

10.2 Risk management tools, methods and mechanisms

This chapter introduces and explores the various tools and methodologies for the effective risk management and hazard identification in aviation safety. This section identifies and describes tools typically used for hazard identification, risk assessment and management.

Hazard Identification

HIRA – Hazard Identification and Risk Assessment **Regulator & Industry**

HIRA (or SRM – Safety Risk Management) is a systematic process used in aviation to identify potential hazards and assess the associated risks to ensure the safety and security of operations. It is an essential component of aviation SMS and is applied across various domains in aviation, including flight operations, maintenance, air traffic control, airport management, and more.

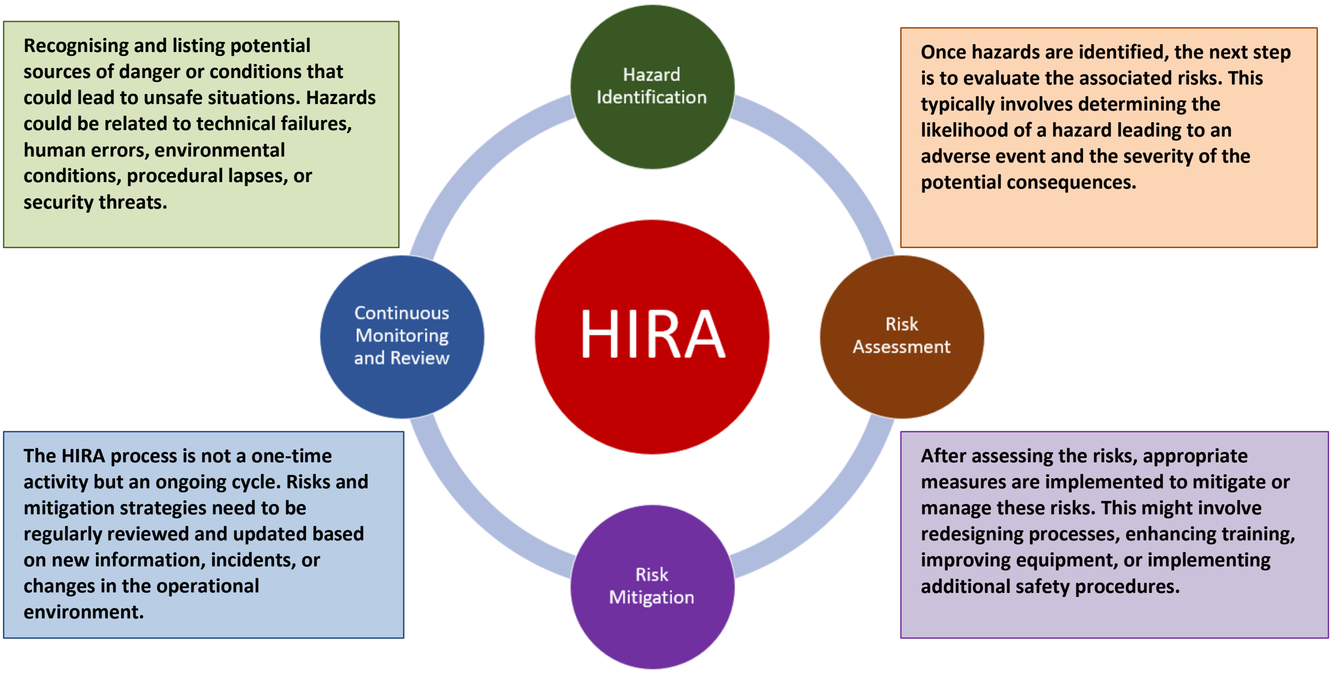

Figure 6. HIRA assessment.

Hazard identification

There are two main methodologies of hazard identification, reactive and proactive. **Reactive** hazard identification involves analysing past incidents and accidents to uncover hazards that contributed to these events, revealing system deficiencies. In contrast, **proactive** hazard identification focuses on collecting and analysing data from less severe events or routine processes to identify potential hazards before they lead to significant incidents. This proactive approach relies on safety data from flight data analysis programs, safety reporting systems, and the safety assurance function to predict and prevent accidents. ICAO SMM also provides guidance and identifies main sources for hazard identification which include[10]:

- Monitoring of normal operations
- Automated monitoring systems
- Safety reporting
- Audits
- Training feedback forms
- Service provider safety investigations
- Aviation accident reports
- State reporting systems and state oversight reports
- Trade associations and information exchange

Safety Management System and Safety Culture Working Group (SMS WG) in the *Guidance on hazards identification* provides a list of tools and techniques for hazard identification which include:

- Brainstorming
- Hazard and Operability Studies (HAZOPS)
- Checklists
- Failure Modes and Effects Analysis (FMEA)
- Structured What-if (SWIFT)
- Dynamic Models
- Future Hazards Identification through FAST method

<u>Security Value</u>

Examining the current development state of aviation security, such methods are already well established, and form a key part of security management systems. Threat identification, risk assessment, risk mitigation, and continuous improvement are all key concepts in the aviation security community. Furthermore, the hazard identification element is different in security, as intentional threats must be considered. However, by reviewing these defining processes as they are applied in safety, further knowledge can be gained on how they apply in security.

For example, analysis of incidents in human-technical systems such as aviation has long been identified within safety science as lacking objectivity and having a narrow focus on cause. Searching only for a technical “root cause” leading to only a technical fix, whilst at the same time there could be a cultural issue contributing to the same incident – thus there would need to be a safety culture improvement to achieve comprehensive mitigation. These valuable safety insights, gained from incident investigation as part of the HIRA process, can be considered and applied to the security domain.

Additionally, there is scope for using this method to aid in the design of integrated security and safety risk management processes.

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[10] ICAO Doc 9859 – Safety Management Manual. Fourth edition, 2018.

HIRA - Risk Management tool	
Complexity	★ ★ ★ ☆ ☆
Accessibility	★ ★ ★ ★ ★
Scalability	★ ★ ★ ★ ★
Impact on operation	★ ★ ★ ★ ☆
Added value	★ ★ ☆ ☆ ☆
Maturity	★ ★ ★ ★ ★
This method is straight-forward to use and understand, although there are in-depth steps to complete within the cycle. It is highly accessible, with many resources available to guide users in the application of the process. Similarly, it is broad enough to apply to many areas and has been extensively researched and used throughout the safety domain. There is a low value score, as this method is already established in security, however there is some benefit to be gained from reviewing this safety method to improve the same processes as used in security.	

Table 5. HIRA Assessment.

HIRA Guidance

- ECAST, GUIDANCE ON HAZARDS IDENTIFICATION. Safety Management System and Safety Culture Working Group (SMS WG). March 2009.
- UK CAA. CAP 760, Guidance on the Conduct of Hazard Identification, Risk Assessment and the Production of Safety Cases: For Aerodrome Operators and Air Traffic Service Providers. December 2010.
- ICAO Doc 9859 – Safety Management Manual. Fourth edition, 2018.

Intelligent Aviation Safety Hazard Identification Method — Regulator & Industry

Intelligent Aviation Safety Hazard Identification Method described by Xiong[11] combines Text Mining and Deep Learning (DL) technologies as applied on the incident data and hazard knowledge. This method uses advanced technology to analyse aviation safety incident reports and identify key safety hazards.

This methodology firstly involves a model called BERT reading through incident reports to understand the meaning of words based on their context. The information from BERT is then passed to another model, Bi-LSTM-CRF, which digs deeper into the text to find specific safety hazards mentioned in the reports. These identified hazards are stored in a database called Neo4j, which helps visualise connections between different incidents and hazards. This creates a "knowledge graph" that shows how different safety issues are related. With this knowledge graph, analysts can quickly see the relationships between incidents and hazards, making it easier to understand what caused an incident and how to prevent similar ones in the future.

The method was tested with real incident records from an aviation maintenance company, proving that it can effectively identify safety hazards and help manage aviation safety more effectively.

[11] Xiong et al., (2024). Enhancing aviation safety and mitigating accidents: A study on aviation safety hazard identification. At: Enhancing aviation safety and mitigating accidents: A study on aviation safety hazard identification - ScienceDirect

The paper shows that the proposed method can effectively identify civil aviation safety hazard entities and uncover the intrinsic connection between incidents and hazards. This allows relevant personnel to understand the nature and mechanism of an incident and proactively apply preventative measures.

<u>Security Value</u>

In security context if adapted, this method could be beneficial for better understanding of the connection between threats/risks and incidents. An empirical value to security is hard to ascertain, however as the complexity and dynamics of aviation security systems continue to increase, there is value in examining such advanced methods as Deep Learning, which facilitate complex analyses.

The method provides a solution for dealing with poor quality (i.e. unstructured) reporting data, which is a current issue with security. There is a need within security for knowledge from security reports to be presented in an accessible format, such that relevant decision makers can analyse the incident mechanism rapidly and comprehensively grasp the critical information – this method helps to achieve this.

Interestingly, the paper provides a mechanism for promulgating the extracted knowledge to “front-line” personnel. This could also add value to security as it could provide a bridge between data analysis outputs and real-world operational activities. However, the current status of this method as it might apply to security is in an exploratory phase. Whilst limited in its immediate usefulness, there is value in maintaining such horizon scanning for advanced methods.

IASHIM – hazard identification method	
Complexity	★★★★★
Accessibility	★☆☆☆☆
Scalability	★★★☆☆
Impact on operation	★★★★☆
Added value	★★★☆☆
Maturity	★☆☆☆☆
This method is extremely complex, utilising advanced computational methods to provide safety insights. Hence, it scores low on accessibility and would require a high degree of effort to implement in the current security sphere. Significantly, the method is not currently mature as applied to security data and would be a pioneering approach. There is potential for complex insights to be gained, otherwise unavailable through more simplistic methods, however the value of this method is more centred around horizon-scanning and future approaches for an increasing complex security environment.	

Table 6. IASHIM assessment.

Systems Theoretic Process Analysis (STPA) — Industry

STPA is a proactive and comprehensive approach to safety analysis that helps prevent accidents by considering how all parts of a system interact, starting from the earliest stages of design. It is a modern method used to identify potential hazards in complex systems, typically in the aircraft design domain. Unlike traditional approaches that mainly focus on individual component failures, STPA looks at how different parts of a system might interact in unsafe ways, even if none of them actually fail.

STPA is effective for analysing very complex systems. It can identify hidden risks early in the development process, which might only have been discovered during operation with traditional methods. This includes both what the system is supposed to do and what it might accidentally do. It can be used right from the beginning of a project. This helps in designing safety into the system from the start, reducing the need for expensive fixes later on. STPA considers all aspects of a system, including software and human operators, ensuring that nothing is overlooked in the hazard analysis.

STPA helps in identifying vulnerabilities that might not be obvious when examining components in isolation, such as the way different security protocols or tools might unintentionally create a gap or overlap that could be exploited.

Through the expert interviews it was identified that STPA is already extended to security domain by the STPA-SEC. STPA-SEC is applied for component and product-oriented security assessments in cyber security, where it helps in identifying control actions that could prevent security breaches or minimise their impact[12].

Security Value

Just as STPA considers the interactions between various components in a safety system, it can be adapted to analyse interactions in a security system. This could add value in the security domain because risks often emerge not from a single point of failure but from complex interactions between different system elements—like technology, people, and processes.

Applying STPA to the wider security environment can provide a more in-depth, proactive, and integrated approach to identifying and mitigating security risks. By considering the entire system, including human factors and interactions between different components, STPA helps build a more resilient security framework. Furthermore, there is myriad guidance on STPA available, as it is a heavily studied component of safety systems science.

STPA – hazard identification method	
Complexity	★ ★ ★ ★ ★
Accessibility	★ ☆ ☆ ☆ ☆
Scalability	★ ★ ★ ★ ★
Impact on operation	★ ★ ★ ★ ☆
Added value	★ ★ ★ ★ ☆
Maturity	★ ★ ☆ ☆ ☆
This method scores highly in complexity, as it requires intricate knowledge of a system for a complete analysis to occur (which will often require several experts to contribute). Whilst at a smaller, conceptual scale it can be straight-forward to implement, when examining an entire system (e.g. an airport security checkpoint) there will be multiple components and iterations to consider and apply. There is also no directed or automatic output, and conclusions must be drawn from the analysis, which requires a degree of extant knowledge. It has the advantage of being widely applicable to any system, but whilst it is very mature in the safety space, there is less development of the method within aviation security. Nevertheless, there is a high potential for added value, given the comprehensive insights that have been gained from safety.	

Table 7. STPA assessment.

[12] William Young Jr PhD, Reed Porada (2017). System-Theoretic Process Analysis for Security (STPA-SEC): Cyber Security and STPA. At: STAMP_2017_STPA_SEC_TUTORIAL_as-presented.pdf (mit.edu)

STPA Guidance

- Leveson N.G., Thomas J.P., (2018). STPA Handbook. STPA Handbook (MIT-STAMP-001)
- William Young Jr PhD, Reed Porada (2017). System-Theoretic Process Analysis for Security (STPA-SEC): Cyber Security and STPA. STAMP_2017_STPA_SEC_TUTORIAL_as-presented.pdf (mit.edu)

Risk Management

Bowtie — Regulator & Industry

The Bowtie method is a widely used risk management tool in aviation safety that helps visualise and analyse the relationship between potential hazards, the risks they pose, and the control measures in place to prevent or mitigate those risks. The name "Bowtie" comes from the shape of the diagram, which resembles a bowtie, with the hazard at the centre, leading to two wings representing preventive and mitigative measures.

The Bowtie method originated as a simplified fusion of fault and event tree methodologies and was further developed in the 1990s by the oil and gas industry to enhance risk management. Recognised for its effectiveness, the Bowtie method has since been adopted across various industries, including aviation, where it complements the Swiss cheese model by visually illustrating a barrier-based approach to risk management.

This method, referenced in ICAO's Safety Management Manual and Annex 19, not only identifies safety controls but also examines potential control failures and their management, providing valuable insights into an organisation's risk mitigation strategies. Its strength lies in its qualitative approach, making it a practical tool for both proactive risk assessment and reactive safety event classification[13].

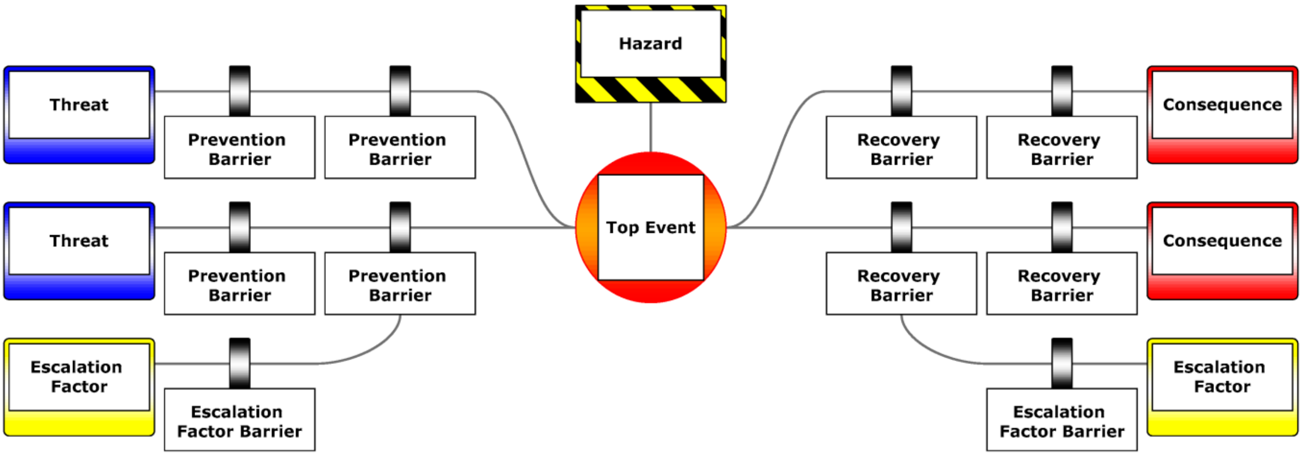

Figure 7. Simple Bowtie diagram[14].

The starting point of the diagram is the hazard, which is anything that could potentially cause harm. In aviation, a hazard could be anything from a technical failure, human error, environmental conditions, or operational procedures. The top event is the point where control is lost over the hazard, leading to an undesired outcome. For example, this could be the loss of control of an aircraft or in aviation security breach of the flight deck, hijack or explosion.

Threats are depicted on the left-hand side of the bowtie. These are potential causes that could lead to the top event. For example, threats could include equipment failure, adverse weather, pilot error or security related threats such as using aircraft as a weapon, sabotage, introduction of a prohibited article on board the aircraft. The left side of the bowtie is dedicated to identifying these threats.
Preventive Controls (Between Threats and Top Event):

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[13] UK CAA, *Where did bowtie come from?, at:* Where did bowtie come from | Civil Aviation Authority (caa.co.uk)

[14] *Image source: Aust, J.; Pons, D. Bowtie Methodology for Risk Analysis of Visual Borescope Inspection during Aircraft Engine Maintenance. Aerospace 2019, 6, 110. https://doi.org/10.3390/aerospace6100110*

Between threats and Top event are the measures in place to prevent the threats from causing the top event. In aviation, preventive controls might include regular maintenance checks, training programs, safety protocols or security measures. Consequences are the possible outcomes that could result from the top event. In aviation, consequences could range from minor incidents to accidents and catastrophic consequences.

Between Top Event and Consequences there are mitigation controls which are designed to minimise the impact if the top event does occur. In aviation, mitigative controls might include emergency response procedures, evacuation plans, or crash-resistant aircraft design. In security terms this includes for example, LRBL (Least Risk Bomb Location), procedures to deal with the hijacked aircraft, response to identification of prohibited article on board.

In aviation safety the Bowtie method helps identify all possible threats and consequences related to a particular hazard, ensuring a comprehensive analysis of potential risks. This method is widely used in risk management but also this is a common method of investigation of incidents and accidents by methodical assessment of root cause – Root Cause Analysis (RCA). By clearly mapping out preventive and mitigative controls, the Bowtie diagram allows aviation safety professionals to evaluate the effectiveness of existing safety measures and identify areas that need improvement.

The visual nature of the Bowtie diagram makes it an effective tool for communicating complex safety information to stakeholders, including pilots, engineers, and management. Bowtie diagrams are used in training programs to help personnel understand the interrelationships between hazards, risks, and controls, promoting a safety-oriented culture within the organisation.

An example of a safety bowtie may include a hazard such as "engine failure during flight." The Bowtie diagram would help identify various threats like poor maintenance, bird strikes or fuel contamination. It would also outline preventive measures such as regular engine inspections, bird hazard management, and fuel quality checks. On the right side, the diagram would show the potential consequences, such as an emergency landing or crash, and mitigative controls like pilot emergency training, onboard fire suppression systems, or reinforced cockpit structures.

Bowties range in complexity from simple diagrams to detailed analyses of potential threats and protective measures, making them effective for visualising and assessing both simple and complex risks. Australian Civil Aviation Safety Authority provides multiple examples of complex bowtie risk analysis for Air Transport Operations – Larger Aeroplanes, Air Transport Operations – Smaller Aeroplanes, Air Transport Operations – Rotorcraft and other supporting resources. Multiple examples of bowtie risk analysis are presented in downloadable form[15].

[15] Civil Aviation Safety Authority at: Using our bowtie risk analysis | Civil Aviation Safety Authority (casa.gov.au)

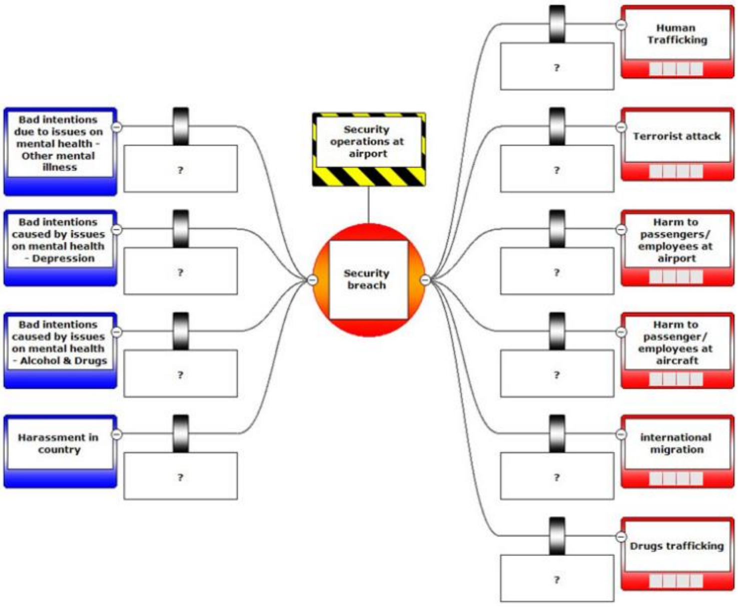

Figure 8. Bowtie application in aviation security context[16].

<u>Security Value</u>

This tool method is already utilised in security domain, however more standardised and widespread application of bowtie methodology specifically in security would bring additional benefits. Their versatility enhances their value in the security domain and in an integrated approach to safety and security risk management. When both safety and security threats are represented together, the bowtie diagram becomes a tool for integrated management of these risks.

By incorporating both safety and security threats into a single bowtie diagram, organisations could visualise the interconnectedness of these risks and identify areas where they overlap. This integrated approach allows for a more holistic understanding of potential hazards, ensuring that both safety and security measures are considered in tandem rather than in isolation.

This integrated Bowtie diagram can also serve as a valuable resource during safety and security meetings. By representing and discussing both types of threats within the same framework, stakeholders can better collaborate and make informed decisions that address all aspects of risk. This approach not only enhances the effectiveness of risk management strategies but also fosters a unified culture of safety and security within the organisation.

Bowtie – Root Cause Analysis, Risk Management	
Complexity	★★★☆☆
Accessibility	★★★★★
Scalability	★★★★★
Impact on operation	★☆☆☆☆
Added value	★★★★★
Maturity	★★★★★

[16] Verschoor E. (2019) *Mitigating and preventing the effects of a security breach with a simple bowtie,* at: [Mitigating and preventing the effects of a security breach with a simple bowtie]

This method has medium complexity, as conceptually it is simple to understand, but to create a fully comprehensive diagram necessitates occasional complex inputs. There is also likely to be variability in the complexity of the diagram that depends on the complexity of the system it is representing. It is accessible and can be implemented easily, and there is lots of guidance and existing research available. There is a strong potential for this to add value to security, as it allows mapping of complex and simple systems, and can address safety and security in an integrated way.

Table 8. Bowtie model assessment.

Bowtie Guidance

- UK CAA (2020). CAA Strategy for Bowtie Risk Models. cap1329-bowtie-strategy-issue-2-2020.pdf
- Civil Aviation Safety Authority, Australia. Using our bowtie risk analysis | Civil Aviation Safety Authority (casa.gov.au)

Fault Tree Analysis — Regulator & Industry

Fault Tree Analysis (FTA) is an analytical technique used to identify all realistic ways in which an undesired event, critical to safety or reliability, can occur within a system. The fault tree is a graphic representation of the parallel and sequential combinations of faults—ranging from hardware failures and human errors to software errors—that lead to the specified top event. Importantly, a fault tree is not a comprehensive model of all possible system failures but is tailored to analyse only the faults that realistically contribute to the specific top event being studied[17].

Eurocontrol, in its '*Fault Tree Analysis (FTA) Guidance Material*', describes FTA as a tool to identify and analyse the conditions and factors that cause or contribute to a specific undesirable event, with a primary focus on enhancing system safety and performance[18].

FTA can be used for incident/accident investigation, allocation of safety requirements and confirmation that safety objectives have been met. It can be utilised for both qualitative and quantitative analysis. Through the FTA the following can be identified:

- causes leading to top event,
- factors which can affect particular safety measure, as well as the required mitigations,
- common events and causes of failure

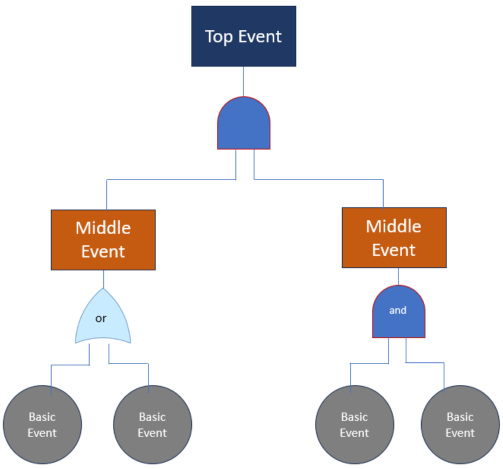

Figure 9. Fault Tree Analysis model.

[17] NASA (2002), *Fault Tree Handbook with Aerospace Applications,* Version 1.1 Fault Tree Handbook with Aerospace Applications
[18] Eurocontrol (2005), Fault Tree Analysis (FTA) Guidance Material, European Air Traffic Management at: 33526.pdf (skybrary.aero)

FTA is a widely used tool in aviation safety that can be applied both manually and through specialised software. This tool can equally provide many benefits for aviation security and in integrated safety – security management.

An example of its application in aviation safety is the analysis of the Tenerife Accident of 1977, as demonstrated below:

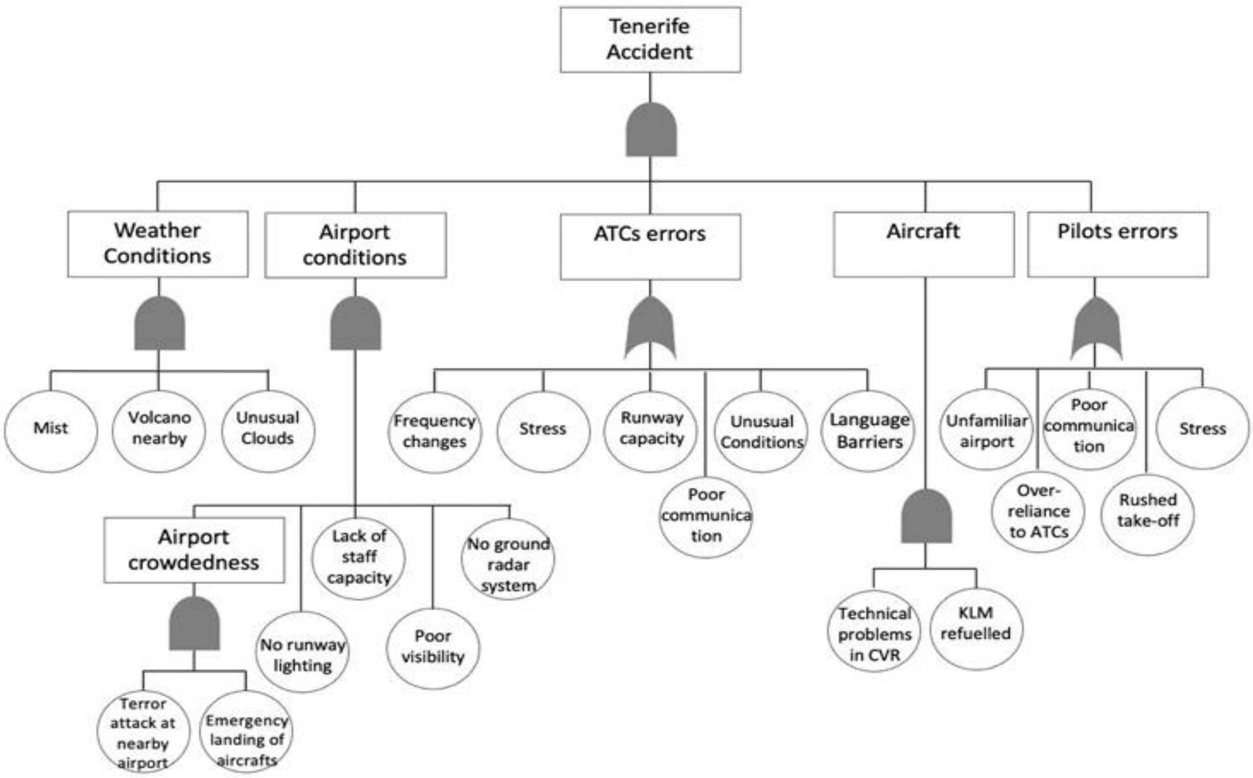

Figure 10. Tenerife accident analysis using FTA method[19].

In integrated approach to safety – security risk management and investigation of accidents FTA can be used to depict both safety and security causes of events.

Integrated use of FTA for safety and security was outlined by Andrew J. Kornecki and Mingye Liu in "*Fault Tree Analysis for Safety/Security Verification in Aviation Software"*[20]. Safety and security both aim to prevent mishaps by ensuring hazards or threats are quickly detected and addressed. The key difference lies in their focus: safety addresses how system failures or accidental conditions might harm the environment, while security deals with how external threats, such as malicious attacks, could exploit system vulnerabilities. A breach in security can often lead to safety violations. Both safety and security requirements establish the minimum mandatory standards needed to protect against these risks. Described FTE software considers both safety and security considerations applying integrated approach to the safety – security management and investigation.

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[19] Image source: Fatih OZTURK , Ahmet Ebrar SAKALLI, Gokmen TAK , Emin TARAKCI (2022), *Tenerife Accident Analysis: a comparison of Fault Tree Analysis, Failure Mode and Effects Analysis and Causal Analysis based on System Theory*, Gazi University Journal of Science at: [10.35378-gujs.1014604-2045774.pdf (dergipark.org.tr)](10.35378-gujs.1014604-2045774.pdf)

[20] Andrew J. Kornecki, Mingye Liu (2013), *Fault Tree Analysis for Safety/Security Verification in Aviation Software,* Electronics 2013, 2(1), 41-56; at: **https://doi.org/10.3390/electronics2010041**

Security Value

FTA may provide numerous benefits in the realm of aviation security. FTA allows for the structured analysis of potential security threats by examining how various failures or breaches could lead to critical security incidents. This methodical approach ensures that all significant risk factors are thoroughly considered, and none are overlooked.

Another benefit is the visual representation of risks. The graphical nature of FTA makes it easier to comprehend complex security risks and understand the relationships between different failure points. This may enhance communication among security teams and stakeholders, facilitating better collaboration and understanding.

FTA also enables focused mitigation strategies. By identifying the specific causes that could lead to a security breach, FTA supports the development of targeted mitigation strategies, ensuring that resources are allocated efficiently to address the most critical areas of concern.

In addition, FTA assists in the assessment of countermeasures. It allows for the evaluation of existing security measures by analysing their effectiveness in preventing undesired events. This process helps identify any gaps in the current security framework and highlights areas where enhancements are necessary.

The detailed analysis provided by FTA also enhances decision-making. It gives decision-makers a clear understanding of the risks involved and the effectiveness of potential countermeasures, leading to more informed and effective decisions.

Finally, FTA contributes to proactive risk management. By anticipating potential security failures before they occur, FTA enables organisations to manage risks proactively, thereby improving overall security preparedness and reducing the likelihood of incidents.

FTA – Root Cause Analysis, Risk Management	
Complexity	★★★☆☆
Accessibility	★★★★★
Scalability	★★★★★
Impact on operation	★☆☆☆☆
Added value	★★★★★
Maturity	★★★★★
As for the Bow-Tie approach, this method is medium-complex, being conceptually simple to understand, but requiring larger knowledge inputs for a comprehensive model to be drawn. The complexity of the tree will be dependent on the system it is representing. It is easy to implement with high accessibility, and it is a widely used and researched approach in safety. Despite it being a very mature approach, there is a high potential added value to security, as a range of systems can be mapped, and safety and security can be addressed simultaneously.	

Table 9. FTA method assessment.

FTA Guidance

- EUROCONTROL. Fault Tree Analysis Guidance Material. 33526.pdf (skybrary.aero)

The Fishbone methodology, also known as the Ishikawa or cause-and-effect diagram, is a tool used for root cause analysis (RCA) and risk management in aviation safety. It helps identify and organise potential causes of a problem to pinpoint the root cause or to identify system vulnerability and risk. First step of this process is defining suitable framework that will be used in the process. Figure 11 represents fishbone analysis model with the use of SHELL framework. The SHELL model is a common framework to analyse human factors and their interactions with various components of a system. The analysed components include the Liveware (human element in the centre of the system) interacting with Liveware (other humans), Software (processes and procedures), Hardware (equipment, technology) and Environment (working environment, noise, lighting, temperature). Other common framework for fishbone analysis is 5M – Manpower (people performance), Machine (equipment, technology), Material (raw material, information), Milieu (environment, working conditions), Method (the way of doing things). Furthermore, organisations can develop their own fishbone framework which makes this methodology even more portable to security domain.

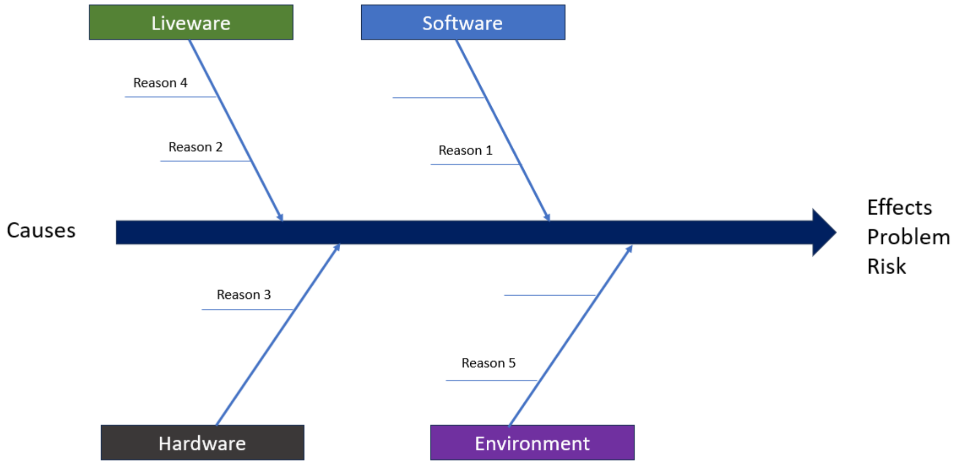

Figure 11. Fishbone method - with SHELL framework applied.

To create an Ishikawa (or fishbone) diagram, an organisation should begin by selecting a problem to analyse, often informed by recent safety data, a risk register, or top priority risks. The problem should be clearly documented at the head of the diagram, ensuring it is well-defined by considering factors such as what, when, where, and why the issue exists. The next step involves identifying the major factors or categories contributing to the problem, which may be customised or based on default categories like materials, machines, people, methods, and environment. The diagram is then populated by exploring each category in detail, asking "Why?" repeatedly to uncover underlying causes and sub-causes, typically up to five levels deep. The output is a comprehensive list of root causes, which should be prioritised and addressed using additional data sources and analysis techniques[21].

[21] Flight Safety Foundation (2017). *Global Safety Information. Additional Toolkit Details.* flightsafety.org at: Version-2.0-Toolkits-Level-1-Draft-1.pdf (flightsafety.org)

The example of more complex fishbone application is presented on a diagram below:

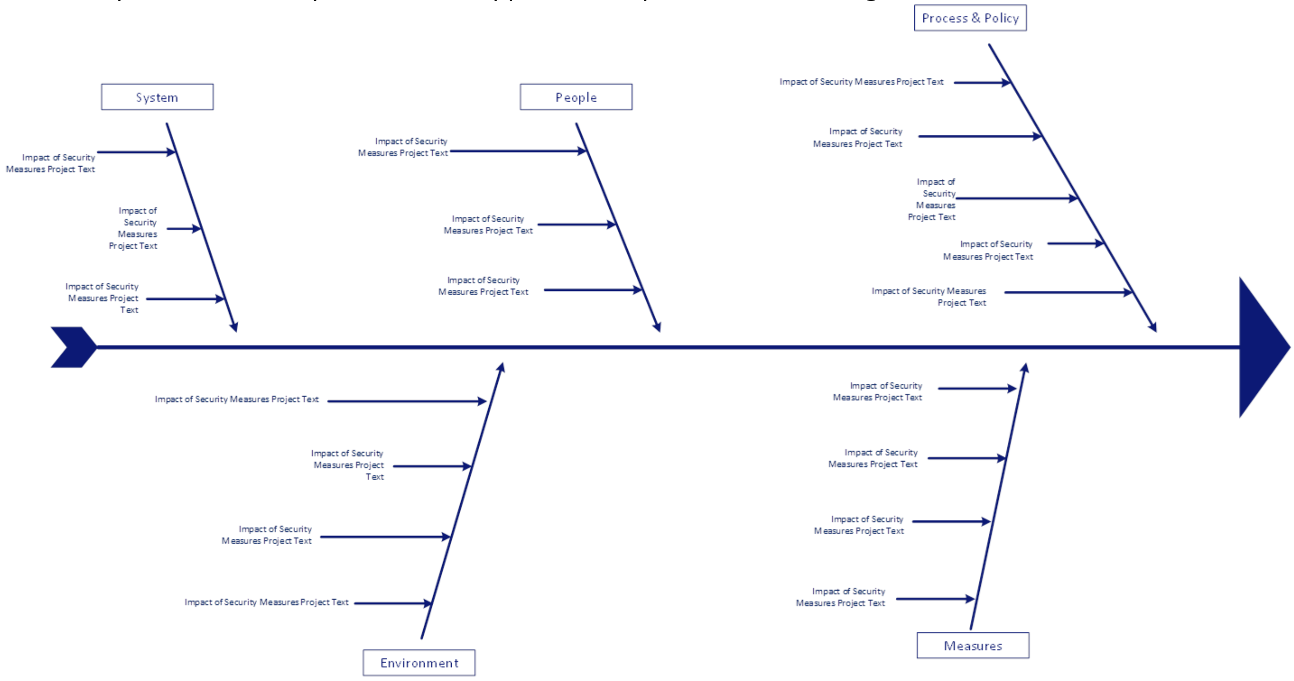

Figure 12. Fishbone method.

<u>Security Value</u>

This risk management and root cause analysis tool, commonly used in aviation safety, can be similarly applied to aviation security using frameworks like SHELL or customised alternatives like the example of more complex diagram above. It can also be leveraged for integrated management of safety and security risks by analysing security causes alongside safety ones. This approach offers the benefit of a more holistic understanding of safety and security risks, leading to better-informed organisational management.

Whilst root cause analysis tools are well integrated in the aviation safety and form a foundation for investigation of non-compliances and more general in safety management, in aviation security they remain underutilised. Further investigation and standardisation of RCA in security domain would further mature the system. Communication between the regulators and entities and review of RCA and proposed corrective actions would enable a stronger security system.

Fishbone – Root Cause Analysis, Risk Management	
Complexity	★ ★ ☆ ☆ ☆
Accessibility	★ ★ ★ ★ ★
Scalability	★ ★ ★ ★ ★
Impact on operation	★ ☆ ☆ ☆ ☆
Added value	★ ★ ★ ★ ★
Maturity	★ ★ ★ ★ ★
This method and tool, commonly used in safety, is simple to apply and understand and can be flexibly applied to any security issue, with minimum operational impact. There is high potential added value to security, as it produces potential root causes at a high or low level and will aid analysis of potentially complex problems and promote focus on risks in an easily implementable way. It perhaps lacks the ability to provide complex insights or evaluate large amounts of data, but is a comprehensive initiation point for less mature security entities.	

Table 10. Fishbone method assessment.

Fishbone Guidance

- Britton T., (2024). How to Use Fishbone Diagrams in Aviation SMS – Walkthrough. How to Use Fishbone Diagrams in Aviation SMS - Walkthrough (asms-pro.com)
- Liang Cheng, S.Z.Y.; Arnaldo Valdés, R.M.; Gómez Comendador, V.F.; Sáez Nieto, F.J. A Case Study of Fishbone Sequential Diagram Application and ADREP Taxonomy Codification in Conventional ATM Incident Investigation. Symmetry 2019, 11, 491. https://doi.org/10.3390/sym11040491
- Distefano, Natalia & Leonardi, Salvatore. (2014). Risk assessment procedure for civil airport. INTERNATIONAL JOURNAL FOR TRAFFIC AND TRANSPORT ENGINEERING. 4. 10.7708/ijtte.2014.4(1).05.

10.3 Safety assurance tools, methods and mechanisms

This chapter examines safety tools, methods and mechanism that contribute to safety assurance. Under SMS framework this are the tools that enable performance monitoring and measurement, management of change and continuous improvement.

This section includes compliance monitoring and oversight tools in aviation, highlighting the industry's evolution towards more sophisticated oversight methods cantered on risk and performance. Traditionally, aviation safety oversight relied heavily on ‘direct and inspect’ approach focused primarily on compliance with established regulations. However, there is a growing recognition of the advantages of shifting from this compliance-based oversight model to a more advanced system that evaluates entities based on their risk management and performance outcomes. This transition aims to enhance the effectiveness of oversight by focusing resources on areas of higher risk and encouraging continuous improvement within organisations.

Occurrence Reporting System Regulator & Industry

A reporting system in aviation is a structured process (mechanism) used by aviation personnel, including pilots, air traffic controllers, maintenance staff, and other relevant stakeholders, to report safety-related incidents, hazards, and other operational issues. The primary purpose of these systems is to collect data on safety occurrences to identify trends, prevent future incidents, and enhance overall safety within the aviation industry. Reporting tools are a well-established and integral component of an SMS in aviation.

Stakeholder interaction during this project indicates that the industry is considering reporting as a tool that contributes to aviation security. Reporting is mandated in the EU through the Regulation (EU) No 376/2014 - Occurrence Reporting. Mandatory reporting includes in Article 4, point 1 (a)(viii) security-related occurrences. Annex I- Occurrences related to the operation of aircraft provides a list of reportable security-related occurrences which include bomb threat or hijack, difficulty in controlling intoxicated, violent or unruly passengers and discovery of a stowaway. Entities in scope of Occurrence Reporting regulation will most likely be more advanced in relation to reporting systems which is required by the regulation.

Reporting of occurrences and incidents or accidents can be **mandatory**, where certain incidents, such as accidents or serious incidents, must be reported by law. This ensures that critical information is captured and analysed to prevent future occurrences; **voluntary**, where individuals can report hazards or unsafe conditions without fear of reprisal. This encourages a safety culture where personnel are proactive in identifying potential risks; **confidential**, which allow personnel to report safety concerns confidentially, encouraging more open communication about potential issues; or, **anonymous** where the identity of person reporting the issue is protected but the organisation can gain insight into operational practices.

While reporting tools are also utilised in aviation security, certain areas, such as reporting systems for security screeners, are less developed and utilised in a less structured manner. ICAO Security Culture promotional materials, tools and resources play significant role in promoting reporting in security domain[22]. Aviation security would benefit from adopting some of the reporting tools currently utilised in safety.

Through team stakeholders and experts interviews it was also identified that currently, MORs are reviewed exclusively by the safety team and are not shared with the security team, while security incidents are similarly reviewed only by the security team without being shared with safety. It would be beneficial to develop a mechanism to facilitate the joint review of both safety and security data. This integrated approach would enable a comprehensive understanding of potential risks and drive the implementation of corrective and preventive actions that address both safety and security concerns effectively.

Additionally, analysing approach to reporting in safety and comparing to security domain and extending use of reporting systems to all areas of aviation including screeners may bring additional benefits. A number of data analysis tools also rely on a large amount of data available for analysis, and reporting systems that allow for easy and quick reporting of occurrences are essential to grow an extensive database.

EASA CSR – Confidential Safety Reporting

Confidential safety reporting is an independent reporting system set up to collect and share safety related information. Individuals are able to report malpractices, irregularities and potential unsafe actions outside their organisation in a confidential manner. Information obtained is a tool to detect potential safety hazards which then can be monitored and dealt accordingly. The reporting system is open to individuals of all aviation safety areas including pilots, cabin crew, air traffic controllers, maintenance, design and production personnel, airport personnel, third country operator staff, contractors and subcontractors.

[22] ICAO Security Culture at: Security Culture (icao.int)

CHIRP - Confidential Human Factors Incident Reporting Programme

CHIRP is an independent and impartial charity focused on enhancing safety in the aviation and maritime sectors. It operates a confidential human factors incident reporting system that enables individuals working in these industries to report safety concerns without fear of being identified. CHIRP then collaborates with the relevant organisations, with the consent of the reporters, to ensure that appropriate actions are taken to address the issues raised. Occasionally CHIRP reports contain reference to security procedures like security checks[23]. It would be valuable for security domain to filter and analyse security data and to maintain continuous monitoring of the reported issues.

While security reports often contain sensitive information that could expose system vulnerabilities, a similar tool in the security domain, if initiated by the regulator, could offer significant value and provide valuable insights into operational practices. Moreover, such a tool could enhance the overall security framework by enabling the reporting of human factors related to screeners in a confidential and constructive manner.

The Aviation Safety Reporting System (ASRS) – online reporting tool

The ASRS, similarly to CHIRP is a voluntary, confidential, and non-punitive reporting system aimed at enhancing aviation safety by encouraging pilots and other aviation professionals to report unsafe occurrences and hazardous situations. Although funded by the FAA, the program is managed by NASA, which is responsible for collecting, de-identifying, cataloguing, and analysing the reports.

This approach fosters a safety culture where pilots and other personnel can openly discuss and learn from their mistakes. The primary goals of ASRS are to improve the current national aviation system and provide data for future system planning. Reports can be submitted by pilots, air traffic controllers, cabin crews, and mechanics. Feedback, including bulletins, newsletters, and data analyses, is provided to air carriers, researchers, and government agencies to investigate unsafe practices and implement corrective measures.
Reporting is a mature tool in aviation safety also utilised in aviation security. There are a number of software-based systems available on the market that offer comprehensive solutions for safety management, document control, integrated audit management and remote and mobile access via app and more.

Security Value

The security domain could greatly benefit from revising its reporting approach, making it essential for all security personnel. Additionally, evaluating and sharing de-identified data could enhance lessons learned and support the creation of security case studies to be shared with the broader security and/or safety community. The adoption of electronic reporting tools that enable reporting from any location, including mobile devices, would facilitate the development of a more comprehensive database for analysis and learning.

These reporting systems may also include security related data. For example, UK CHIRP reports are in public domain and Ground Handling and Security is among the topics covered. Security related issues are being reported to CHIRP and it would be valuable to filter, analyse and monitor security trends. Other confidential reporting systems which are not publicly available may also contain security related data. By consolidating all security data or developing a tool that facilitates its collection and continuous monitoring of this by security staff, organisations can enhance data oversight, improve awareness of reported issues by security staff, and strengthen risk management practices.

[23] CHIRP Aviation Feedback, Cabin Crew, Edition CCFB 83, July 2024.

Reporting – safety management mechanism	
Complexity	★★☆☆☆
Accessibility	★★★★☆
Scalability	★★★★☆
Impact on operation	★★★☆☆
Added value	★★★★★
Maturity	★★★★★
Reporting systems as a mechanism are well established, hence score very highly in maturity. They are straight-forward to use and understand and are accessible (although must be designed in a way that encourages use and valid data collection). They are also widely applicable across fields, with some adaptation. Effective use of reporting systems does require some effort (e.g. small time expenditure and cultural shift toward making it standard business practice) but the added security benefits are potentially very large.	

Table 11. Reporting tools assessment.

Reporting Systems Guidance

- ICAO Doc 9859 - Safety Management Manual. Fourth Edition, 2018.
- Connell Linda, NASA (2011). Aviation Safety Reporting System. Power Point.

Root Cause Analysis Methods Industry

Root Cause Analysis is an investigation tool carried out under Just Culture, that through development of full understanding of events and non-compliances contributes to continuous improvements of safety. RCA is carried out as part of safety risk management and is used to carry out investigations to identify latent conditions that may have contributed to non-compliances, incidents or accidents. RCA also support continuous improvement of safety through better understand operational risks.
Methods of RCA vary and typically it is organisational decision when to use which method. Selection of a specific method also depends on complexity of analysed event.

Why – Why analysis (5 Whys)

This RCA method involves clearly stating the problem and asking 'why' five times until the root cause of the issue is identified. This concept is widely used in different types of business, including aviation safety and security.

Typically, this method is used for less complex problems that do not require investigation of multiple casual factors. For simple problems, it may not be necessary to ask 'why' 5 times as root cause may be identified sooner.

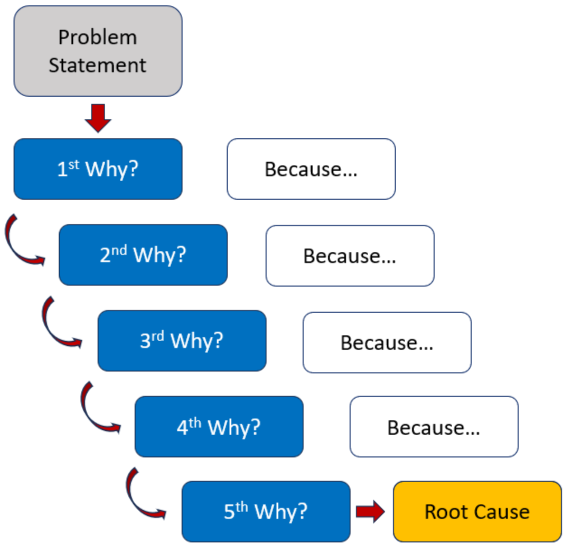

Figure 13. 5 *Whys method.*

If the identified problem is of more complex nature, the 5 Why's methodology can be also utilised with additional questions as shown in Figure 19.

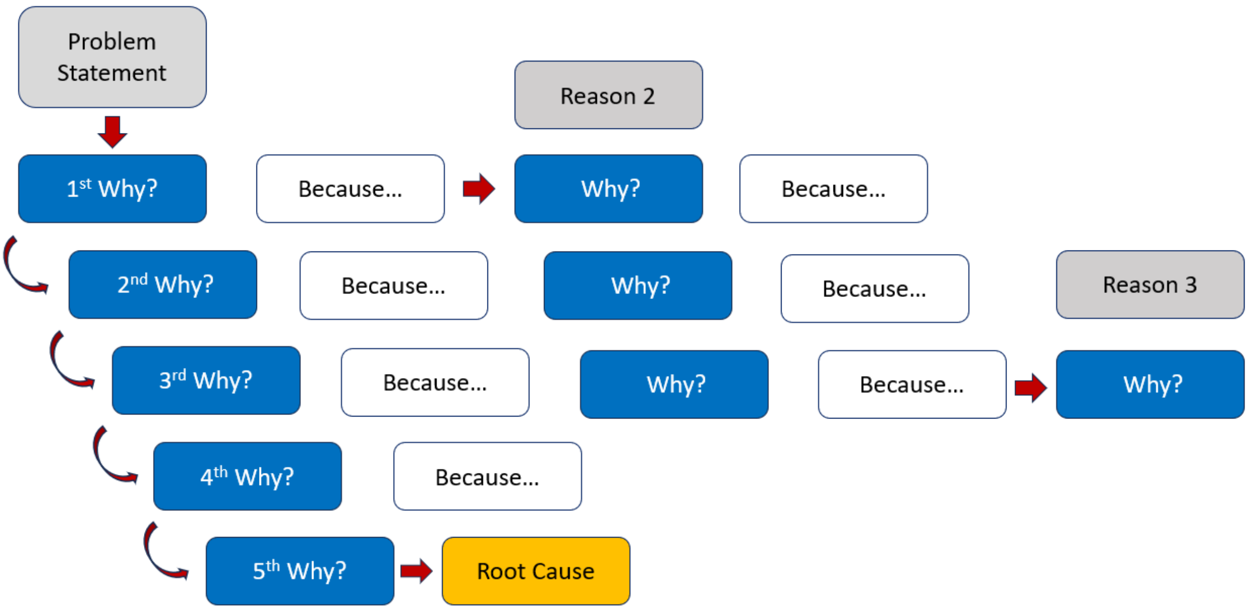

Figure 14. 5 Whys method for more complex problems.

<u>Security Value</u>

Similarly to other RCA methods described in this report, they remain underutilised in aviation security. Advancing the investigation and standardisation of RCA within the security domain could strengthen the overall system. Improved communication between regulators and industry entities, alongside a review of RCA processes and proposed corrective actions, would contribute to a more robust security framework, better awareness of underlying issues and improvement in risk management.

5 WHY'S – Root Cause Analysis	
Complexity	★ ☆ ☆ ☆ ☆
Accessibility	★ ★ ★ ★ ★
Scalability	★ ★ ★ ★ ★
Impact on operation	★ ☆ ☆ ☆ ☆
Added value	★ ★ ★ ★ ★
Maturity	★ ★ ★ ★ ★
This tool is an extremely simple and accessible way to achieve the goal of defining a root cause (which then proceeds to enable rectification and mitigation). It can be applied to almost any security problem, although very complex issues may require additional analysis. It is low impact and very mature, having been used extensively within aviation safety and indeed other business areas. There would be high added value in increasing the use of this methodology within aviation security.	

Table 12. 5 Why's methodology assessment.

More complex RCA methods include but are not limited to:

- Bowtie (described in safety management tools section)
- Fault Tree Analysis (described in safety management tools section)
- Fishbone (described in safety management tools section)

RCA Guidance

- UK CAA. Root cause analysis. Regulation, policy and guidance for UK airworthiness approval holders. Root cause analysis | Civil Aviation Authority (caa.co.uk)
- UK CAA. CAP1760: Effective Problem Solving and Root Cause Identification. Version 2, April 2019

Risk Based Oversight RBO — Regulator

RBO is an approach that prioritises oversight activities according to an organisation's risk profile. This method shapes the planning of oversight efforts by allocating resources based on the identified risks, allowing for a concentrated focus on areas of higher concern. The risk profile considers not only the inherent risks associated with the organisation's operations but also its safety performance and the outcomes of previous oversight activities.

RBO aims to pinpoint the safety-related risks that the aviation industry should prioritise. By combining safety performance metrics with confidence data, regulatory resources are focused on the areas needing the most attention (resource to risk). Enhanced data analysis and improved information sharing enable regulators to better understand the factors influencing each sector of the aviation industry and how these sectors are interconnected. Additionally, the complexity of the organisation is considered and assessed to provide the baseline for planned oversight activities and to ensure consistent approach is taken for similar organisations.

RBO is based on 5 principles outlined in below figure.

Figure 15. Five principles of RBO.

RBO goes beyond merely assessing regulatory compliance. It takes an additional step by evaluating how effectively the organisation implements these requirements and the overall effectiveness of the systems in place. This approach generates a confidence score, which serves as the foundation for determining the oversight schedule.

Figure 16. The RBO scheme as proposed by EASA[24]

Essential steps in this approach are:

- Calculating the complexity based on type of operation, area of operation, number and type of aircrafts (for air operators), number of staff.
- Establishing base level of oversight that can be either increased or deceased (considering resources)
- Assess confidence level considering performance
- Plan oversight cycle

[24] EASA (2016) Practices for risk-based oversight at: [Practices for risk-based oversight | EASA]

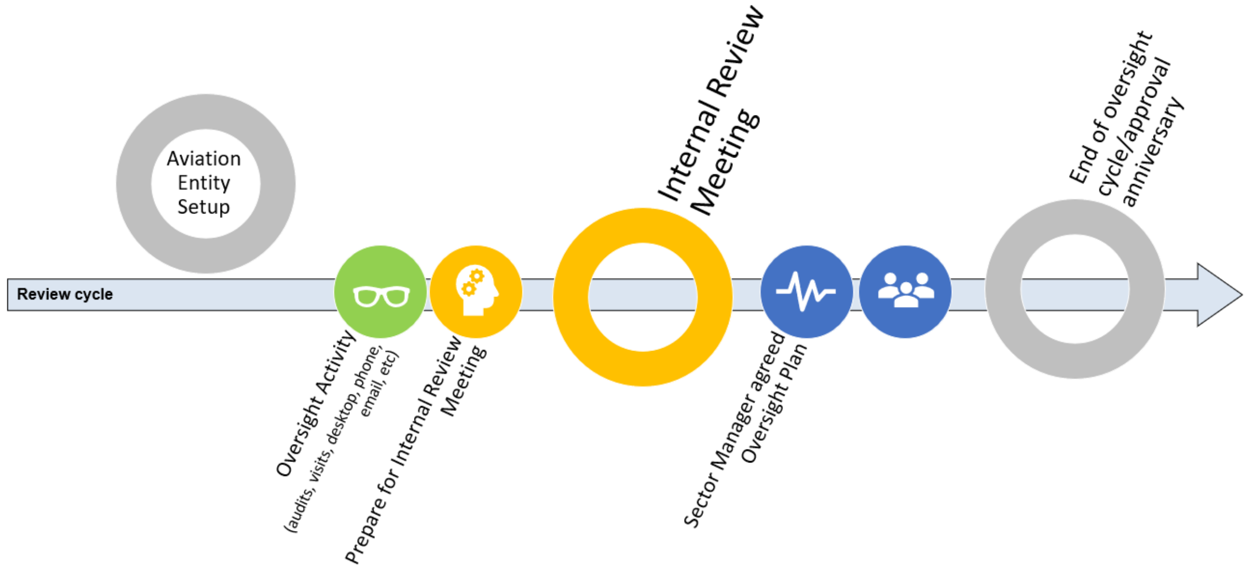

Figure 17. RBO oversight cycle. Source: CAAi RBO training.

Internal Review Meeting

An Internal Review Meeting (IRM) is a formal gathering of key personnel responsible for different safety areas within the regulator/ authority to assess and discuss the organisation's safety risk management practices. The entity's safety risks and hazards are reviewed to identify areas of concern. The IRM members collaboratively assess the effectiveness of the safety risk management within the organisation. They discuss and document the safety performance, highlighting key strengths and weaknesses. Agreed-upon safety risks identified during the review cycle are recorded. Any necessary changes or future oversight focuses are reviewed and agreed upon. Lastly, items for discussion are prepared for the upcoming Accountable Manager Meeting.

There may be mutual safety and security benefits when security experts/auditors attend IRM. Security experts can share insights into the entity security performance and issues and vice versa this in turn give better awareness of entity's performance overall. It is recognised some security data may be sensitive or confidential, however even without sharing sensitive information IRM may provide a common and standardised platform for exchanging of concerns regarding given entity.

A Security-focused IRM could be beneficial in strengthening the overall security framework within the aviation sector. By adopting this approach, regulators could enhance RBO in the security domain, fostering a more proactive and collaborative environment for managing security risks. A Security IRM would allow regulators and relevant stakeholders, such as airline security teams, airport authorities, and law enforcement agencies, to come together to conduct a comprehensive assessment of an entity's security posture. This collaborative approach ensures that all perspectives are considered, leading to a more robust evaluation of potential vulnerabilities and threats.

A security IRM would help in prioritising oversight activities based on the entity's security risk profile. By identifying the most pressing security concerns, resources can be allocated more effectively, focusing on areas that require immediate attention. It would also improve communication and coordination among various stakeholders involved in aviation security. This increased collaboration can lead to more timely and effective responses to security threats, as well as the sharing of best practices and lessons learned.

Security Value

Introducing RBO in the security domain could significantly enhance efficiency, flexibility, and effectiveness. IATA has highlighted RBO's benefits in safety, particularly how it enables regulators to allocate resources where they are most needed based on assessed risks, rather than a one-size-fits-all approach[25]. Applying RBO in security would mean focusing on areas with higher risks, potentially streamlining oversight efforts for compliant entities while concentrating resources on higher-risk areas. This approach would not only reduce administrative burdens but also support a more dynamic response to emerging security threats, helping regulators and industry stakeholders manage risks more proactively and efficiently.

RBO requires a high level of maturity from both the entity and the regulator, where mutual trust and collaboration are essential for driving continuous improvement. It's necessary to carefully assess the impact of this oversight model on operations, considering its complexity. A gradual, phased implementation of RBO may be more advantageous, allowing both parties to adapt progressively and ensuring a smoother transition to this advanced approach. For example, the UK CAA is progressing toward this type of oversight through a voluntary SeMS framework for entities. By utilising entity self-assessments and assessments of Phase 1 and Phase 2 SeMS entities, the focus is on gathering and analysing more security data. This approach aims to build the necessary maturity before fully transitioning to the more mature model[26].

RBO – oversight method	
Complexity	★★★★☆
Accessibility	★★★☆☆
Scalability	★★★★☆
Impact on operation	★★★★★
Added value	★★★★★
Maturity	★★★☆☆
This is a complex tool with multiple concepts combining to create an overall approach, each requiring detailed understanding and experience. It can be widely applied but requires phased implementation and a degree of maturity in the system. The concepts are quite accessible, with numerous resources available online, provided by international bodies and state appropriate authorities. The benefits to security are likely to be high, taking into account the existing progress towards an RBO model in various aviation security areas.	

Table 13. RBO assessment.

RBO Guidance

- UK CAA, Risk Based Oversight. https://www.caa.co.uk/publication/download/19917
- SMICG, Risk-Based and Performance-Based Oversight – Guidance. May 2022
- EASA, Practices for risk-based oversight. November 2016. Practices for risk-based oversight | EASA
- EASA, Gian Andrea Bandieri, Risk-based oversight PowerPoint. 11. RBS EASA Risk-based oversight.pdf

[25] IATA, (2402) IATA Safety Podcast: Risk-based IOSA – What to expect? - YouTube
[26] UK CAA. Security Management Systems overview. At: Security Management Systems overview | Civil Aviation Authority (caa.co.uk)

PBO approach to oversight is based on consistent, proportionate, and efficient allocation of operational oversight teams or 'field force' based on the entity performance. This includes modification of the volume, type and focus of the oversight according to risk and organisational performance. In this approach compliance remains a necessary foundation but it constitutes only one element of the system.

EASA adopts a performance-based approach to oversight that emphasises outcomes over strict regulations. This method sets performance objectives and standards, with ongoing monitoring and assessment to ensure compliance. By focusing on results, it allows operators greater flexibility to innovate and find more efficient and effective ways to meet safety goals. PBO is built on key principles that focus on outcomes, flexibility, and continuous improvement[27].

The PBO regulatory framework shifts the focus of oversight from traditional tick-box compliance to a more dynamic approach. In this model, the regulator evaluates an entity's performance based on the entity's own risk assessment, which is grounded in effective risk management through its management system. This approach emphasises collaborative discussions with the entity over formal inspections, thereby facilitating smoother regulatory changes and fostering a more nuanced understanding of risks and mitigations. Oversight activities are then prioritised based on the risk profile of the organisation, directing resources where they are most needed. The ongoing monitoring of an organisation's performance is a necessary element of PBO. This includes analysing data, tracking performance metrics, and making adjustments to improve safety and efficiency continuously.

PBO relies heavily on data collection, analysis, and feedback to inform decisions. This ensures that oversight is based on actual performance data and trends rather than theoretical models or assumptions. Effective PBO requires strong communication and collaboration between the regulator and the entity being overseen. Mutual trust and cooperation are essential for sharing information, addressing risks, and ensuring continuous improvement. This poses similar challenges as RBO approach where higher maturity of both the entity and the regulator is required. Additionally, development of suitable measurable performance indicators is required.

PBO emerged as a solution to the growing complexity and scale of regulated entities. Regulators needed a more effective method to focus on areas that pose the greatest safety risks, ensuring ongoing improvements in safety within an increasingly challenging environment. PBO requires a well-developed and mature regulatory framework, where safety risk management is acknowledged as the key approach for addressing and enhancing aviation safety[28]. Similarly to RBO approach, adoption of PBO is complex and may require staged implementation if adapted for aviation security domain. Again, SeMS is seen as a stepping stone to the development of more mature way of oversight. In the UK, SeMS was created in 2015 to replicate SMS route to risk and performance-based oversight. Entities voluntarily implementing SeMS are better able to assure security of their operations and identify their own risk preparing them for more mature oversight system[29].

Security Value

Similarly to RBO, introduction of PBO would enhance efficiency, flexibility, and effectiveness enabling the regulators to allocate the 'field force' where it is needed the most. Applying PBO in security would mean focusing on areas with poorer performance, potentially streamlining oversight efforts for compliant entities while concentrating resources on higher-risk areas.

[27] SofemaOnline (2023). EASA Regulatory Risk and Performance-Based Oversight Fundamentals. At: EASA Regulatory Risk and Performance-Based Oversight Fundamentals - Blog - Aviation Services & Education - SofemaOnline
[28] Pierobon M., (2014). Performance-Based Oversight. Flight Safety Foundation at: Performance-Based Oversight - Flight Safety Foundation
[29] Aviation Security Insights (2020). Performance Based Oversight, SeMS and the professionalisation of training. At: Performance Based Oversight, SeMS and training professionalisation (caainternational.com)

In aviation security domain, PBO approach is utilised by the UK CAA for the oversight of security training. This approach however does not replace traditional compliance-based oversight (CBO), but it used to compliment a CBO. This approach was introduced in 2019 with its first stage – Quality Assurance Framework (QAF). Entities in scope are first enrolled in QAF that consists of self-assessment and subsequent external assurance visit by qualified assessors. In the following year, the entity enters a PBO stage which entails reflective self-assessment and an external assurance visit. The process is focused on continuous improvement and open communication between the entity and the regulator. Detail of UK approach can be found in CAP 2204 - Understanding the CAA Quality Assurance Framework.

Measuring performance in security domain remains challenging, however the example where the entity performance is assessed is a UK CAA approach to SeMS oversight. Performance is assessed through the Security Performance Data (SPD) that is submitted to the regulator in regular intervals.

PBO – oversight method	
Complexity	★ ★ ★ ★ ☆
Accessibility	★ ★ ★ ☆ ☆
Scalability	★ ★ ★ ★ ☆
Impact on operation	★ ★ ★ ★ ★
Added value	★ ★ ★ ★ ★
Maturity	★ ★ ★ ☆ ☆
As for RBO, this is a complex method with multiple concepts combining to create an overall approach, each requiring detailed understanding and experience. It can be widely applied, but requires phased implementation and a degree of maturity in the system. The concepts are quite accessible, with numerous resources available online, provided by international bodies and state appropriate authorities. The benefits to security are likely to be high, taking into account the existing progress towards an PBO model in various aviation security areas.	

Table 14. PBO assessment.

PBO Guidance

- Aviation Security Insights (2020). Performance Based Oversight, SeMS and the professionalisation of training. At: Performance Based Oversight, SeMS and training professionalisation (caainternational.com)
- SMICG, Risk-Based and Performance-Based Oversight – Guidance. May 2022
- Pierobon M., (2014). Performance-Based Oversight. Flight Safety Foundation at: Performance-Based Oversight - Flight Safety Foundation
- UK CAA. CAP2204 - Understanding the CAA Quality Assurance Framework

The next section explores data analysis tools that could be adapted for use in aviation security. Availability and analysis of data is fundamental for the risk management. While aviation safety has advanced significantly in data analysis, utilising artificial intelligence systems and computer modelling, aviation security lags in this area. Introduction of more advanced and mature oversight systems like RBO also requires access to large quantity of data. The effectiveness of data analysis in security is heavily dependent on the quality of reporting tools, the volume of reports, and the extent of the database. The tools presented here originate from academic research and could be beneficial in enhancing aviation security. However, to achieve the level of sophistication seen in aviation safety, a well-established and standardised reporting system is required.

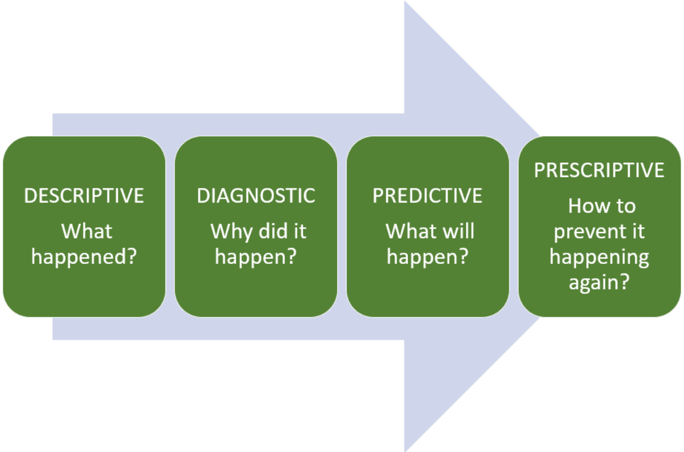

Figure 18. Data analysis systems.

Diagnostic statistical analysis — Regulator & Industry

Diagnostic statistical analysis refers to a set of statistical methods and techniques used to investigate and determine the underlying causes or factors contributing to specific outcomes or patterns observed in data. Unlike descriptive statistics, which summarise data, or predictive statistics, which forecast future trends, diagnostic analysis seeks to explain why certain events occur by identifying relationships, dependencies, and causal links within the data.

Other forms of data analysis include descriptive analytics, predictive and prescriptive analytics. Descriptive analysis is typically the first step of analysis highlighting the trends. Predictive analysis involves predicting future trends and potential impact. Prescriptive analysis suggests response actions and improvements[30].

The key aspect of diagnostic statistical analysis is identification of root cause to uncover fundamental reasons behind specific outcomes like equipment malfunction, procedural deficiencies or human error. Safety application includes incident and accident investigation, performance monitoring and development of policies and procedures.

Using statistical analysis to assess safety levels and diagnose underlying causes is an established practice, already applied in security contexts such as compliance data analysis. As pointed out in Reporting Tools section, safety domain has access to much larger data to analyse mainly due to the more 'open' nature of safety domain comparing to security domain. Aviation security data is not that easily available, shared and publicised making statistical analysis on a large scale more challenging.

Examined paper '*Human factors and aviation safety: what the industry has, what the industry needs'*[31] discusses how statistical analysis is commonly used in aviation to determine safety levels and identify causes of safety incidents. While this method is widely accepted, the passage warns that simply looking at statistics can be misleading, especially when trying to understand how different regions or contexts handle safety. The numbers show patterns and relationships, but they don't explain the deeper reasons behind those patterns.

The main argument is that the true answers to improving safety in aviation aren't just in the numbers. Instead, we need to understand the processes and factors, such as cultural influences and human behaviour, that lead to those numbers. The paper suggests that to make aviation safer, we should take a broader view, rethink our current safety strategies, and focus more on understanding these underlying factors rather than just relying on statistics. This could have implications for use of statistical analysis in aviation security.

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[30] Holliday M., (2021). What Is Diagnostic Analytics? How It Works and Examples. Oracle NatSuite at: What Is Diagnostic Analytics? How It Works and Examples | NetSuite

[31] Aurino, D. E. M. (2000). Human factors and aviation safety: what the industry has, what the industry needs. Ergonomics, 43(7), 952–959. https://doi.org/10.1080/001401300409134

Security Value

The security value of diagnostic statistical analysis is expansive and established – in both safety and security it can enhance the ability to proactively manage and mitigate risks, ensuring a more secure and efficient aviation environment.

Statistical analysis can identify unusual patterns in data (e.g. passenger information, cargo manifests) that may indicate the presence of a threat, thus helping to predict incidents before they materialise. Furthermore, such analysis can identify trends in data that may not be obvious through manual inspection, including recognition of behaviours or activities that correlate with security breaches, or identifying new emerging threat methodologies based on historical data.

There are also benefits to be gained in resource optimisation; statistical analysis can highlight ways of efficiently balancing the allocation of resources, which is critical in an increasingly pressurised working environment. This also will add benefit to the passenger experience.

However, analysis must be conducted in an informed manner – any qualitative links between incidents and mitigations must be established in a critical way, and caution should be used when generalising.

Diagnostic statistical analysis – data analysis method	
Complexity	★ ★ ★ ★ ★
Accessibility	★ ☆ ☆ ☆ ☆
Scalability	★ ★ ★ ☆ ☆
Impact on operation	★ ★ ★ ☆ ☆
Added value	★ ★ ★ ☆ ☆
Maturity	★ ★ ★ ☆ ☆
This method has a high complexity and low accessibility as there is a high level of specialist knowledge required to execute it effectively. Whilst statistical analysis can apply to any data, the scalability is limited within security due to constraints on data sharing and confidentiality. The overall value, therefore, is limited by the availability of suitable data for analysis and the requisite level of knowledge to analyse it effectively. However, diagnostic statistical analysis remains a potentially critical tool to enable evidence-based root cause analysis to take place; a critical component in predicting and preventing future occurrences.	

Table 15. Diagnostic statistical analysis assessment.

Diagnostic Analysis Guidance

- Aurino (2010). Human factors and aviation safety: what the industry has, what the industry needs. https://doi.org/10.1080/001401300409134
- Honeywell Aerospace (2019). From Data to Predictive Analytics. eBook_PredictiveInsights.pdf (honeywell.com)

Data mining in aviation safety involves using advanced computational techniques to analyse large datasets related to aviation operations, incidents, and accidents. The goal is to identify patterns, correlations, and trends that may not be immediately obvious but are critical for improving safety. Data mining can uncover recurring patterns or trends in safety data that could indicate potential risks or areas needing improvement. It also can predict future incidents or identify factors that could lead to safety breaches. By automating the analysis of vast amounts of data, data mining makes it easier and faster to extract valuable safety insights, supporting continuous improvement in aviation safety management.

Aviation Safety offices currently use a mix of manual and automated methods to collect and analyse incident reports. While safety officers, who are experts in the field, handle the data analysis, they often lack advanced data mining tools. Some officers have basic tools for automating database queries and report generation, but the actual analysis relies on relatively simple methods to extract useful insights from the data.

The Aviation Safety Data Mining Workbench utilises three key techniques to analyse aviation safety data. The first technique, FindSimilar, combines information retrieval and data mining methods to analyse both text and structured data. The second technique, FindAssociations, explores the incident database to identify subsets of data with noteworthy correlations. The third technique, FindDistributions, focuses on a specific field or attribute within the incidents, determining its overall distribution. It then compares this distribution across various subsets of data, highlighting those that deviate significantly from the overall pattern, which may indicate potential anomalies requiring further attention[32].

Proof-of-concept application of this tool was undertaken by American Airlines and is described by Nazeri (2003) in '*Application of Aviation Safety Data Mining Workbench at American Airlines'*[33]. Although this research is old, it replicates the degree of maturity seen in some security entities with respect to data analysis, hence can provide present-day insights.

<u>Security Value</u>

Using data mining tools to perform novel analyses and/or to make analysis more efficient could have application to security data. Data Mining Workbench can identify patterns, correlations and trends which can be useful in risk assessment and management in both local and national context.

The Aviation Safety Data Workbench could be adapted to filter security-related data form existing databases allowing for better awareness of existing patterns and trends contributing to risk management in aviation security.

[32] Skybrary. Aviation Safety Data Mining Workbench. At: Aviation Safety Data Mining Workbench | SKYbrary Aviation Safety

[33] Nazeri Z., (2003). Application of Aviation Safety Data Mining Workbench at American Airlines. At: safety_mining_workbench.pdf (SECURED) (flightsafety.org)

Data mining – data analysis tool	
Complexity	★ ★ ★ ★ ★
Accessibility	★ ☆ ☆ ☆ ☆
Scalability	★ ★ ★ ☆ ☆
Impact on operation	★ ★ ★ ☆ ☆
Added value	★ ★ ★ ☆ ☆
Maturity	★ ★ ★ ☆ ☆
This tool is highly complex, making use of statistical tools to evaluate data. The study showed that the tool improved the efficiency of existing work, offering insights without the need for extensive analysis by a human. However, the accessibility is still scored a low as there would be a degree of effort associated with implementing this with security data and users still need to have a degree of background knowledge. Prerequisite for this is the availability of large databases to analyse.	

Table 16. Data mining assessment

Natural Language Processing — Regulator & Industry

Natural Language Processing (NLP) is used to extract, interpret, and analyse meaningful information from large volumes of unstructured text data. NLP techniques enable computers to read, understand, and derive insights from text, which is a crucial aspect when dealing with vast datasets that include human language, such as reports, social media posts, or documents. By applying NLP, data analysts can automate the extraction of insights from text-based data, making it possible to analyse patterns, trends, and relationships that might not be apparent through traditional data analysis methods.

The paper '*Natural Language Processing for Aviation Safety Reports: From Classification to Interactive Analysis'*[34] describes the different NLP techniques designed and used to manage and analyse aviation incident reports.

<u>Security Value</u>

Report data holds significant value, and its sheer volume can make manual analysis both complex and resource intensive. NLP tools offer a solution by automating the categorisation, analysis, and interpretation of security incident reports. By leveraging NLP, organisations can efficiently sort reports into relevant categories, identify patterns, and extract key insights. This approach not only reduces the burden on analysts but also enhances the ability to understand and respond to threats more effectively. In the context of aviation security, applying NLP can lead to quicker identification of trends, improved situational awareness, and more informed decision-making, ultimately strengthening overall security measures.

[34] Tanguy L., at al., (2016). Natural Language Processing for Aviation Safety Reports: From Classification to Interactive Analysis. At: https://doi.org/10.1016/j.compind.2015.09.005

NLP – data analysis tool	
Complexity	★ ★ ★ ★ ★
Accessibility	★ ★ ★ ☆ ☆
Scalability	★ ★ ★ ☆ ☆
Impact on operation	★ ★ ★ ☆ ☆
Added value	★ ★ ★ ☆ ☆
Maturity	★ ☆ ☆ ☆ ☆
This is an advanced tool that requires specific knowledge to understand and implement effectively and hence scores highly on complexity. In recent years accessibility has significantly improved with the availability of open-source frameworks and libraries. However, more advanced implementation may still require expertise in data science and programming. Its novelty means it still needs further examination within safety, but the key limiting factor on the security value is that it requires large amounts of quality data to implement effectively. Reporting systems may need to be more mature before NLP can yield significant benefits, however the concept remains important to explore.	

Table 17. NLP assessment.

Multi Criteria Decision Analysis (MCDA) — Regulator & Industry

It is a decision-making technique or methodologies that help evaluate and prioritise options when multiple, often conflicting criteria are involved. MCDA is widely used in various fields such as business, engineering, environmental management, and healthcare, where decision-making involves complex trade-offs between different objectives.

The quality of data analysis in aviation safety heavily relies on the quality of the input data. Statistical analysis isn't very useful if the data is flawed or inappropriate. Wilke et al., (2014) in the paper *'A Framework for Assessing the Quality of Aviation Safety Databases'*[35] suggests a framework for evaluating the quality of data, using airport surface safety (like runway and taxiway safety) as an example. Since airport safety data comes from various stakeholders with different database qualities, it's important to combine and analyse this data to ensure accurate safety assessments.

To solve this issue, the paper proposes a method to validate the quality of external data by looking at how the data was collected and investigated. It uses a technique called MCDA to assign numerical weights to twelve safety databases, based on the quality of the data collection and investigation processes at different organisations. The model considers factors like possible errors during data collection, the organisation's safety culture, data accessibility, and how consistent the reporting system is over time. These weights, combined with an internal data quality check and a measure of how much an organisation reports, help to determine how reliable a database is.

This framework for assessing data quality, originally designed for aviation safety databases, could also be applied to security databases. However, its effectiveness in the security domain might be limited by the inherent opacity and sensitivity of security data. Security information is often classified or restricted, which can make it difficult to obtain a complete and transparent dataset.

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[35] Wilke et al., (2014). A Framework for Assessing the Quality of Aviation Safety Databases. At: https://doi.org/10.1016/j.ssci.2013.11.005

Security Value

In the context of security, organisations may be less willing or able to share data due to confidentiality concerns, which could affect the comprehensiveness and accuracy of the analysis. Additionally, the variability in how different security agencies collect, report, and handle data could introduce inconsistencies, further complicating the process. Despite these challenges, adapting this framework could still provide valuable insights into the quality of security databases, especially if tailored to account for the unique constraints of the security environment. By carefully considering these limitations and working towards greater transparency where possible, security organisations could improve the reliability of their data analysis and ultimately enhance security outcomes.

MCDA – data quality analysis tool	
Complexity	★ ★ ★ ★ ★
Accessibility	★ ☆ ☆ ☆ ☆
Scalability	★ ☆ ☆ ☆ ☆
Impact on operation	★ ★ ★ ☆ ☆
Added value	★ ★ ★ ☆ ☆
Maturity	★ ★ ★ ☆ ☆
This is an advanced tool using numerical modelling, which requires specific knowledge to understand and implement effectively. Owing to the challenges of data sharing and quality in the security domain, such a tool "as is" is not scalable, furthermore, the concept requires more development within the safety domain. The prerequisite for this tool is a mature and robust reporting system and a good quality data. The value is therefore limited in practicality, but the concept of database evaluation is beneficial, and the tool could prove useful when security data is more mature.	

Table 18. MCDA analysis.

Human Performance Modelling (HPM) — Industry

Computer modelling tools were identified through literature review undertaken for this report. NASA study '*A Cross-Model Comparison of Human Performance Modelling Tools Applied to Aviation Safety*' outlines computer modelling methods to develop predictive capabilities to improve pilot performance. Computer modelling tools are also examined by Gore and Corker in the paper '*Increasing Aviation Safety Using Human Performance Modeling Tools: An Air Man-machine Integration Design and Analysis System Application'.*

The research papers examined provide a list of computer modelling tools and their use:

Adaptive Control of Thought-Rational (ACT-R)
A theory and a cognitive modelling tool. The theory describes how humans organise knowledge and produce intelligent behaviour. The cognitive modelling tool simulates the application of this theory to the extent that is practically possible.

Air Man-machine Integration Design and Analysis System (Air MIDAS)
Explore the computational representations of human-machine performance to aid crew system designers.

Distributed Operator Model Architecture (D-OMAR)
Event-based architecture for developing human performance models or agents for agent-based systems.

Attention-Situation Awareness (A-SA)
Model predicts pilot situation awareness.

HOOTL simulation
Model to predict human error in the aviation environment in surface operations. HOOTL simulations are described as effective means of predicting system vulnerabilities and will indicate possible mitigation measures and strategies.

Computer modelling to aid in safety mitigations and system design could also be applied to the security environment. These are complex computational models that are not widely accessible tools for security managers. The inclusion of these models in this report is to illustrate the gulf between human performance research as it applies to safety and as specifically applied to aviation security. Human behaviour may show parallels between safety and security, but specific modelling of humans within the security context to such an advanced level is absent from the literature. Clearly, aviation safety demands these advanced approaches, in particular when it comes to extremely high-value and extremely high-risk contexts such as space travel. In security, an assertion can be made that the risk picture simply does not warrant the use of such detailed techniques. However, that is not to say that complex approaches should be discarded – where the research resource can exist, it remains valid to examine (if not utilise) such human performance models through the security lens.

Security Value

These approaches, if applied with the correct ancillary knowledge, could provide deeper insights into how humans behave within the security system, and thus enable effective mitigation to be built or added to the security process.

Computer modelling – human performance tool	
Complexity	★ ★ ★ ★ ★
Accessibility	★ ☆ ☆ ☆ ☆
Scalability	★ ★ ★ ☆ ☆
Impact on operation	★ ★ ★ ☆ ☆
Added value	★ ★ ★ ☆ ☆
Maturity	★ ★ ★ ☆ ☆
These tools are highly advanced and require a significant amount of specialised knowledge to implement. Whilst the subject of the computational models is human performance, which is a cross-sectional topic, there would be significant effort required to utilise these tools in security. The deep level of insight that could be afforded must be balanced with the risk picture in security and whether more simplistic methods give a better cost-benefit profile.	

Table 19. Computer modelling assessment.

Computer Modelling Guidance

- NASA (2005). A Cross-Model Comparison of Human Performance Modelling Tools Applied to Aviation Safety.
- Gore and Corker (2002). Increasing Aviation Safety Using Human Performance Modeling Tools: An Air Man-machine Integration Design and Analysis System Application.

Management of Change

Change Management **Regulator & Industry**

Change management is "*a formal process to manage changes within an organisation in a systematic manner, so that changes which may impact identified hazards and risk mitigation strategies are accounted for, before the implementation of such changes*."[36]

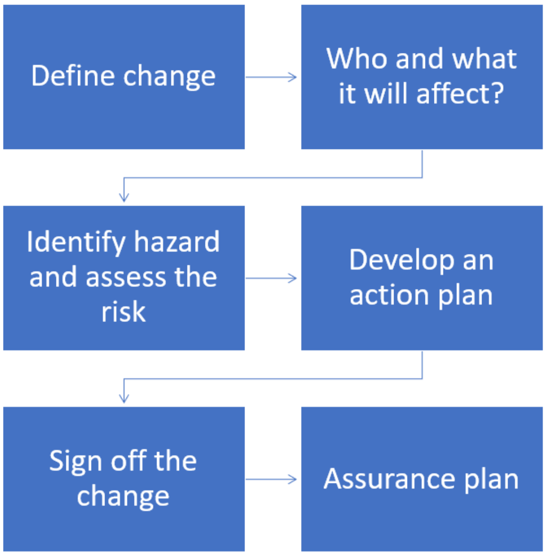

Figure 19. Steps of change management process as described in the ICAO Doc 9859 – SMS Manual.

Change can impact the effectiveness of current safety risk controls and may introduce new hazards and risks. It's essential to identify these hazards and assess and manage the associated risks according to the organisation's existing safety risk management procedures[37]. In the safety domain management of change process is required by regulations in most areas and is part of a Safety Management System. Authority requirements include a process to assess the changes proposed by the entity. Major changes require prior approval by the authority to ensure potential new hazards are captured, mitigated and monitored appropriately.

Stakeholders' interaction undertaken during this study demonstrates that change management is a tool that can be utilised for the introduction of security measures, however this process is much less standardised in aviation security as it is not mandated. Management of change is listed as a pillar of UK CAA Security Management System (SeMS)[38] and it forms part of IATA approach, however it does not form part of ICAO SeMS model. UK entities that voluntarily join the SeMS framework and entities implementing the IATA framework are responsible to establish and document change management process as required under the framework applied.

[36] ICAO (2018), Doc 9859 Safety Management Manual. Fourth Edition, 2018
[37] Ibid.
[38] UK CAA (2021), CAP 1223 Framework for an Aviation Security Management System (SeMS). Third Edition, 2021.

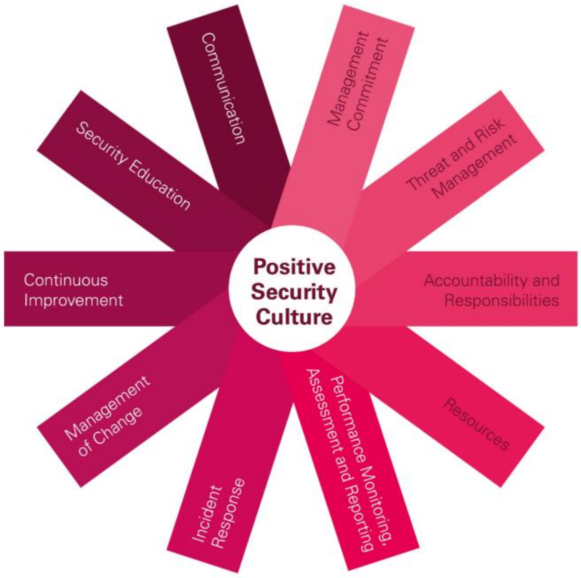

Figure 20. UK CAA SeMS framework.[39]

Security Value

There are potential benefits of introducing a standardised Management of Change (MoC) process to aviation security. Standardised MoC processes ensure that changes are implemented consistently across the entire aviation security system. This reduces variability in how changes are applied, leading to more predictable outcomes and enhancing overall security reliability. A formalised MoC process would ensure for thorough risk assessment before changes are implemented. By identifying potential hazards and vulnerabilities associated with proposed changes, organisations can take proactive steps to mitigate risks, reducing the likelihood of security breaches or failures.

MoC processes typically involve structured communication and documentation. This ensures that all stakeholders, including security personnel, management, and regulatory bodies, are informed of changes and their implications, fostering transparency and collaboration. Additionally, by having a standardised approach to managing change, aviation security organisations would more effectively adapt to emerging threats and new technologies. The MoC process facilitates timely and well-coordinated responses to changes in the security environment.

An MoC process encourages ongoing evaluation and feedback. This allows sto learn from each change, refine their processes, and continuously improve their security measures, leading to a more resilient security framework over time.

An MoC process also helps in the efficient allocation of resources, ensuring that personnel, technology, and financial investments are optimally used during changes, leading to cost-effective security enhancements.

These benefits would collectively contribute to a more robust and responsive aviation security system, capable of addressing the dynamic challenges of the aviation environment.

[39] Image source: UK CAA (2021), CAP 1223 Framework for an Aviation Security Management System (SeMS). Third Edition, 2021.

MoC – safety management tool	
Complexity	★★☆☆☆
Accessibility	★★★★★
Scalability	★★★★★
Impact on operation	★★☆☆☆
Added value	★★★★☆
Maturity	★★★★★
The concept of change management is straightforward to understand, hence scores 2 out of 5 for complexity. It is also highly accessible, with many mechanisms and tools being available – there is a low barrier to implementation. The high scalability (change management is generic and can apply at many scales and types of organisation) and maturity (change management is widely utilised and studied within and external to aviation) scores mean that apply this method to security would potentially add value. Change management approaches are naturally already used in the aviation security sphere, but the value comes from looking to how this has been standardised within safety.	

Table 20. MoC assessment.

MoC Guidance

- Celso Figueiredo. Management of change basics. AFI FRA Risk Assessment Workshop (Virtual, 27 February to 2 March 2023). PowerPoint.
- UK CAA. CAP 1223. Framework for an Aviation Security Management System (SeMS). Third edition 2021.
- IATA. Security Management System Manual. Edition 7, 2024.

Safety Case — Industry

Safety case is a "*documented assurance, including argument and supporting evidence, of the achievement and maintenance of safety*"[40]. A CAA guidance document - CAP 760 defines Safety Case as "*a documented body of evidence that provides a demonstrable and valid argument that a system is adequately safe for a given application and environment over its lifetime". ICAO guidance defines Safety Case as "a document which provides substantial evidence that the system to which it pertains meets its safety objectives*[41]". There is no one single, accepted definition of a Safety Case, however agreement exits that it refers to a comprehensive assessment that presents a clear and valid argument demonstrating that a system is safe. It includes detailed descriptions of the system, its safety objectives, and the associated risk assessments and risk management activities at key stages of the system's life cycle.

Under the SMS framework, safety assurance practices may vary between entities, but a systematic risk assessment and demonstration that the system is safe are fundamental to all. Safety Cases are commonly employed to demonstrate and provide evidence of the safety of operations when changes are proposed. "*A Safety Case is an explicit documentation of a safety critical system, its corresponding safety objectives, and the associated safety risk assessment and risk management of the system, at appropriate milestones in the life of the system*"[42].

[40] Skybrary, Safety case at: Safety Case | SKYbrary Aviation Safety

[41] ICAO, GUIDANCE MATERIAL ON BUILDING A SAFETY CASE FOR DELIVERY OF AN ADS-B SEPARATION SERVICE, Version 1.0 – September 2011

[42] Ibid

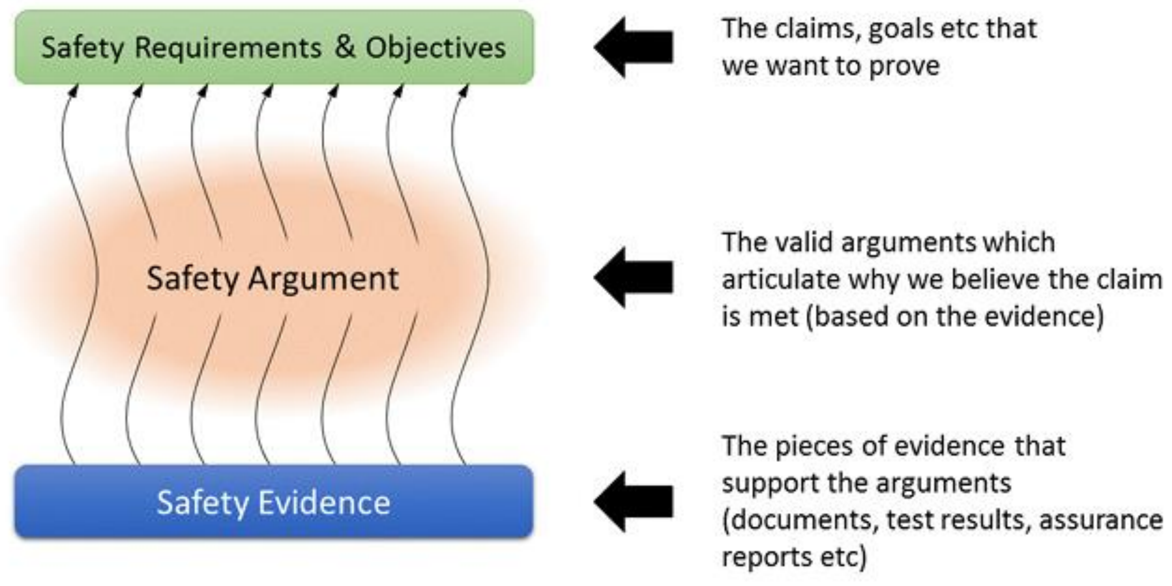

Figure 21. A general form of a Safety Case[43].

An example of a Safety Case may include a safety case for construction works within the runway strip at Dubai International Airport in 2013. The project involved collaboration with Dubai Airports' departments, Dubai Air Navigation Services (DANS), and construction companies. As various construction activities were planned within the runway strip during ongoing flight operations, particularly before and after the temporary closure of runway 12R/30L in 2014, the safety case aimed to identify potential hazards, assess associated risks, and implement effective mitigation measures to ensure the safety of runway operations, adjacent taxiways, and the construction site[44].

Aviation safety cases, traditionally used to demonstrate that operations or changes in an aviation environment are safe, can be adapted for aviation security to ensure that security risks are adequately identified, assessed, and mitigated. Engagement with aviation stakeholders indicates Safety Cases are utilised in the industry to ensure safety, when new security measures are introduced. This tool could be used in aviation security environment only or in integrated approach to safety and security management.

Security Value

Just as safety cases involve identifying potential hazards and assessing risks, a security case would involve identifying potential security threats, such as terrorism, cyber-attacks, or unauthorised access. These threats can be analysed to determine their likelihood and potential impact on aviation operations. Similar to how a safety case demonstrates the safety of a system, a security case would provide evidence that the security measures in place are effective in mitigating identified threats. This could include physical security measures, cyber defences, personnel vetting processes, and procedural controls.

In a safety case, mitigation measures are designed to reduce risks to acceptable levels. For a security case, this could involve developing and implementing security protocols, training programs, technology upgrades, and emergency response plans to address specific security threats.

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[43] Image source: Defence Safety Authority. Manual of Air System Safety Cases (MASSC). At: [MASSC_Issue_3.pdf (SECURED) (publishing.service.gov.uk)]

[44] Dubai Airports (2013). *Safety Case for construction works within the runway strip.* At: [Safety Case for construction works within the runway strip - airsight GmbH]

Security cases can be integrated with safety management systems to create a comprehensive risk management approach that considers both safety and security risks. This ensures that the overlap between safety and security, such as the risk of sabotage or insider threats, is effectively managed. Just as safety cases are often required to demonstrate compliance with safety regulations, security cases could be used to demonstrate compliance with security regulations and standards, such as those set by the ICAO or national aviation authorities. Security cases would involve collaboration with various stakeholders, including airport authorities, airlines, security agencies, and regulatory bodies, ensuring that all perspectives are considered and that the security measures are robust and comprehensive.

By applying the structured and systematic approach of safety cases to aviation security, organisations can better manage security risks, enhance the protection of assets, and ensure the safe and secure operation of aviation activities.

It should be noted that a Safety Case, depending on the complexity of the issue, can be a lengthy and detailed document that requires significant time and effort to prepare. Developing the necessary skills to create an effective Safety Case may also be necessary.

Safety Case - safety management tool	
Complexity	★ ★ ★ ★ ☆
Accessibility	★ ★ ★ ☆ ☆
Scalability	★ ★ ★ ☆ ☆
Impact on operation	★ ★ ★ ☆ ☆
Added value	★ ★ ☆ ☆ ☆
Maturity	★ ★ ★ ★ ★
The conceptual underpinnings of this method (risk, and the mitigation thereof) are common to security, and therefore easily understood and transferred. However, given that safety cases can sometimes be highly detailed, the complexity scores highly. The method is fairly accessible, however, requires systematic analysis and evidence gathering and could therefore be difficult to apply in security. The level of data gathering and collaboration required to formulate a comprehensive safety case means that the 'impact on operation' and scalability both score 3 out of 5. As a mature, well-researched and utilised method, there is potentially some value that can be added to security; security already uses detailed risk assessment as part of demonstrating that systems and process are secure, so by studying the safety case method more integrated and holistic approaches could be developed.	

Table 21. Safety Case method assessment.

Safety Case Guidance

- CAA Safety Regulation Group. CAP 760 Guidance on the Conduct of Hazard Identification, Risk Assessment and the Production of Safety Cases. For Aerodrome Operators and Air Traffic Service Providers. 10 December 2010.
- ICAO GUIDANCE MATERIAL ON BUILDING A SAFETY CASE FOR DELIVERY OF AN ADS-B SEPARATION SERVICE, Version 1.0 – September 2011.
- Civil Aviation Safety Authority – Australia. Guidelines for the preparation of safety cases covering CASR Part 171 services. ADVISORY CIRCULAR AC 171-02v1.1. November 2022.

Continuous Improvement

Management System Assessment Tool – EASA | Industry

EASA Management System Assessment Tool (MSAT) is a framework designed to help aviation organisations evaluate and improve their management systems. This tool is particularly focused on ensuring that organisations comply with the EASA regulatory requirements for management systems, which are critical for maintaining high standards of safety and efficiency in aviation operations.

"The tool assesses the compliance and effectiveness of the Management System through a series of features based on ICAO Annex 19 and EASA Management System requirements for organisations. It is set out using the 12 elements of the ICAO SMS Framework (…), some additional EASA Management System requirements within the EU environment, including the need to comply with Regulation (EU) 376/2014 on "occurrence reporting" and some key enablers to foster a "just culture environment". Each feature should be reviewed to determine whether the feature is "Present", "Suitable", "Operating" and "Effective"[45]".

Security Value

Similar approach is already developed in aviation security for the assessment of SeMS under UK SeMS framework. Nevertheless, more widespread and standardised use of such tools could benefit aviation security domain, and the design of such a tool at the international level would allow easy accessibility, data gathering, and comparison of SeMS maturity levels and performance. In particular, additional perspectives are gained in safety by data sharing approaches. One example includes London Luton Airport, where safety culture surveys (a component of SMS assessment) are shared between organisations and used as a basis for workshop interactions (Stroeve et al., 2022). Similar collaborative approaches would benefit security by facilitating the pooling of insights and the construction of a more holistic risk profile.

MSAT– EASA SMS assessment tool	
Complexity	★☆☆☆☆
Accessibility	★★★★★
Scalability	★★★★★
Impact on operation	★★☆☆☆
Added value	★★★★☆
Maturity	★★★★☆
This SMS assessment tool is designed to be easily understood and facilitated, and can be widely applied to varying organisations. It's use has minimal impact on an operation, and the concepts it is based on are mature and well-researched. Similar assessment tools do exist for security management systems, however they are not applied universally, hence there is a potential opportunity for adding value with more widespread and standardised use of a SeMS assessment tool.	

Table 22. MSAT assessment.

[45] EASA (2023). Management System Assessment Tool. At: Management System Assessment Tool | EASA (europa.eu)

- EASA (2023). Management System Assessment Tool. At: Management System Assessment Tool | EASA (europa.eu)
- UK CAA. Security Management Systems overview. Security Management Systems overview | Civil Aviation Authority (caa.co.uk)

Aviation Safety Culture Inquiry Tool (ASC-IT) — Regulator & Industry

This tool has been developed to assist organisations in aviation with the assessment and management of their safety culture and is applicable to the entire civil aviation sector for both operational (like airlines, airports, ground handling providers, maintenance repair organisations, air navigation service providers) as well as non-operational bodies (like policy making agencies, regulators and inspecting agencies). The tool can be applied to all categories of organisations in aviation and to different levels within such organisations and provides a capability for benchmarking against similar organisations or other sectors within the aviation industry.

Figure 22. 7 steps of ASC-IT approach[46].

Security Value

While existing security culture assessments are valuable tools, the maturing concept of security culture may benefit from development of a more detailed and nuanced approach to measuring security culture based on more advanced approach and in line with new technologies (software based). ASC-IT could provide foundations for development of such tools in security domain. There are many similarities between good safety culture and good security culture, hence little modification of this tool would be required to apply it within security. Similarly, it is generic enough to apply to all sectors, hence will enable benchmarking to take place across security entities.

ASC-IT – Safety Culture assessment tool	
Complexity	★ ★ ☆ ☆ ☆
Accessibility	★ ★ ☆ ☆ ☆
Scalability	★ ★ ★ ★ ★
Impact on operation	★ ★ ☆ ☆ ☆
Added value	★ ★ ★ ★ ☆
Maturity	★ ★ ★ ☆ ☆
This tool has low complexity – whilst appropriate question design and a relevant technological platform are needed, it is simple to use and understand. Furthermore, there is limited challenge in its implementation, although there would need to be some adaptation to security specific themes. It is exceptionally scalable, applying to all areas of aviation and even applicable outside of the aviation domain. The concept of organisational culture and its assessment is currently at a mid-point in its maturity.	

[46] Image Source: Montjin and Balk (2010). ASC-IT Aviation Safety Culture Inquiry Tool: Development from theory to practical tool. At: ASC-IT-Seven-steps-to-improve-your-safety-culture.pdf (nlr.org)

Taken together, there is a high potential for added value to security (although existing security culture assessments are already bringing benefits).

Table 23. ASC-IT assessment.

ASC-IT Guidance

- A.D. Balk (2016). ASC-IT: Seven steps to improve your safety culture. ASC-IT-Seven-steps-to-improve-your-safety-culture.pdf (nlr.org)

10.4 Safety promotion tools, methods and mechanisms

This section explores safety promotion tools and methodologies focused on training. It outlines various training methodologies in safety that have proven effective in improving staff performance. Aviation training is slowly transitioning from rigid, syllabus-based methods to competency-based training and assessments. Gaining insight into these safety approaches could pave the way for developing a similar framework in the security domain.

Training and Education

Competency Based Training and Assessment	Regulator & Industry

Competency-Based Training and Assessment (CBTA) in aviation is an approach that prioritises evaluating individuals based on their demonstrated abilities and skills rather than adhering to fixed training requirements. This method involves identifying the essential competencies for specific aviation roles, creating training programs to cultivate those competencies, and assessing individuals' performance against established standards. CBTA emphasises developing and evaluating the specific skills, knowledge, and behaviours necessary for effective job performance[47]. This methodology is primary utilised by the industry however, the regulator has to develop suitable oversite mechanisms supported by national regulatory requirements.

Facilitation of the implementation of CBTA is one of the strategic priorities of EASA as defined in the European Plan for Aviation Safety (EPAS)[48] for 2023 – 2025. The transition from traditional, task-based training to Competency-Based Training and Assessment in aviation offers potential safety benefits and operational efficiencies, but it requires regulators, competent authorities, and the industry to reach the necessary maturity for effective implementation. This strategic priority focuses on successfully adopting CBTA for all licenses and ratings, ensuring a sufficient supply of qualified instructors and competent personnel in national authorities, and leveraging new technologies and data-driven training approaches.

In aviation security domain, regulation (EU) No2015/1998 defines security technical competencies of all staff within the scope of the regulation as demonstrated in below example:

11.2.3.8 Training of persons implementing baggage reconciliation shall result in all of the following competencies: (…)

General training obligations dictate that training must encompass theoretical, practical, and on-the-job components. However, the extent to which this aligns with the CBTA approach in the safety domain remains unclear. Typically, security training follows a more traditional approach, relying on written knowledge assessments rather than the competency-based assessments defined in safety training.

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[47] UK CAA (2023). *Navigating the Future with Competency-Based Training and Assessment*. Aviation Safety Insights at: Navigating the Future with Competency-Based Training and Assessment (caainternational.com)

[48] EASA. European Plan for Aviation Safety (EPAS) 2023 – 2025. Volume I, Strategic Priorities at: European Plan for Aviation Safety (EPAS) 2023-2025 | EASA (europa.eu)

ICAO Doc 10002, Cabin Crew safety Training Manual offers a clear guidance for operators regarding CBTA approach to security training is also included in this manual. This approach includes specification of cabin crew tasks, sub-tasks, essential knowledge, task list standards, training media and required competencies. Required competencies are relevant for simulated exercises and include application of policies and procedures, communication, leadership and teamwork, passenger management, problem solving and decision making, situational awareness and management of information.

CBTS is commonly recognised as the most effective educational approach to enhancing performance of staff. This approach is still not fully developed in aviation security domain; it may however bring significant benefits when applied to security roles as well as safety.

Recent example of switching from traditional to a CBTA approach includes Dangerous Goods Training required by Subsection 1.5 of the IATA Dangerous Goods Regulations (DGR). Knowledge, skills and attitude are defined as three core competency factors and levels of proficiency are assigned from Introductory, Basic to Intermediate and Advanced.

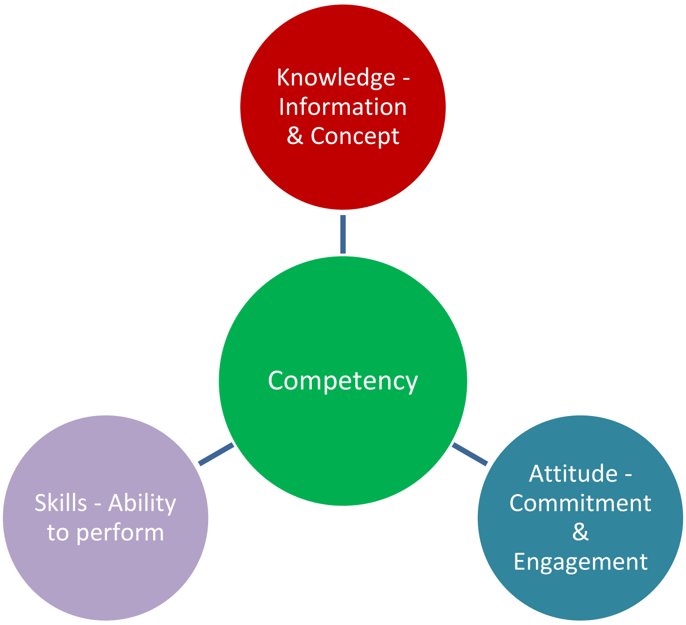

Figure 23. Three competency factors as described by IATA[49]

IATA in CBTA guidance to Dangerous Goods training provides a number of benefits of this approach:

- ability to help personnel achieve their highest potential while ensuring a minimum standard of competence,
- addressing function-specific training needs,
- promoting continuous learning and performance improvement,
- focusing on learning rather than just passing tests,
- integrating the necessary knowledge, skills, attitudes, and experience for job proficiency,
- supporting the implementation of safety management systems (SMS),
- ensuring an adequate number of qualified instructors, designers, and assessors.

The shift to CBTA presents challenges for competent authorities, as they must adapt their safety oversight programs and evaluate the effectiveness of processes rather than relying on prescriptive rules. EASA plans a phased approach to incorporating CBTA in licensing, allowing time for the industry to gain experience before considering changes to current training requirements based on hours or time.

[49] IATA (2023). *Competency-based Training and Assessment Approach*. Dangerous Goods Training Guidance Edition 1.

Implementing this approach in aviation security would pose significant challenges, including the need to revise regulatory requirements, allow time for the industry to gain experience, and manage the impact on operations. Currently, CBTA is in its early stages of maturity, with only a few areas of aviation, such as flight crew training, having reached a more advanced stage. Despite these challenges, CBTA appears to be the future of aviation training and is likely to expand into the security domain, either as an integrated approach (safety – security training) or as a standalone method.

CBTA – training method	
Complexity	★★★★☆
Accessibility	★★★★☆
Scalability	★★★★★
Impact on operation	★★★★★
Added value	★★★★☆
Maturity	★★☆☆☆
This training method scores highly on complexity as there are many elements that make up an effective competency-based training programme. There is a large amount of effort and resource required to implement such a programme, hence the accessibility and impact scores are also elevated. The concept is relatively novel, being currently rolled out to various aviation safety areas – the advantages that this could present to security replicate those posited for safety.	

Table 24. CBTA approach assessment.

CBTA Guidance

- ICAO Doc 10002, Cabin Crew Safety Training Manual, Second Edition, 2022
- IATA White Paper, Competency-Based Training and Assessment (CBTA) Expansion within the Aviation System. cbta-expansion-within-the-aviation-system.pdf (iata.org)
- IATA, Competency-based Training and Assessment Approach, Dangerous Goods Training Guidance Edition 1

Evidence Based Training (EBT) Regulator & Industry

Evidence-Based Training (EBT) is an innovative approach to aviation training that focuses on using real-world data and evidence to design, implement, and assess training programs for flight crews. Unlike traditional training methods that may rely heavily on prescriptive, one-size-fits-all approaches, EBT tailors training to the specific needs and experiences of pilots, addressing the most relevant risks and operational challenges they are likely to face. EBT is applicable across various aspects of pilot training, from initial training to recurrent training, and is aimed at enhancing pilot performance and safety through targeted, data-driven strategies. This methodology is primary utilised by the industry however, the regulator has to develop suitable oversite mechanisms supported by national regulatory requirements.

EBT is primarily used in the training of airline pilots but can also be applied to other areas of aviation, such as cabin crew training and other operational roles where safety is critical. The approach is designed to be flexible, allowing training programs to evolve as new data and evidence emerge. EBT is particularly valuable in addressing both routine and non-routine situations that pilots may encounter, thereby improving decision-making, risk management, and overall operational safety.

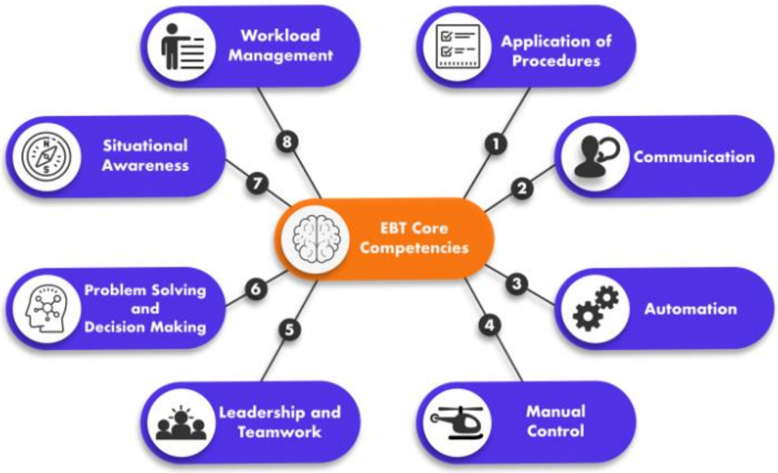

Figure 24. EBT Core Competencies[50].

EBT was developed through the IATA Training and Qualification Initiative (ITQI), launched in 2007. A working group, including representatives from airlines, civil aviation authorities, and other stakeholders, was tasked with creating a new methodology for recurrent training and assessment. This led to the development of EBT. In 2013, ICAO endorsed EBT by publishing the Manual of Evidence-Based Training (Doc 9995), and an IATA/ICAO/IFALPA "*Evidence-Based Training Implementation Guide*" was also released to assist operators in implementing EBT[51].

EBT focuses on the specific skills and competencies that are most critical for safety, ensuring that training is relevant and effective. As EBT is based on real-world data, it allows training programs to adapt to changing operational environments and emerging risks and by concentrating on the areas that pose the greatest risk, EBT enhances the overall safety of flight operations. Additional benefit of EBT is efficient use of resources as EBT helps airlines allocate training resources more effectively by focusing on the most pressing needs, rather than following a rigid training curriculum.

Some limitations are also apparent as EBT relies heavily on the availability and accuracy of operational data, which can be a limitation if data is incomplete or not representative. Additionally, transitioning from traditional training methods to EBT can be complex, requiring significant changes in training design, delivery, and assessment. EBT represents a shift from conventional training models, gaining regulatory approval and alignment with existing standards can be challenging and complex. It also needs to be considered that developing and maintaining an EBT program can be resource-intensive, requiring ongoing data analysis and program adjustments.

EBT could be applied to aviation security, though with some adaptations to meet the specific needs of this domain. EBT in aviation security would focus on developing and assessing the competencies of security personnel based on real-world scenarios and threats. This would involve training that reflects current security challenges, such as evolving terrorist tactics or cyber threats. However, introduction of EBT in security domain would also encounter significant challenges. Unlike pilot performance data, security incidents might not always be as well-documented and details of security attacks and breaches may not be in public domain, making it harder to establish a comprehensive evidence base. Development of comprehensive evidence base would be heavily dependent on information sharing and access to detailed security reports that currently remain confidential. Integrating EBT into existing security training frameworks would also require significant changes to regulations, training programs, and resource allocation significantly impacting operational and regulatory environment.

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[50] Image source: Jop Dingemans (2022). *Evidence Based Training in Aviation: Focussing on What Matters.* At: [Evidence Based Training in Aviation: Focussing on What Matters (pilotswhoaskwhy.com)]

[51] IATA, Evidence-Based Training (EBT) at: [IATA - Evidence-Based Training (EBT)]

The current IATA EBT Implementation Guidance includes the integration of security procedures within the Safety and Emergency Procedures (SEP) training component of ground training for pilots. This indicates that flight crew safety training may already encompass aspects of security training. By embedding security procedures into the broader safety training framework, airlines can ensure that pilots are not only proficient in handling safety-related scenarios but are also equipped to manage security threats effectively.

Security Value

While transferring EBT to security screening would require adaptation to account for the specific challenges and responsibilities of screeners, the fundamental principles of competency-based, data-driven, and scenario-focused training could significantly enhance the effectiveness of training programs for aviation security personnel. EBT emphasises developing specific competencies required for effective performance. This approach can be transferred to security screeners by identifying key competencies such as threat detection, decision-making under pressure, and effective communication, and tailoring training programs to develop these skills.

EBT – training method	
Complexity	★★★★★
Accessibility	★★★★☆
Scalability	★★☆☆☆
Impact on operation	★★★★★
Added value	★★★☆☆
Maturity	★★★☆☆
This training method has a high complexity, as it requires an analysis of data to distil required security competencies. Where it is already used, within safety, it requires an implementation period. As a new training method, there would be a large impact on existing security training programmes, but there is a potential to add value, as evidence-based training can keep up with the increasingly complex and technical screening role.	

Table 25. EBT training assessment.

EBT Guidance

- ICAO Doc 9995, Manual of Evidence-based Training. First edition, 2013.
- IATA, Evidence-Based Training Implementation Guide, Edition 2, Effective January 2024.
- EASA, Oversight guidance for the transition to Mixed EBT Implementation. Version 3.5, 2Q 2022.
- EASA, Explanatory Note to Decision 2015/027/R. Implementation of evidence-based training (EBT) within the European regulatory framework.

"CRM can be defined as a management system, which makes optimum use of all available resources (equipment, procedures and people) to promote safety and enhance the efficiency of flight operations[52].

CRM training encompasses a wide range of knowledge, skills and attitudes including automation management, monitoring and intervention, resilience development, surprise and startle effect management, safety culture and cultural differences, teamwork, leadership, information processing, communication or Threat and Error Management (TEM). CRM emerged in response to a growing recognition that human error was a significant factor in aviation accidents. The concept evolved from a 1979 NASA study, which studied the role of human factors in aviation accidents[53]. The study revealed that many accidents were not due to mechanical failure but rather to failures in communication, decision-making, and leadership among flight crews. This led to the development of a new approach to training that focused on the non-technical skills essential for safe flight operations, including teamwork, communication, situational awareness, and problem-solving.

Initially, CRM training was designed for flight crews, with the goal of improving the interpersonal aspects of the cockpit environment. Over time, the concept expanded to include all members of the aviation team, including cabin crew, maintenance personnel, and air traffic controllers. CRM training became a cornerstone of aviation safety, emphasising the importance of effective communication, the sharing of information, and the use of all available resources to manage situations that arise during flight operations. The evolution of CRM has contributed to significant reductions in human error and has become a global standard in aviation, continuously adapting to new challenges and incorporating lessons learned from ongoing research and real-world incidents.

- **1970's – introduction of cockpit voice recorders (CVR)**
- 1979 – NASA research study of aircraft accidents
- Cockpit Resource Management - CRM training emerged after the recognition that the technical skills of piloting an aircraft were insufficient to ensure safety and best performance
  recognising own vulnerabilities and own strengths
- 1900's – CRM training extended to cabin crew and air traffic controllers also incorporating a broader range of skills
- 2000's - CRM became an integral part of aviation safety culture, extending its reach to maintenance personnel, dispatchers, and ground crew
- 2001 - Human Factors incorporated into 7th edition of Annex 17
- 2010's - CRM to address new challenges related to human-automation interaction
- 2017 – First Edition of GASeP – human factors to be included in certification and use of security equipment
- 2020's - CRM has continued to adapt to the evolving aviation landscape, addressing issues related to pilot fatigue, mental health, and the effects of the COVID-19 pandemic on aviation safety
- 2021 – ICAO Doc 10151 First Edition Manual on Human Performance (HP) for Regulators
- 2022 – ICAO 41st Assembly WP – 130 specifically refers to human factors in the aviation security domain
- 2024 – GASEP Second Edition – human factors in security domain as priority area for ICAO

Table 26. Evolution of CRM in aviation.

[52] EASA (2017). Crew Resource Management in practice. Version 1 – December 2017 at: [CRM Training Implementation | EASA (europa.eu)]

[53] NASA (1980), Resource Management on the Flight Deck, California at: https://ntrs.nasa.gov/api/citations/19800013796/downloads/19800013796.pdf

Air Operations regulation provides specific details on CRM training for flight crew and cabin crew. Below chart lists all CRM topics required for flight crew and cabin crew.

Human Factors in aviation	General instructions on CRM	Principles and objectives
Human performance and limitations	Threat and error management	Stress and stress management
Fatigue and vigilance	Personality awareness, human error and reliability, attitudes and behaviours, self-assessment and self-critique	Assertiveness, situation awareness
Information acquisition and processing	Automation and philosophy on the use of automation	Specific type-related differences
Monitoring and intervention	Shared situation awareness, shared information acquisition and processing	Workload management
Effective communication and coordination inside and outside the flight crew compartment (for flight crew)	Leadership, cooperation, synergy, delegation, decision-making actions	Surprise and startle effect
Resilience development	Cultural differences	Operator's safety culture and company culture, standard operating procedures (SOPs) organisational factors, factors linked to the type of operations
Effective communication and coordination with other operational personnel and ground services	Case studies	Effective communication and coordination between all crew members including the flight crew as well as inexperienced cabin crew members (cabin crew)

Table 27. Full list of CRM topics for Aircrew.

Aviation security has lagged in incorporating human factors principles to enhance staff contributions to overall aviation safety. The 41st ICAO Assembly highlighted the significance of human factors in aviation security, making it a priority area for ICAO[54]. In second edition of GASeP, human factors became priority area for ICAO. The GASeP prioritises the human component as essential for ensuring safe and secure aviation. It emphasises the need for a deep understanding of human factors and their impact on the performance of the aviation security workforce. GASeP calls for clearly defined and documented security policies that outline organisational expectations and requirements for staff performance, considering factors such as individual capabilities, equipment, and work environments.

The plan stresses the importance of addressing emerging workforce needs and challenges, with the goal of supporting staff effectively and making aviation security roles attractive and professional career choices. This focus on human factors is crucial for the long-term sustainability of civil aviation security[55].

Security Value

Many aspects of CRM training are directly applicable to security personnel. Understanding both the strengths and limitations of human capabilities, along with strategies to mitigate human limitations, could significantly enhance aviation security. Like aircrew and other aviation professionals, security staff encounter challenges such as stress, fatigue, errors, and limitations in attention, perception, and information processing. Implementing CRM principles in their training could help address these challenges and improve overall performance.

CRM – training tool	
Complexity	★ ★ ☆ ☆ ☆
Accessibility	★ ★ ★ ★ ★
Scalability	★ ★ ★ ★ ★
Impact on operation	★ ★ ★ ☆ ☆
Added value	★ ★ ★ ★ ★
Maturity	★ ★ ★ ★ ★
This training tool, or topic, is centred on human factors. As an application of a field of knowledge to the security training system, it is a straight-forward method which is highly accessible. It is also applicable to all security entities and is a mature topic. Human factors are already a consideration within security, however, the concept of CRM as a package is not often thought about. There is therefore added value to be found in an examination of various concepts in CRM and their application to security.	

Table 28. CRM training assessment.

CRM Training Guidance

- UK CAA, CAP 737 - Flight Crew Human Factors Handbook. Version 2, February 2023.
- EASA, Crew Resource Management in practice. Version 1 – December 2017.
- EASA, CRM Training Implementation. CRM Training Implementation | EASA

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[54] ICAO Working Paper, HUMAN FACTORS IN THE AVIATION SECURITY DOMAIN, 41st Assembly Session, A41-WP\130

[55] ICAO (2024). *Doc 10118. Global Aviation Security Plan*. Second Edition, 2024 at: GLOBAL AVIATION SECURITY PLAN 2nd Ed.EN.pdf (icao.int)

Human Factors Training — Industry

Development and promotion of the role of human factors in aviation security became a Global Priority Area 3 in the second edition of GASeP published in 2024. "*The human component is critical to ensure safe and secure aviation. Human factors and the impact they have on the performance of the aviation security workforce should be better understood, with defined and documented security policies in place, which set organization expectations and requirements for staff and their performance (which may be impacted by their abilities, the equipment they use and the environments in which they function).*"[56]

In the safety domain, CRM training (described more in detail in Training Tools section) serves as a foundation for enhancing capabilities in human factors and performance. However, the aviation security sector has been relatively slow in integrating human factors principles into staff training. By developing specialised training syllabi and introducing tailored human factors training for security personnel, aviation security could significantly improve staff performance, decision-making, and overall operational effectiveness. Such training would address the unique challenges faced by security staff, equipping them with the skills necessary to manage stress, fatigue, and situational awareness, ultimately contributing to a more secure aviation environment.

Rapid development of screening technology, use of computer tomography, Artificial Intelligence and common introduction of automated systems also has an impact on human performance. These systems often change the role of the human in the system which should be analysed and addressed with appropriate training and capacity building activities.

Human Performance & Human Factors – training tool	
Complexity	★★☆☆☆
Accessibility	★★★★☆
Scalability	★★★★★
Impact on operation	★★★☆☆
Added value	★★★★★
Maturity	★★★★★
Integrating human factors into aviation security conceptually, as a method, is straightforward and accessible, with numerous resources available. It is also applicable to all security entities and is a mature topic. Human factors are already a consideration within security, however, a detailed integration of the topic to a specific standard (as seen in safety) has not yet occurred. There is therefore added value to be found in an examination of various concepts in human factors and how to embed them in security.	

Table 29. HF and HP training assessment.

Human Factors Guidance

- UK CAA. CAP737, Flight-crew human factors handbook. Second Edition, February 2023.
- ICAO/UK CAA. Motivation and performance of staff in an aviation security environment. UK - Guidance on Human Factors.pdf (icao.int)
- Aviation Security Insights (2021). Security Culture and Human Performance – the missing link? Aviation Security Culture and Human Performance – the missing link? (caainternational.com)
- UK CAA. CAP 716, Aviation Maintenance Human Factors. cap716.pdf (SECURED) (caa.co.uk)

[56] ICAO (2024). Doc 101118, Global Aviation Security Plan. Second Edition, 2024.

Conclusion

This part of the research aimed to identify safety tools that can contribute to effective implementation of security measures. To enable investigation of safety tools and clearly define the scope of the research, the team had to define safety tool. Safety tool was therefore defined as a mechanism, process, practice, or technology designed to ensure the effective implementation, continuous monitoring, and ongoing improvement of safety measures. It encompasses international standards and regulations, communication methods, accountability frameworks, and tools for raising awareness, all of which contribute to the proactive management and enhancement of safety in various environments. Additionally, definitions of a tool, method and mechanism were defined for the purpose of this report.

Initial stakeholder engagement and expert interviews provided a starting point to define tools currently used by the industry to implement and ensure efficiency of security measures. This was complemented by academic literature review. Identified in this way safety tools were categorised into following categories:

Safety Management and Policy

- SMS
- Annex 13 – Aircraft Accident and Incident Investigation
- Descriptive analysis

Risk management tools, methods and mechanisms

- Hazard Identification
    - HIRA
    - Intelligent Aviation Safety Hazard Identification Method
    - Systems Theoretic Process Analysis (STPA)
- Risk Management
    - Bowtie
    - Fault Tree Analysis
    - Fishbone

Safety assurance tools, methods and mechanisms

- Performance Monitoring and Measurement
    - Occurrence Reporting
    - Root Cause Analysis methods
    - Risk Based Oversight (RBO)
    - Performance Based Oversight (PBO)
    - Diagnostic Statistical Analysis
    - Aviation Safety Data Mining Workbench
    - Natural Language Processing
    - Multi Criteria Decision Analysis (MCDA)
    - Human Performance Modelling (HPM)
- Management of Change
    - Change Management process
    - Safety Case
- Continuous Improvement
    - Management System Assessment Tool – EASA
    - Aviation Safety Culture Inquiry Tool (ASC-IT)

Safety promotion tools, methods and mechanisms

- Training and Education
    - Competency Base Training and Assessment
    - Evidence Based Training
    - Crew Resource Management (CRM)
    - Human Factors Training

How safety tools are used in security domain is also dependant on specific safety area. Engagement with stakeholders and experts shows that some areas may refer to specific tools for implementation of security measures. For example, aircraft design organisations will more commonly refer to safety assessment for aircraft design organisations or air operators to safety case or safety action group.

Each tool was assessed with consideration to its complexity, accessibility to security managers, scalability to different domains, impact its introduction would have on operation, what value it would add to security domain and its overall maturity. Additional resources and reading material on each tool are also included in each section.

Certain tools are commonly used across both safety and security domains without requiring adaptation, such as Bowtie Analysis. However, there are also tools that, while applicable to aviation security and easily accessible are underutilised or applied in a less structured and standardised manner for example various root cause analysis methods. Additionally, some tools could be adapted to the aviation security domain, potentially enhancing overall aviation safety. There are tools that are specific to certain areas of aviation safety, which are neither easily adaptable nor add value in other contexts. Finally, some tools in the safety domain are either not easily accessible, are complex, or are still in the early stages of maturity.

The research team is not stipulating that all presented tools should be immediately implemented in security domain. This report may serve as knowledge base for entities and individuals in the security domain to gain more awareness of available tools. Additionally, regulators and decision-makers may identify areas requiring better awareness.

General observations deriving from the investigation of safety tools that may contribute to the effective implementation of security measures include the following points:

- From stakeholders and experts' engagement is clear that there is a need to assess where security domain can 'open up' to the wider aviation community.
    - More available information regarding security incidents/breaches. This could widen available database and enable collective learning and development leading to breaking silos.
    - Allowing a vetted aviation safety professional to observe and assess security practices could offer valuable insights or assurance.
- There is a need to develop better information sharing and cooperation strategies between safety and security.
    - For example, standardisation of Internal Review Meeting as joined-up safety-security forum.
    - Better sharing of security incidents/breaches data and development of case studies.
- Enabling development of much wider database in aviation security.
    - Investigating and standardising use of reporting systems in security domain for example, including screeners.
    - Wider and more transparent database would allow for more sophisticated machine learning and Artificial Intelligence systems to analyse security data and predictive modelling.
- Development of Human Factors capability in aviation security domain.
    - CRM training could be analysed and adapted for security screeners.
    - Introduction of competency-based assessment would improve general staff performance.

Engagement with stakeholders and experts has highlighted the need for the security domain to become more transparent and integrated with the wider aviation community. Increasing the availability of information on security incidents and breaches would expand the existing databases and foster collective learning, helping to break down silos. Additionally, allowing vetted aviation safety professionals to observe and assess security practices could provide valuable insights and enhance overall assurance.

There is also a clear need to improve information-sharing and cooperation between safety and security. This could include standardising internal review meetings as joint safety-security forums leading to better awareness of both safety and security experts. Improvement in sharing of security incident data would lead to the development of comprehensive case studies. Expanding and standardising reporting systems within the security domain, such as those used by screeners, would contribute to a broader and more transparent database. This, in turn, would support the development of more advanced machine learning and AI systems for analysing security data and predictive modelling.

Furthermore, there is a need to develop Human Factors capabilities within aviation security. For example, Crew Resource Management (CRM) training could be analysed and adapted for security screeners, and the introduction of competency-based assessments would likely improve overall staff performance and effectiveness in the security domain.

Finally, investigation of safety tools that might contribute to the effective security measures also provides an insightful starting point for the next stage of this research which is investigation and development of an integrated safety and security risk management methodology.

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Annex A Literature Review

	Paper	Summary	Key Tools	Evaluation
1.	Analysis of the Aviation Safety Management System by Fractal and Statistical Tools Bugayko et al., (2019) [Title of paper (nau.edu.ua)]	*World civil aviation is an open-source system that is affected by a large number of related and non-related factors. Aviation safety is one of the prioritized directions in the industry. Its managerial decision-making process is primarily based on a versatile analysis of security data in which the choice of the appropriate mathematical apparatus is fundamental. This article suggests applying **fractal-statistical analysis** to evaluate the aviation safety management system in terms of determining the random distribution of quantitative dynamics of aircraft crashes with lethal consequences in the period from 1946 to 2017. This allows us to verify the adequacy of **probabilistic approaches** appliance in analysing the dynamics of aviation disasters. The results of research carried out on the basis of the Hurst exponent have allowed us to conclude that the dynamics of aviation disasters is characterized by the effect of "spatial memory". In other words, these are "hidden laws", for which further investigation can become an effective tool for the development of proactive methods in managing aviation safety.*	Advanced statistical methods	A statistical method for investigating the distribution of fatal accidents, to verify the use of probabilistic approaches – further investigation into the underlying dynamics of the system becomes a tool for developing proactive safety approaches. This could have application in security systems.
2.	Human factors and aviation safety: what the industry has, what the industry needs Aurino (2010) https://doi.org/10.1080/001401300409134	*The use of statistical analyses to assert safety levels has persuasively been established within the aviation industry. Likewise, variations in regional statistics have led to generalizations about safety levels in different contexts. Caution is proposed when qualitatively linking statistics and aviation's resilience to hazards. Further caution is proposed when extending generalizations across contexts. Statistical analyses—the favoured diagnostic tool of aviation—show sequences of cause/effect relationships reflecting agreed categorizations prevalent in safety breakdowns. They do not, however, reveal the processes underlying such relationships. It is contended that the answers to the safety questions in contemporary aviation will not be found through the numbers, but through the understanding of the processes underpinning the numbers. These processes and their supporting beliefs are influenced by contextual constraints and cultural factors, which in turn influence individual and organizational performance. It is further contended that the contribution of human factors is fundamental in achieving this understanding. This paper, therefore (1) argues in favour of a macro view of aviation safety, (2)*	Diagnostic statistical analysis	Using statistical analysis as a method to assert safety levels and diagnose causes. This is already used in security (e.g. compliance data) however this paper also argues a premise for a revised safety paradigm – this could have implications for use of statistical analysis in security.

		suggests the need to revise a long-standing safety paradigm that appears to have ceased to be effective, and (3) discusses the basic premises upon which a revised safety paradigm should build.		
3.	Experiences in Mining Aviation Safety Data Nazeri et al., (2001) https://doi.org/10.1145/375663.375743	*The goal of data analysis in aviation safety is simple: improve safety. However, the path to this goal is hard to identify. What data mining methods are most applicable to this task? What data are available and how should they be analyzed? How do we focus on the most interesting results? Our answers to these questions are based on a recent research project we completed. The encouraging news is that we found a number of aviation safety offices doing commendable work to collect and analyze safety-related data. But we also found a number of areas where data mining techniques could provide new tools that either perform analyses that were not considered before, or that can now be done more easily.* *Currently, Aviation Safety offices collect and analyze the incident reports by a combination of manual and automated methods. Data analysis is done by safety officers who are well familiar with the domain, but not with data mining methods. Some Aviation Safety officers have tools to automate the database query and report generation process. However, the actual analysis is done by the officer with only fairly rudimentary tools to help extract the useful information from the data.* *Our research project looked at the application of data mining techniques to aviation safety data to help Aviation Safety officers with their analysis task. This effort led to the creation of a tool called the "Aviation Safety Data Mining Workbench". This paper describes the research effort, the workbench, the experience with data mining of Aviation Safety data, and lessons learned.*	Data mining techniques Aviation Safety Data Mining Workbench	Using data mining tools to perform novel analyses and/or to make analysis more efficient. This could have application to security data.
4.	Application of Aviation Safety Data Mining Workbench at American Airlines Nazeri (2003)	*This paper describes the application of the MITRE Corporation's Aviation Safety Data Mining Workbench to AA's Aviation Safety Action Plan data, to demonstrate the usefulness of data and text mining tools in the analysis of aviation safety data and assesses the ability of these tools to enhance internal airline safety analysis.*	As above – case study at American Airlines.	Specific applications of the tool may be useful in security.

	Application of Aviation Safety Data Mining Workbench at American Airlines (flightsafety.org)			
5.	A Cross-Model Comparison of Human Performance Modelling Tools Applied to Aviation Safety NASA (2005)	*The NASA Aviation Safety Program (AvSP) was created to perform research and develop technology to reduce the rate of fatal aircraft accidents in the USA. Under AvSP, the System Wide Accident Prevention project uses current knowledge about human cognition to develop mitigation strategies to address current trends in aviation accident and incident profiles. System Wide Accident Prevention is comprised of four elements, one being Human Performance Modelling. The objective of the Human Performance Modelling Element is to develop predictive capabilities to identify likely performance improvements or error vulnerabilities during system operations. During the time period of interest (FY01-FY04), this element investigated the application of human performance modelling (HPM) to predict the performance of flight crews of commercial air transport carriers in two different modelling efforts. The first effort modelled flight crew taxiway operations at Chicago O'Hare airport with an emphasis on predicting taxiway errors (e.g., wrong turns or missed turns). The second effort modelled the use of NASA's synthetic vision system (SVS), which depicts a clear, 3-dimenisional view of terrain and obstacles regardless of the actual visibility or weather conditions. In this effort, the simulated flight crew performed instrument approaches into Santa Barbara airport under instrument meteorological conditions (IMC) under baseline and SVS configurations. In both efforts, HPM proved to be a valuable research tool for understanding these new systems and their impact on human performance.* 1. Adaptive Control of Thought-Rational (ACT-R) A theory and a cognitive modelling tool. The theory describes how humans organize knowledge and produce intelligent behaviour. The cognitive modelling tool simulates the application of this theory to the extent that is practically possible. 2. Air Man-machine Integration Design and Analysis System (Air MIDAS)	Human Performance Modelling (HPM) Tools Computer modelling	Computer modelling to aid in safety mitigations and system design – could be applied to the security environment. Limited in that these are complex computational model that are not widely accessible tools for security managers.

		Explore the computational representations of human-machine performance to aid crew system designers 3. Distributed Operator Model Architecture (D-OMAR) Event-based architecture for developing human performance models or agents for agent-based systems 4. Attention-Situation Awareness (A-SA) Model predicts pilot situation awareness		
6.	Increasing Aviation Safety Using Human Performance Modeling Tools: An Air Man-machine Integration Design and Analysis System Application Gore and Corker (2002)	*Human Performance Modelling (HPM) tools are computational, human-out-of-the-loop (HOOTL) representations of several micro models of operatorenvironment performance used to predict complex humansystem interactions. HOOTL processes provide economical (in terms of time and money) means of studying complex human-system performance. As technologies and automation increase to assist the human operator in the increasingly cognitively demanding world, human-related vulnerabilities may arise that may impact the system safety by increasing procedural error rates. Hollnagel's conceptualization of human error will be used as the theory behind a HOOTL simulation currently underway at NASA Ames Research Center to predict human error in the aviation environment in surface operations. One of the HOOTL simulation tools being used to generate human-system performance predictions is the emergent HOOTL tool termed Air Man-machine Integration Design and Analysis System (MIDAS). This paper will outline the current understanding of factors underlying human error and the considerations that need to be heeded in developing HOOTL simulations for human-automation predictions. These HOOTL simulations will be shown to be effective means of predicting system vulnerabilities and will allude to possible intervention strategies.*		Same research as above by NASA.
7.	A Framework for Assessing the Quality of Aviation Safety Databases Wilke et al., (2014) https://doi.org/10.1016/j.ssci.2013.11.005	*The quality of data analysis and modelling is dependent on its inputs and statistical analysis is of limited value with inappropriate data. This paper proposes a framework for assessing data quality using the example of airport surface safety, i.e. runway/taxiway safety. The nature of airport surface safety is such that there is a need to account for data from a number of stakeholders, who may possess databases differing in quality, and aggregate this data for subsequent analysis to provide robust safety assessment and mitigation. To address these issues, this paper*	Multi-Criteria Decision Analysis (MCDA) Linear model Data quality assessments.	Modelling the quality of safety databases by modelling the error sources. This could be applied to security databases, however,

		proposes a framework for the validation of external data quality based on the underlying data collection and investigation processes. Multi-Criteria Decision Analysis (MCDA) using a linear model is applied to derive quantitative weights for twelve safety databases based on the quality of the underlying organizational data collection and investigation processes. The model takes eleven criteria in relation to possible error sources during data gathering and pre-processing, organizational safety culture, data accessibility, and the consistency of the reporting system over time into account. These weights combined with an internal data quality validation and an indication of the reporting level of an organization can give a robust indication of the quality of a database. This method is recommended for use for data quality assessments in aviation safety.		may be limited by the opacity of security data. The paper focusses on airport surface safety.
8.	The Role of Safety Architectures in Aviation Safety Cases Denney et al., (2019) https://doi.org/10.1016/j.ress.2019.106502	*We develop a notion of safety architecture (SA), based on an extension to Bow Tie Diagrams (BTDs), to characterize the overall scope of the mitigation measures undertaken to provide safety assurance at both design time and during operations. We motivate the need for SAs, whilst also illustrating their application and utility in the context of aviation systems, through an example based upon a safety case for an unmanned aircraft system mission that successfully underwent regulatory scrutiny. We elaborate how SAs fit into our overall safety assurance methodology, also discussing the key role they play in conjunction with structured assurance arguments to provide a more comprehensive basis for the associated safety case. We give a formal semantics as a basis for implementing both BTDs and SAs in our assurance case tool, AdvoCATE, describing the functionality afforded to support both the related safety analysis and subsequent development activities, e.g., enforcement of well-formedness properties, computation of residual risk, and model-based views and transformations.* SAs represent a barrier model of safety giving a rigorous basis for risk analysis. SAs should be a core component of aviation safety cases.	**Safety architectures** (SAs) (formalised to extend **Bow Tie Diagrams** (BTDs)) The **AdvoCATE toolset** (provides support for SAs and other aspects of safety cases.	The notion of safety architecture (i.e. a characterisation of scope of mitigation measures to provide safety assurance during design and operation) could be extended to "security architecture". Uses extended bow-tie diagrams (already a security tool).
9.	Systems Theoretic Process Analysis (STPA) MIT OpenCourseWare	*Identify accidents and hazards > Draw the control structure > Step 1: Identify unsafe control actions > Step 2: Identify causal factors and create scenarios.*	Hazard analysis tool	A modelling tool used in safety (as per CAA Lunch and

	STPA Handbook (MIT-STAMP-001)	*STPA (System-Theoretic Process Analysis) is a relatively new hazard analysis technique based on an extended model of accident causation. In addition to component failures, STPA assumes that accidents can also be caused by unsafe interactions of system components, none of which may have failed. Some of the advantages of STPA over traditional hazard/risk analysis techniques are that:* *• Very complex systems can be analysed. "Unknown unknowns" that were previously only found in operations can be identified early in the development process and either eliminated or mitigated. Both intended and unintended functionality are handled.* *• Unlike the traditional hazard analysis methods, STPA can be started in early concept analysis to assist in identifying safety requirements and constraints. These can then be used to design safety (and security) into the system architecture and design, eliminating the costly rework involved when design flaws are identified late in development or during operations. As the design is refined and more detailed design decisions are made, the STPA analysis is also refined to help make more and more detailed design decisions. Complete traceability from requirements to all system artifacts can be easily maintained, enhancing system maintainability and evolution.* *• STPA includes software and human operators in the analysis, ensuring that the hazard analysis includes all potential causal factors in losses.* *• STPA provides documentation of system functionality that is often missing or difficult to find in large, complex systems.* *• STPA can be easily integrated into your system engineering process and into model-based system engineering.*		Learn) which seems HIGHLY applicable to the security environment.
10	Assessing and Advancing Safety Management in Aviation Stroeve et al., (2022) https://doi.org/10.3390/safety8020020	*A safety management system (SMS) is the overall set of procedures, documentation, and knowledge systems as well as the processes using them, which are employed within an organisation to control and improve its safety performance. Safety management systems are often observed as being bureaucratic, distinct from actual operations, and being too much focused on the prevention of deviations from procedures rather than on the effective support of safety in the real operational context. The soft parts of advancing safety in organisations, such as the multitude of interrelations and the informal aspects in an organisation that influence*	SMS Maturity and Refinement Tool (SMART)	A tool to support continuous improvement in SMS and safety in organisations. The basis of the tool use is the multi-level perspective on SMS

		safety, are often only considered to a limited extent. As a way forward, this paper presents two coupled approaches. Firstly, a generic tool for assessing the maturity of safety management of aviation organisations is presented, which accounts for recent insights in effectively incorporating human factors. This assessment tool provides insight into the strong and weak topics of an organisation's SMS. Secondly, an overview is given of a range of approaches that aim to improve the safety of aviation organisations by strengthening relevant organisational processes and structures, with a focus on human factors. The relations of these approaches with SMS are discussed, and the links with topics of the SMS maturity assessment tool are highlighted. *These methods for SMS maturity assessment are focused on particular air transport organisations, namely air navigation service providers (EASA questionnaire, CANSO maturity scheme) or aircraft operators (Shell SMS assessment). All approaches for SMS maturity assessment are mostly based on traditional perspectives on safety and safety management, and they lack insights from recent research in advancing safety management. To overcome these limitations, a generic air transport SMS Maturity Assessment and Refinement Tool (SMART) was developed. For this development, the EASA questionnaire and the CANSO SMS maturity scheme were used as a basis. Their topics were generalized, reformulated, and combined where appropriate. For instance, specific Air Traffic Management (ATM) systems, procedures, or relationships were removed to allow more general use of the questions. Next, we analysed what questions from the Shell questionnaire could add new aspects, leading to addition of some questions. Furthermore, insights from developments in research in human factors, Safety-II, and resilience engineering were used as a basis for some topics. Finally, the topics in SMART were structured following the SMS components of ICAO Annex 19.* EASA Questionnaire As part of the acceptable means of compliance and guidance material for the implementation and measurement of safety key performance indicators, EASA has published a questionnaire for measurement of the effectiveness of safety management. The questionnaire is based on a		topics in a questionnaire. Allows single user-single org and multi-user multi-org contexts. This could be created for SeMS.

		maturity survey in the ATM Safety Framework, which was developed by EUROCONTROL to support ANSPs in assessing the maturity of their SMS. This maturity survey comprises eleven study areas. The study areas are specified in more detail by one to four topics per study area and 26 topics in total. For each of these topics maturity levels are defined on a five-point scale CANSO Maturity Scheme The Civil Air Navigation Services Organisation (CANSO) has published a Standard of Excellence in SMS. It includes a definition of SMS maturity along five levels for its thirty-six SMS objectives. The development of the CANSO scheme used the above-mentioned publications of EASA [12] and EUROCONTROL [13], but it has also added some items, and it provides some useful formulations. Shell SMS assessment The SMS HSE MS self-assessment questionnaire of Shell lists safety management topics and related current aviation practices, typical supporting evidence, and interpretation/guidance for aircraft operators. It consists of thirty-two topics distributed over eight groups, which are scored on a four-point scale.		
11	ASC-IT Aviation Safety Culture Inquiry Tool: Development from theory to practical tool Montjin and Balk (2010)	*This tool has been developed to assist organisations in aviation with the assessment and management of their safety culture and is applicable to the entire civil aviation sector for both operational (like airlines, airports, ground handling providers, maintenance repair organisations, air navigation service providers) as well as non-operational bodies (like policy making agencies, regulators and inspecting agencies). The tool can be applied to all categories of organisations in aviation and to different levels within such organisations and provides a capability for benchmarking against similar organisations or other sectors within the aviation industry.*	Aviation Safety Culture Inquiry Tool (ASC-IT)	Similar to extant security culture questionnaire. Expressing high level safety culture characteristics in more detailed indicators.
12	The challenges in defining aviation safety performance indicators Roelen and Klompstra (2012)	*The introduction of safety management systems in aviation has apparently triggered the European Commission to require ANSPs to measure safety performance by the following three indicators (European Commission, 2010):*	Risk analysis tool Just Culture Questionnaire	Limited novel tools however important statements on the limitations of them

	Roelen and Klompstra - Aviation Safety Performance Indicators - PSAM 2012 - Preprint (researchgate.net)	*• The effectiveness of safety management as measured by a methodology based on the ATM safety maturity survey framework. • Application of the Risk Analysis Tool on the reporting of three categories of occurrences: separation minima infringements, runway incursions and ATM-specific occurrences. • The level of presence or absence of just culture as measured through a questionnaire.* *The performance of safety management systems are monitored by means of safety performance indicators. Aviation safety performance indicators should provide an indication of the probability of an accident, the development and measurement of proper safety performance indicators however is not straightforward. Event sequence models like IRP and CATS are based on phenomenological knowledge and operational experience and are quantified with operational performance data and expert judgement, so they could be used for the development of lagging indicators. Leading indicators are associated with organisational and managerial issues, though are difficult to quantify and their relation with accident risk is less obvious. Though, it should be noted that the distinction between leading and lagging indicators however is still subject to confusion. The Performance Scheme Regulation includes requirements for safety performance indicators, though there are several potential problems with these indicators. They are composite indicators, but its weighting process is value-laden and therefore not necessarily neutral. It is unclear how they link to the risk control process. Reporting on separation minima infringements, runway incursions and ATM-specific occurrences is based on information gathered by manual reporting systems which have a weakness in the possibility of (invisible) underreporting. Another difficulty may arise if a safety performance score is used to compare between different stakeholders. Unless the safety performance can be measured really objectively, it is necessary that differences in safety performance will first have to be thoroughly investigated and understood before any conclusion on relative safety performance is drawn.*		as applied to safety; this will have implications for security.

13	Safety Intelligence: Incremental Proactive Risk Management for Holistic Aviation Safety Performance Patriarca et al., (2019) https://doi.org/10.1016/j.ssci.2019.05.040	*Aviation safety is traditionally managed based on the analysis of accidents and incidents. Such strategies allowed aviation safety to evolve greatly, but have the major drawback of being reactive, i.e. mostly based on hindsight. Acknowledging the need to avoid restricting safety analysis only to negative aspects, such as errors and failures, regulations progressively aimed to delve into the complexity of the work domain. In this context, EUROCONTROL developed a reporting framework harmonized with EU and ICAO regulations, the Toolkit for ATM Occurrence Investigation (TOKAI), which allows a structured and unified reporting for Air Navigation Service Providers (ANSPs). This paper, starting from the theoretical benefits of a structured strategy for learning from events, and the operational application of TOKAI in line with EU and ICAO regulations, provides examples on how an incremental proactive risk assessment strategy can be structured, starting from reporting of adverse events. The paper includes examples of data-driven analyses and holistic safety dashboard that can be developed using TOKAI data to empower the decision-makers' Safety Intelligence. All this is possible by the adoption of a neutralised language/taxonomy that facilitates a similar conversation for both occurrences but also day to day operations.* The concept of Safety Intelligence is explored in the ATM domain. Learning from accidents is explored for incremental proactive risk assessment. The TOKAI reporting framework is presented. Factor analysis and multi-dimensional scaling are used for analysing TOKAI data. An illustrative case study is presented for a European ANSP in a de-identified way	Toolkit for ATM Occurrence Investigation - TOKAI	This paper is specifically related to air traffic management, but there could be an exploration of how TOKAI could be applied to the security system. E.g. using data driven analysis and holistic security dashboard developed using data to empower decision makers security intelligence.
14	How does aviation industry measure safety performance? Current practice and limitations Kaspers et al., 2019 How does aviation industry measure safety performance? Current practice and limitations	*In the safety performance assessment tool created by the Safety Management International Collaboration Group (SMICG, 2013), metrics are divided into three tiers, where tier 1 metrics measure the outcomes of the whole civil aviation domain, tier 2 indicators depict safety management performance of operators and tier 3 metrics address the activities of the regulator (SMICG, 2014). SPI should have an alert level (i.e., limit of what is acceptable) and safety indicators support the*	Performance assessment tool with tiered metrics.	Limited novelty in this tool, however the paper raises an interesting limitation in that companies use tools that do not

	| International Journal of Aviation Management (inderscienceonline.com)	*monitoring of existing risks, developing risks and implementation of mitigation measures (ICAO, 2013b). If implemented in this way, safety management allows a performance-based approach, which is expected to create more flexibility for the users to achieve safety goals in addition to compliance. SPI might have up to three functions within safety management: monitoring the state of a system, deciding when and where to take actions and motivating people to do so (EUROCONTROL, 2009; Hale, 2009); their establishment may also foster motivation towards safety (Hale et al., 2010).* *The results of this paper are limited by the aviation specific topic and guidance. Furthermore, when discussing metrics, companies often use tools that not always show up directly when searching on the topic of measuring safety, whilst those tools may actually give an indication of the level of safety. The companies themselves are able to point the tools they use themselves, this does not mean that these show up in the academic literature or the guidance given in the aviation industry.*		show up in the academic literature!
15	Natural Language Processing for Aviation Safety Reports: From Classification to Interactive Analysis Tanguy el al., (2016) https://doi.org/10.1016/j.compind.2015.09.005	*In this paper we describe the different NLP techniques designed and used in collaboration between the CLLE-ERSS research laboratory and the CFH/Safety Data company to manage and analyse aviation incident reports. These reports are written every time anything abnormal occurs during a civil air flight. Although most of them relate routine problems, they are a valuable source of information about possible sources of greater danger. These texts are written in plain language, show a wide range of linguistic variation (telegraphic style overcrowded by acronyms or standard prose) and exist in different languages, even for a single company/country (although our main focus is on English and French). In addition to their variety, their sheer quantity (e.g. 600/month for a large airline company) clearly requires the use of advanced NLP and text mining techniques in order to extract useful information from them. Although this context and objectives seem to indicate that standard NLP techniques can be applied in a straightforward manner, innovative techniques are required to handle the specifics of aviation report text and the complex classification systems. We present several tools that aim at a better access*	Natural Language Processing as a tool:- -Automatic document classification -Interactive search tool -Interactive identification tool	Report data is valuable and there is a vast amount of it – manual analysis is complex and requires considerable resources. These NLP tools could be used in security to categorise, analysis, and understand security incident reports (for example).

		to this data (classification and information retrieval), and help aviation safety experts in their analyses (data/text mining and interactive analysis). *Some of these tools are currently in test or in use both at the national and international levels, by airline companies as well as by regulation authorities (DGAC, EASA, ICAO).*		
16	A Review of Selected Aviation Human Factors Taxonomies, Accident/Incident Reporting Systems, and Data Collection Tools Beaubien (2002) A REVIEW OF SELECTED AVIATION HUMAN FACTORS TAXONOMIES, ACCIDENT/INCIDENT REPORTING SYSTEMS, AND DATA REPORTING TOOLS (air.org)	*We believe most ASAPs collect Human Factors data using text narratives that require costly and time-consuming content analysis. To address this problem, we are developing a generalized Human Factors taxonomy and electronic data reporting/analysis tool that will be provided at no cost to industry.* *1.Be comprehensive in its treatment of Human Factors issues;* *2. Be user-friendly, even for those with minimal formal training in Human Factors;* *3. Reliably classify similar events despite differences in the reporter's verbal skills;* *4. Apply equally well to describing the problems faced by pilots at regional and major air carriers;* *5. Allow carriers to identify specific causes of incidents and provide specific guidance for resolving them;* *6. Facilitate communication among pilots, management, researchers, and regulators;* *7. Not place excessive demands on the user;* *8. Be generic enough to be adapted for use with other forms of safety-related data.*	Human factors taxonomy and electronic data reporting tool	This paper examines extant reporting functionality and suggests a list of factors that must apply to an ideal system (tool). There is a very useful list comparing data collection tools on p.39.
17	The Aviation Safety Reporting System NASA ASRS - Aviation Safety Reporting System (nasa.gov)	*The Aviation Safety Reporting System (ASRS) is a voluntary, confidential, and non-punitive incident reporting system that was designed to promote aviation safety by encouraging pilots to report unsafe occurrences and hazardous situations (http://asrs.arc.nasa.gov). Although funded by the FAA, the program is maintained by NASA, Taxonomies, Reporting Systems, and Data Collection Tools 9 which collects, de-identifies, catalogs, and analyzes the incident reports. NASA's participation has helped to create a safety culture that encourages pilots to openly discuss and learn from*	The Aviation Safety Reporting System (ASRS) – online reporting tool	Such tools exist in security but are less "open".

		their errors (National Aeronautics and Space Administration, 1999). The goals of ASRS are to improve the current national aviation system and to provide data for future system planning (Federal Aviation Administration, 1987). ASRS reports may be submitted by pilots, air traffic controllers, cabin crews, and mechanics. Feedback – in the form of periodic bulletins and newsletters, database search requests, quick-turnaround data analyses, and other products – is provided to air carriers, researchers, and government agencies so that they can investigate allegations of unsafe practices and take corrective action (National Aeronautics and Space Administration, 1999).		
18	Confidential Human Factors Incident Reporting Programme CHIRP is maintained by the CHIRP Charitable Trust, an independent organisation that is funded by the UK Civil Aviation Authority (CAA) CHIRP - CHIRP	*CHIRP is an independent and impartial charity dedicated to improving safety in the air and at sea. Our confidential human factors incident reporting system empowers people working in the maritime and aviation sectors to share their safety concerns without the fear of being identified. Once agreed by those who have reported, we follow up with the relevant organisations so that the necessary action can be taken.*	Online reporting tool.	How well is this utilised for security?
19	Major Air Disasters: Accident Investigation as a Tool for Defining Eras in Commercial Aviation Safety Culture Barroso and Munoz-Marron (2023) View of Major air disasters: accident investigation as a tool for defining eras in commercial aviation safety culture (vilniustech.lt)	*The air transport evolution has been littered with major air disasters, the occurrence of which has not only had the negative effects inherent to any disaster. Air accident investigation has provided a wealth of knowledge that has advanced the aviation industry and its safety. International Civil Aviation Organisation has exercised international regulatory leadership since 1947, developing tools with international cooperation, such as the air accident investigation methodology. ICAO has forged a change in perspective on safety attributions or factors in different historical eras, using this methodology to deepen the understanding of the causes and thereby achieve aviation safety improvement. Authors aimed to analyse, through a detailed study of the world's worst aviation accidents, their contribution to understanding the details of aviation safety culture. Beyond the technical issues and fatality rates, the necessary analysis is what knowledge researchers have gained from the beginning, exploring the attributions of reports and knowing what diverse factors have predominated in different eras. Descriptive analyses of air disaster*	Descriptive analysis as a tool (for air disaster investigation)	As applied to security: 1) identify beginning of a global security culture era resulting from evolution in operational security, 2) relate the different eras to the attributions of security incident investigation (root cause analysis)

		investigation have two objectives: to identify the beginnings of a global safety culture resulting from evolution in operational safety and to relate the different eras to the attributions of air accident investigations.		
20	AVSEC Insight IATA (2023) PowerPoint Presentation (iata.org)	*Harnessing the power of real-time, open-source intelligence (OSINT) for enhanced business resilience.* *Evolving threats require predictive and intelligence-led security strategies. Security teams must gather intelligence from every corner that they can.* *The algorithm crawls though 7000+ sources and generates reports by risk category (terrorism, civil unrest, geopolitical risks)*	Information tool	Already in the realm of security but based on open-source material and similar to more widely known safety databases when it comes to information sharing.
21	ICAO Annex 13 Manual of Aircraft Accident and Incident Investigation (Doc 9756)	*International Standards and Recommended Practices for aircraft accident and investigation.* ***Part I — Organization and Planning**, 1st Edition – 2000, includes considerations for the establishment of an aircraft accident investigation authority in terms of its structure, staffing and legislation. The planning of an investigation and the notification process for accidents and incidents are also addressed, as are the initial actions to be taken at an accident site, with particular emphasis on the safety of personnel. A directory of the accident investigation authorities in all States and their contact details is included.* ***Part II — Procedures and Checklists**, 2nd Edition – 2012, provides information on the common techniques and procedures, as well as checklists to assist States in aircraft accident and incident investigations. The manual also provides guidelines on major investigations that can be used, particularly, in the conduct of larger accident investigations.* ***Part III — Investigation**, 1st Edition – 2012, provides guidance for the investigation of all technical areas that may have been involved in an aircraft accident or incident. Likewise, guidance is provided for the several phases of an investigation. Contents addressed include, among others,*	ICAO's Air Accident Investigation Methodology Checklists	Which principles (tools) can be applied to incident analysis in security?

		wreckage investigation, structures and systems investigation, flight recorders, aircraft performance, etc. ***Part IV — Reporting****, 2nd Edition – 2013, provides guidance in developing the final reports as a result of the investigation of aircraft accidents and incidents, including comprehensive guidelines on drafting and processing of safety recommendations. It outlines the format and content and the procedures for consultation, release, distribution, and dissemination of the final report.*		
22	Enhancing aviation safety and mitigating accidents: A study on aviation safety hazard identification Xiong et al., 2024 Enhancing aviation safety and mitigating accidents: A study on aviation safety hazard identification - ScienceDirect	*Identifying promptly potential safety risks and threats in the aviation system reduces the occurrence of aviation incidents (especially accidents), protects passengers' lives and property, and improves aviation emergency management capabilities. Such a strategy has significant implications on mitigating incidents in the aviation system and formulating efficient and orderly safety measures. To this end, this study proposes an Intelligent Aviation Safety Hazard Identification Method that combines Text Mining and Deep Learning (DL) technologies as applied on the incident data and hazard knowledge. Specifically, the Method entails Named Entity Recognition (NER) and knowledge graph visualization. Firstly, the model of Bidirectional Encoder Representations from Transformers (BERT) is employed to process aviation safety incident texts and generate word vectors based on contextual information. The trained word vectors are then input into the model of Bi-directional Long-Short Term Memory and Conditional Random Field (Bi-LSTM-CRF) to extract deep-level safety hazard entities. Next, the extracted safety hazard entities are stored and visualized using the Neo4j database to construct a knowledge graph from which the analyst can directly assess the situation. The effectiveness of this method is validated using incident records of an aviation maintenance company. The proposed method can effectively identify civil aviation safety hazard entities and uncover the intrinsic connection between incidents and safety hazards, which allows relevant personnel to quickly understand the nature and mechanism of an incident and proactively apply preventive measures, thereby providing dynamic support for strengthening aviation safety hazard management.*	Deep learning (subset of machine learning) Text mining	The paper shows that the proposed method can effectively identify civil aviation safety hazard entities and uncover the intrinsic connection between incidents and hazards. This allows relevant personnel to understand the nature and mechanism of an incident and proactively apply preventative measures. For security this could include the connection between threats/risks and incidents.

23	Performance evaluation of airport safety management systems in Taiwan Chang et al., (2015)	*Highlighted the importance of between-entity information sharing on performance data and incidents to the performance of the SMS at various airports.*	Safety conferences	Similar tool could be used in security – e.g. security conferences. This already is deployed in the form of the SEG at airports.

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