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The Thesis

An Aviation Safety Risk Model to Close the Gap between Management and Operational Safety Staff

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ABSTRACT

The thesis probes the safety risk-management component of the complex Commercial Air Transport (CAT) industry. It argues that adoption of the ICAO (2018b) framework failed to address the challenges the industry faces, and suggests that the continuous reduction of risk exposure observed in the last couple of decades has been negatively impacted as a result.

The document begins by outlining a conceptual framework based on a continuous cycle – safety boundaries, risk tools, safety protection, safety benchmarking, and safety culture – that represents a theoretical safety model as an alternative to the current risk-management vision. The research into these topics is based on an interpretivist stance, whereby 26 semi-structured interviews were performed across different segments within the CAT industry. The healthcare sector was also included in the research to enable benchmarking analysis.

Opposed to the commonly established knowledge, the thesis argues that the industry defines and measures the acceptable risk exposure of each organization in a degraded fashion and, in doing this, restricts individual airlines' contributions to industry safety figures. The literature around the subject restricts its research scope to specific topics and fails to address risk management holistically. Compounding the narrowness of the scope, safety-related linear risk models have failed to integrate concurrent events with undesirable states. In contrast, the models based on complexity and systems thinking theory develop a higher conceptual abstraction, but present challenges when airlines try to implement them. It is suggested that in failing to harness the explanatory power provided by clues concerning safety, an exposure uncertainty is developed, which, as this has the potential to produce a gap between management and operational staff, creates a barrier to investments in safety. Moreover, while the extant research and literature identifies safety culture as an important factor in the robustness of commercial aviation risk management, its explanatory power is weak – models fail to explain their impact on safety performance – that is, they fail in terms of operationalizing the concept.

As a significant innovative approach to practice and consequently to the theory that supports it, the current research suggests a new risk model that transforms statistical data into meaningful and easily understandable safety figures. In contrast, the risk model put forward here conveys a proactive perspective when dealing with risk exposure and the drifting of safety systems.

Acknowledgements

Professor Alistair Mutch and Doctor Roy Stratton guided me throughout the academic “journey” for over five years. I wish to express my sincere appreciation for their support, guidance and professionalism and the high standards they always demanded. I will be grateful for the rest of my life. Thanks very much.

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For ethical reasons, it is not possible to thank each of the 24 interviewees who took part in this research individually by name. Nevertheless, their willingness to make themselves available to participate in this research project and the candour they all showed in discussing elements of the challenges they face with someone from a competitor airline, is recognized with deep gratitude. Without their support and participation, academic research would not have been possible.

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I have not forgotten my Mother, whom I cannot possibly thank enough for her support over the course of the whole DBA project. Although not physically present, a dedicated thought goes to my Father, Joaquim, who certainly would have been proud of his son’s efforts to produce this thesis once he had embarked on the doctoral journey.

Finally, to my family: my wife Helena, my daughter Inês and son Diogo, who never complained about my absences and collectively provided reliable support. Now that the writing of the thesis is complete, I am quite sure they will be hoping that the dinner table will be free from my stack of books and manuscripts.

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Abbreviations

3LoD	“Three Lines of Defence” model
AA	Airline Safety Analyst
AB	Airline Executive Board Member
ACMI	A leasing contract that includes Aircraft, Crew, Maintenance, and Insurance
AEB	Accident Evolution and Barrier
AFM	Aircraft Flight Manual
AL	Airline Lecturer
ALARP	As low as reasonably practicable
ARMS	Aviation Risk Management Solutions
AS	Airline Safety Manager
ATM	Air Traffic Management
BSI	British Standards Institution
CAB	Cabin Operations
CAIB	Columbia Accident Investigation Board
CAM	Commercial Aviation Management
CAMO	Continuing Airworthiness Management Organization
CAS	Complex Adaptive Systems
CAT	Commercial Air Transport
CBA	Cost-based analysis
CEO	Chief Executive Officer
CFIT	Controlled Flight into Terrain
CGO	Cargo Operations
CLR	Critical Literature Review
CR	Critical Realism
COO	Chief Operations Officer

DG	Dangerous Goods
DSP	Operational Control and Flight Dispatch
EASA	European Aviation Safety Agency
EBA	European Banking Authority
EGPWS	Enhanced Ground Proximity Warning System
EOFDM	European Operators Flight Data Monitoring
EPAS	European Plan for Aviation Safety
ERC	Event Risk Classification (1st stage of ARMS)
ERCS	European Risk Classification Scheme
ERG	Event Review Group
ERM	Enterprise Risk Management
EU	European Union
EUAR	European Union Agency for Railway
FAA	Federal Agency Administration
FDM	Flight Data Monitoring
FLT	Flight Operations
FMEA	Failure Mode and Effect Analysis
FMECA	Failure Modes, Effects and Criticality Analysis
FOD	Foreign Object Damage
FRAM	Functional Resonance Analysis Method
FRC	Financial Reporting Council
FSF	Flight Safety Foundation
FTE	Full Time Equivalent
GPWS	Ground Proximity Warning System
GRH	Ground Handling Operations
GSE	Ground Support Equipment

HFMEA	Healthcare Failure Mode and Effects Analysis
HL	Health and Lecturer
HS	Healthcare Safety manager
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
INSAG	International Nuclear Safety Advisory Group
IoDSA	Institute of Directors Southern Africa
IORS	Internal Occurrence Reporting Scheme
IOSA	IATA Operational Safety Audit
IRM	Institute of Risk Management
ISHN	Industrial Safety & Hygiene News
ISO	International Organization for Standardization
KPI	Key Performance Indicator
LOC-I	Loss of control in-flight
LoD	Line of Defence
LOSA	Line Operations Safety Audit
MEL	Minimum Equipment List
MMO	Maximum Mach Operating Speed
MNT	Aircraft Engineering and Maintenance
NAT	Normal Accident Theory
NOTOC	Notice to Captain
ORG	Organization and Management System
OPS	Operational Staff
PLOC	Prolonged Loss of Communication
RA	Resolution Advisory

RAG	Resilience Assessment Grid
RCN	Royal College of Nursing
RESA	Runway End Safety Area
ROI	Return on Investment
ROP	Runway Overrun Prevention
ROW	Runway Overrun Warning
RPK	Revenue Passenger Kilometres
RQ	Research Question
RSSB	Rail Safety & Standards Board
SAA	Systemic Accident Analysis
SAG	Safety Action Group
SAQ	Safety Attitudes Questionnaire
SEC	Security Management
SERA	Single European Railway Area
SIRA	Safety Issue Risk Assessment (2nd stage of ARMS)
SMART	Specific, Measurable, Assignable, Realistic and Time-Related
SMICG	Safety Management International Collaboration Group
SMS	Safety Management System
SOP	Standard Operating Procedures
SPI	Safety Performance Indicator
SPT	Safety Performance Target
SQ	Strategic Question
SRA	Society of Risk Analysis
SRB	Safety Review Board
SRM	Safety Risk Management
STAMP	Systems-Theoretic Accident Model and Processes

TCAS	Traffic Collision Avoidance System
TPB	Theory of Planned Behaviour
TSB	Transport Safety Board
UERF	Uncontained Engine Rotor Failure
UK	United Kingdom
VREF	Reference Speed
WAD	Work-as-done
WAI	Work-as-imagined
WHO	World Health Organization

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1 Introduction

1.1 Setting the Context

Chapter 1 outlines the risk-management context within the commercial aviation sector. The aim of the present research is not to support the aeronautical safety investigation branch or to understand reactively what type of malfunction or misconduct resulted in incident, serious incident or even an accident. The emphasis in this research is to develop a risk model capable of continuously identifying the circumstances where there is an augmented risk exposure conducive to undesirable events. The research is aimed at organizations, so that they can proactively manage their risk exposure.

The current research addresses the safety-risk management component of the Commercial Air Transport, or CAT operation. The research takes the European air transport sector and specifically uses the complex CAT[1] as the main backdrop. Nevertheless, other categories of aviation regulated by the European Aviation Safety Agency (EASA), as well as other regional areas, might also take advantage of the research. However, since these regions' safety rules and planning are different, the research does not take them into account.

Safety, the highest priority of any airline, aviation regulator or legislator, requires continuous effort to address any weaknesses detected in the system. Maintaining the current trend in the reduction of the number of accidents will be one of the significant challenges commercial aviation faces in the future. The aviation industry must continue to work in a coordinated way to persistently, tirelessly and collectively improve safety figures. This thesis identifies four gaps[2] pertinent to the risk component of the Safety Management System (SMS), which have yet to be acknowledged in a structured and coordinated way by the aviation industry, and puts these forward as potential barriers to achieving continuous safety improvement.

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[1] "Size, nature and complexity of the activity (EASA 2015):

(a) An operator should be considered as complex when it has a workforce of more than 20 full time equivalents (FTEs) involved in the activity subject to Regulation (EC) No 216/2008 and its Implementing Rules.

(b) Operators with up to 20 FTEs involved in the activity subject to Regulation (EC) No 216/2008 and its Implementing Rules may also be considered complex based on an assessment of the following factors:

(1) in terms of complexity, […];
(2) in terms of risk criteria, […]."

[2] The four gaps are: safety boundaries, risk tools, safety protection and safety culture.

Based on the latest data published by ICAO (2018a), the world's commercial air transport fleet accounts for over 30,000 aircraft,[3] transporting annually more than 4.3 billion passengers and 58 million tons of freight, totalling over 37 million aircraft departures. Over the past two decades, the number of commercial aviation flights have shown a constant average increase of 5.66 and 3.85%, respectively. Europe has contributed over 1.1 billion passengers, representing approximately 26% of the world's total air traffic.

Commercial aviation has been shown consistently to be the safest means of moving people and goods internationally and nationally and this mode of transportation has been shown to be a critical enabler and catalyst for the world's economy (Oliver et al. 2019). Normalized by passenger fatalities per billion passengers-Km, commercial aviation presents the lower *ratio* within the four primary modes of transportation, as Figure 1.1, below, illustrates (EUAR 2016, 2017, 2018). Nevertheless, associated intrinsically with the nature of commercial aviation is its potential to develop scenarios whereby its reliability might be jeopardized, thereby affecting users' trust. The freedom of movement, speed of travel and dependability of the technology – generating tight couplings – have the potential to be affected by environmental hazards, system reliability, human factors and even by the inherent complexity of the commercial aviation system itself, as section 2.2 details.

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[3] Commercial transport fleet of the ICAO Member States at the end of 2018. The number given, accounts for active and parked turbojet and turboprop aircraft with a take-off mass higher than 9,000 Kg (20,000 lbs).

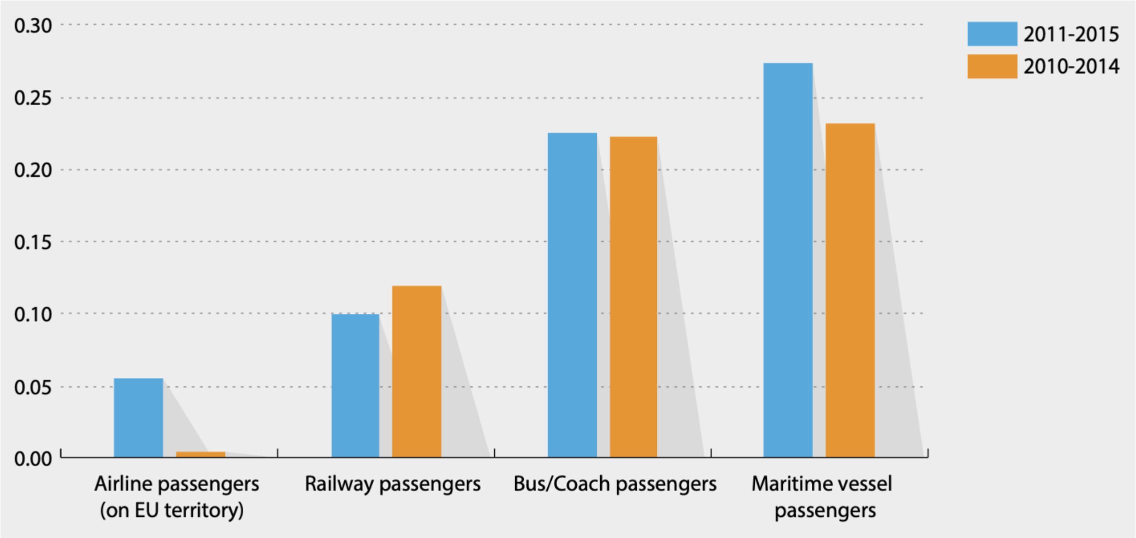

Figure 1.1 – Passenger fatality risk per billion passengers-Km for different modes of transport in the Single European Railway Area (SERA). Source: EUAR (2018)

The outcomes of undesirable events are reflected in the accident and fatality statistics. Regulators, agencies and manufacturers publish this data to understand the trends and to develop action plans and programmes to tackle the areas where it is envisaged further action needs to be taken. Figure 1.2, below, illustrates the commercial aviation context from a global and regional perspective, ultimately from the organizational standpoint.

Figure 1.2 shows the accident rate and on board fatalities of the worldwide commercial jet fleet over the period 1959–2017 (Boeing 2018).[4] The last decade has shown a fatality and hull-loss accident rate of less than one per million departures.[5] While these are impressively low numbers, relaxation of rules may create cracks in the existent safety defences and create opportunities for accidents. Moreover, while acknowledging some fluctuations, analysis of the period shows an almost stagnant rate of evolution, which represents a direct relationship between departures and the number of accidents. Namely, although the number of departures has risen by more than 50% in the last decade,[6] the rate remained unchanged, as Figures 1.3 and 1.4 illustrate, which means that risk exposure in commercial aviation has been halted in its pace of reduction throughout this period (Nisula 2018).

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[4] ICAO figures are slightly higher because they consider scheduled commercial flights, whereas Boeing figures are restricted to the commercial jet fleet. Turboprop commercial jets are not accounted for (Boeing 2018).

[5] A “hull loss accident” is an “aviation accident that damages the aircraft beyond economical repair, resulting in a total loss.” Source: https://en.wikipedia.org/wiki/Hull_loss, accessed 4 September 2020.

[6] According to Airbus (2020), the number of flight departures worldwide has doubled in the last two decades, rising from approximately 18 million to 36 million.

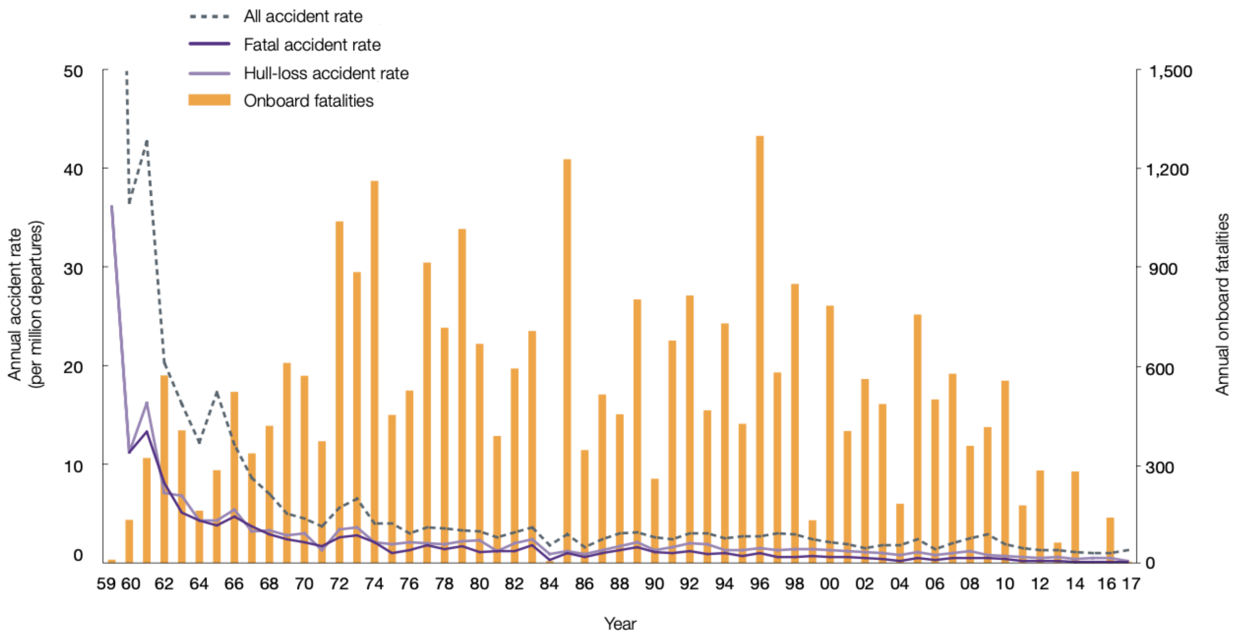

Figure 1.2 – Worldwide commercial jet fleet accident rates and on-board fatalities in the period 1959–2017. Source: Boeing (2018)

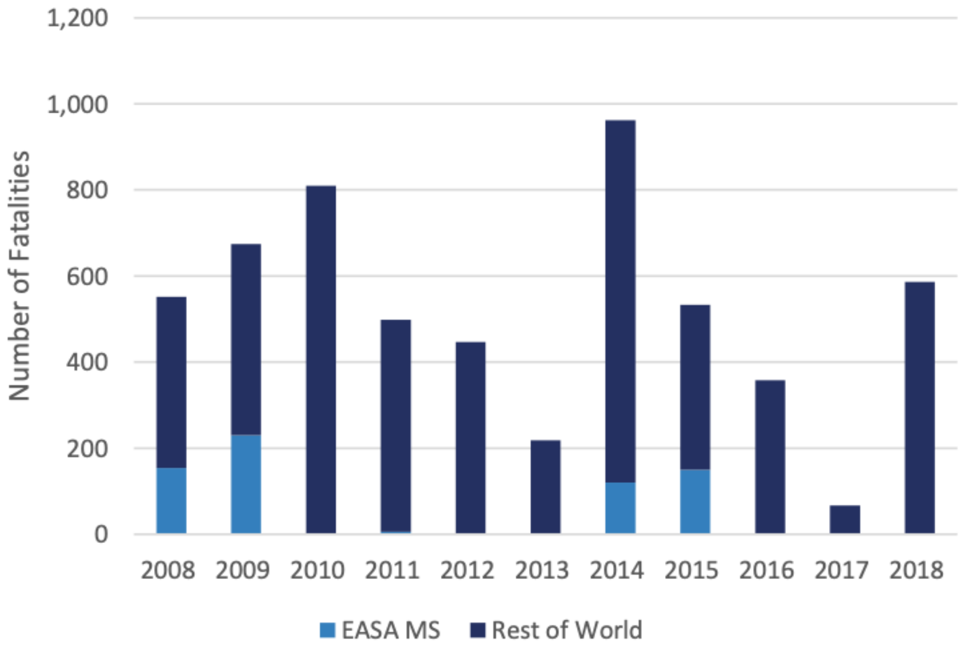

Figure 1.3 – Number of fatalities involving large passengers and cargo aircraft operations worldwide in the period 2008–2018. Source: EASA (2019b)

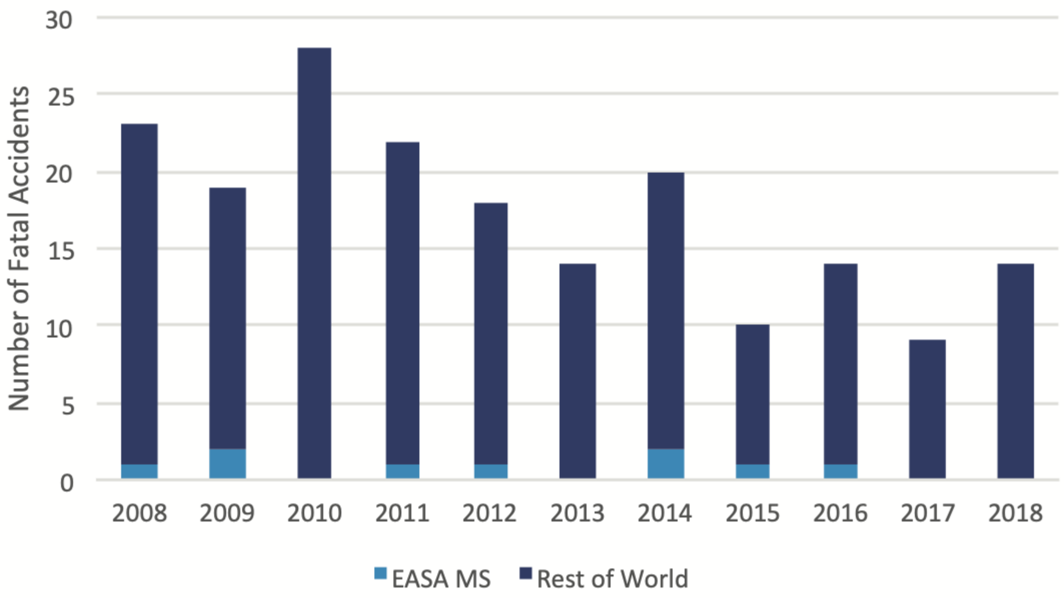

Figure 1.4 – Number of fatal accidents involving large passengers and cargo aircraft operations worldwide in the period 2008–2018. Source: EASA (2019b)

While it is indisputable that, fortunately, despite the steep rise in the number of flights, accidents remain a rarity, nevertheless, where accidents do occur, fatalities continue to be dramatically high.

At the regional level, using the European Risk Classification Scheme (ERCS), the EASA (2019a) identifies the risk areas where efforts should be directed, as Figure 1.5, below, highlights. Further details on the ERCS matrix and 2018 data on aggregated ERCS scores per safety issue are presented in Appendix A. Similar procedures are developed by other stakeholders to identify the main hazards affecting flight safety (Allianz 2019;[7] Airbus 2020).[8]

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[7] Allianz identifies 12 main causes for fatal accidents: loss of control in flight; controlled flight into or toward terrain; runway excursion (landing); unknown or undetermined; system component failure or malfunction (powerplant); fuel; runway excursion (take-off); ground handling; mid-air/near-mid-air collision; fire/smoke (non-impact); other; runway incursion (vehicle, aircraft or person).

[8] Airbus recognizes the existence of eight main contributory causes for fatal accidents: loss of control in-flight; control flight into terrain; runway excursion; undershoot/overshoot of runway; system/component failure or malfunction; fire; abnormal runway contact; unclassified.

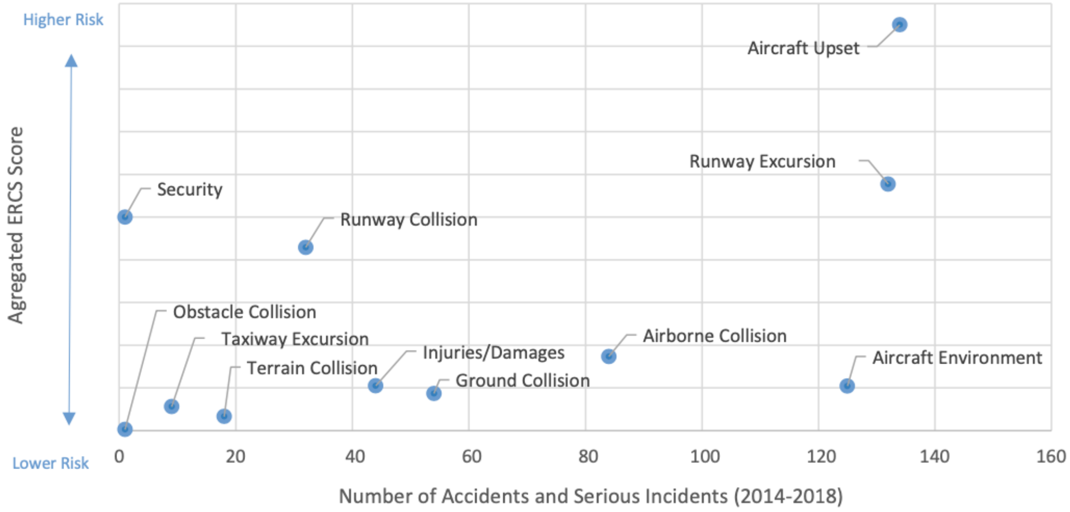

Figure 1.5 – Number of CAT airline and air taxi accidents and serious incidents by key risk area, compared to aggregated risk, in the period 2014–2018. Source: EASA (2019b)

The previous statistics demonstrate how safe commercial aviation is. However, they also show the degree of effort that must be expended continually to improve safety and reduce the number of fatalities. Another relevant subject raised by the data relating to safety is the absence of guidance about how to transform the data into manageable and workable indicators, in order that organizations can better protect themselves against the identified hazards. These are the challenges that, based on the four gaps identified in the critical literature review (CLR) and the research, the current thesis will tackle to ameliorate the present difficulties faced by organizations, which, as put forward by this thesis, has the potential to contribute to a reduction in the current accident statistics. The risk model proposed in Chapter 7 will allow organizations to define their safety boundaries in a more efficient form, identify their risk exposure continuously and manage their available resources judiciously, while also taking into consideration the organizational safety culture.

1.2 Organization of the Thesis

The thesis is presented in eight interrelated chapters as summarized below.

Chapter 1 contextualizes commercial air transport risk-management operations and identifies the purpose of the research: to develop a proactive risk model. In presenting an overview of the industry data, while the chapter acknowledges the impressive safety performance achieved in the industry, it argues that the monitoring of hazards by the regulators does not provide airlines sufficient guidance to enable them to protect themselves against risk entirely effectively. The chapter closes with an outline of the relevant concepts used throughout the thesis.

Chapter 2 surveys the current literature associated with risk management. It begins by claiming that the commercial air-transport sector operates within a complex system mediated by systems thinking and reasoning already embedded within the industry. The chapter then discusses the theoretical concepts that support accident theory, looking at two different types of risk models: the linear model and the model based on complexity and systems theory. Although providing relevant insights into the role of barriers, the drifting concept and the importance of constant monitoring, both models present significant drawbacks that make them inadequate to meet the current needs of the industry. While linear models do not integrate concurrent events with undesirable outcomes, the chapter argues, the latter type conceives risk management at a high level of conceptual abstraction, which is challenging to implement at the organizational level.

Section 2.5 of Chapter 2 provides a thorough review of the deficiencies of risk matrices, which is the primary tool used by the industry. A theoretical model, framed by a “risk-exposure” map, is proposed as a way to convey the level of risk more powerfully.

Chapter 2 concludes by discussing why safety culture is important, what its main characteristics are and how the industry measures it. The scarcity of research about safety culture’s impact on safety performance is highlighted.

Chapter 3 outlines the conceptual framework – the continuous safety-risk management cycle – that represents a theoretical safety model as an alternative to the current risk-management vision. The cycle is based on risk exposure defined upstream and on a continuous monitoring process, which allows proactive risk-based analysis to take place and leads to a more judicious resource allocation. The influence exerted by safety culture is also acknowledged. The second part of the chapter details the strategic questions and research questions that support the research.

Chapter 4 sets out the philosophical premise, research method and design strategy, and the ethical stance that orients the thesis. The chapter begins by discussing the nature of social science, continues by identifying what constitutes knowledge and reality, and then explains why critical realism is the most appropriate philosophical tradition to explore the characteristics of the complex environment faced by airlines. The current research, which takes an exploratory stance, arguably adopting an interpretivist approach, supported by semi-structured interviews, sets out to capture most pertinently the understandings and insights provided by interviewees to address the research gaps. A section is therefore included to explain the criteria by which interviewees were selected and to then explain how the discursive material was processed. The ethical principles are set out and the potential for researcher bias is acknowledged.

Chapter 5 is dedicated to the field research. It discusses the gaps contained in the conceptual framework and looks into each component that contributed to correcting it. A conclusion ends each section, and each chapter ends with a summary that aggregates all of that chapters findings. Three new subjects, identified with the aim of inspiring future research, are suggested: the potential for conflict of interest; safety training/competency of executive management; and the challenges facing commercial airlines in the near future.

Chapter 6 presents the two risk tools – the “risk-exposure” map and the “stack” map – which support the “Oyster Model”. This unique pairing of “risk tools” integrates the insights provided by the CLR and the findings obtained from the research. The innovative perspective brought by the model’s risk tool pairing includes the reasoning conveyed by complexity theory and systems thinking, incorporating the threats that concur with each hazard. The approach of the risk-tools pairing ensures that airlines are equipped with the capability to protect themselves from the hazards monitored by the regulators. Moreover, the “risk-exposure” map also incorporates the protection barriers currently implemented in the field and the influence exerted by the existing safety culture of organizations. In addition, the tool’s continuous data flow allows early detection of the potential drifting into risk exposure that is conducive to undesirable events. Finally, the means of evaluating threats suggests that an organization can rank them in order of priority, using the “stack” map.

Chapter 7 discusses implementation of the “Oyster Model”. It confirms that the model incorporates the stance conveyed by the conceptual framework, follows the risk-management guidelines established in the BSI (2018b) process, and provides reassurances that implementation of it will uphold previous standards. It then describes how the “Oyster Model’s” key strengths relate to philosophical and conceptual constructs, detailing the setup of each stage of the risk-management model: definition of risk level (safety boundaries), risk identification, risk analysis, risk evaluation, risk treatment, risk monitoring and resource allocation.

Chapter 8 summarizes the conclusions.

Section 1.3, below, now presents the concepts used throughout the thesis.

1.3 Relevant Key Concepts and Definitions

The presentation of the key concepts and definitions at the beginning of this section of the thesis is intended to acquaint readers with their meanings. The relevant concepts and definitions came about during the course of the CLR and were developed at the inception of the research in Document 2, where the gaps and the strategic questions (SQs) and research questions (RQs) were initially compiled (Encarnação 2015b). The concepts and definitions that were then used to support the conceptual framework are outlined below as follows: safety hazard, safety risk/safety-risk management, safety boundaries, risk tools, safety protection, and safety culture. To further understanding of the development of the main concepts, additional details are provided in Appendix B.

1.3.1 Safety Hazard

The thesis adopts the ICAO (2018b, p. vii) definition of a safety hazard – “a condition or an object with the potential to cause or contribute to an aircraft incident or accident”.

However, it is important to stress that hazards by themselves do not produce a loss or an undesirable outcome. For example, a blizzard, monsoon, or a dust storm are examples of hazards arising from the natural world. The hazardous conditions that create the perils and threats are precursors to what may lead to an undesirable outcome. The presence of hazardous natural phenomena may impair visibility or could develop icy conditions on a runway. However, the effect of the hazard on an airline operating aircraft capable of landing in conditions of poor visibility will not be the same as the effect on a similar organization flying aircraft not so equipped. Therefore, the potential context or scenario created by the hazard – where potential contributing factors or precursors and causal chains are developed and studied – is what a safety analyst will be assessing. This is why it is essential to appreciate: how and why a hazard or threat affects organizations differently; that the risk assessment does not apply to the threat or hazard per se; and that organizations should assess the scenario or the context created by the threat, instead.

Perils and threats are synonyms of the same reality used interchangeably. Further information on hazards can be found in the Safety Management International Collaboration Group document (SMICG 2018), which presents details of the hazards identified by representatives of the aviation sector.

1.3.2 Safety Risk

A safety risk will be seen as an unpredictable occurrence that is assessed through the interaction of (at least) two variables – the consequence of the outcome and the likelihood (or probability) of the occurrence – and which (following the ICAO definition) are considered to have only the potential to present an adverse outcome. For the current research, a risk will denote a "safety risk", and the contributing factors or precursors of these will be defined as "threats" and "perils", as stated above.

1.3.3 Safety Risk Management

Under the premise of the current research, the safety risk-management process should contain "a systematic set of coordinated activities undertaken within an organization with the aim of identification, analysis, evaluation, mitigation, and monitoring of safety risks to a level[9] defined by the organization or imposed by the stakeholders".

It is important to note that, according to the BSI definition of risk, the risk-assessment phase incorporates three activities: risk identification, analysis[10] and evaluation.[11]

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[9] A safety risk level is equivalent to a safety risk exposure. Therefore, when defining the safety boundaries, one is establishing the acceptable safety risk exposure.

[10] "The purpose of risk analysis is to comprehend the nature of risk and its characteristics including, where appropriate, the level of risk. Risk analysis involves a detailed consideration of uncertainties, risk sources, consequences, likelihood, events, scenarios, controls and their effectiveness. An event can have multiple causes and consequences and can affect multiple objectives" (BSI 2018b, p. 12).

[11] "The purpose of risk evaluation is to support decisions. Risk evaluation involves comparing the results of the risk analysis with the established risk criteria to determine where additional action is required" (BSI 2018b, p. 12).

1.3.4 Safety Boundaries

The approach conveyed by the ICAO promotes a stance whereby every single event presents the exact same level of risk exposure. Each occurrence is classified under the same title, for example: “Quantitative indicators can be expressed as a number (x incursions) or as a rate (x incursions per n movements)” (ICAO 2018b, p. 4–5), and each event represents the same level of risk exposure independently of the predicted outcome, whether using a realistic or worst-case scenario. The perspective put forward by the concept “safety boundaries” diverges from the framework of the ICAO, since risk is not accounted for according to a mere frequency of events but as a set of risk-based occurrences that have the potential to contribute to an adverse outcome. The collection of events, rather than an overview restricted to a single event, forms a “risk-exposure cloud”, as Figures 6.26, 6.27 and 7.36 illustrate.

1.3.5 Risk Tools

Any set of techniques, method or methodology that supports risk analysis and evaluation of potential hazard is considered a risk tool. Peter-AS’s explanation describes it in action: “*I understand [a risk tool] as a method where we could [...] schematize [...] a specific event, which could be framed [...] within a process, [...] or be treated as one […] [and] would end up with [an event] evaluation in terms of risk.*” Paragraph 5.2 discusses several examples of risk tools.

1.3.6 Safety Protection

Safety protection is a concept broader than pure investment. More important than deciding on a specific investment is to allow organizations to understand how they can protect themselves against the hazards presented in the working environment. As noted above, hazards do not affect all organizations in the same way. Therefore, to achieve a balance between production and protection [SQ 3], organizations need to know where improvements are required and then know how to make them. For the current thesis, the concept ought to be understood as a management tool that is used to either allocate or relocate available resources, decide on new investments, and pinpoint where they are most needed. The safety-protection concept encompasses a set of protective practices that, depending on how they are used, have a risk-efficiency associated with them, and where performance depends on how they are used; and, consequently, highlights the utmost importance of correctly managing them (Lu et al. 2016).

1.3.7 Safety Culture

Throughout the current research, safety culture is seen as a holistic environment that influences employees' behaviours and attitudes towards safety; framed by a cognitive and externalized appearance, which is composed of implicit and explicit components, having also an enduring perspective, it is quite a difficult culture to mould. Moreover, safety culture relates to employee, group and organizational attitudes and behaviours – something understood to be influenced by the socialization and leadership phenomena – that, in turn, has a significant impact on the performance of the workforce and which is reflected in daily practice.

Based on these initial concepts, a framework was drawn up, presented in figure 1.6 (which is a copy of 3.14) against which to assess the existing literature, which is the task of the next chapter.

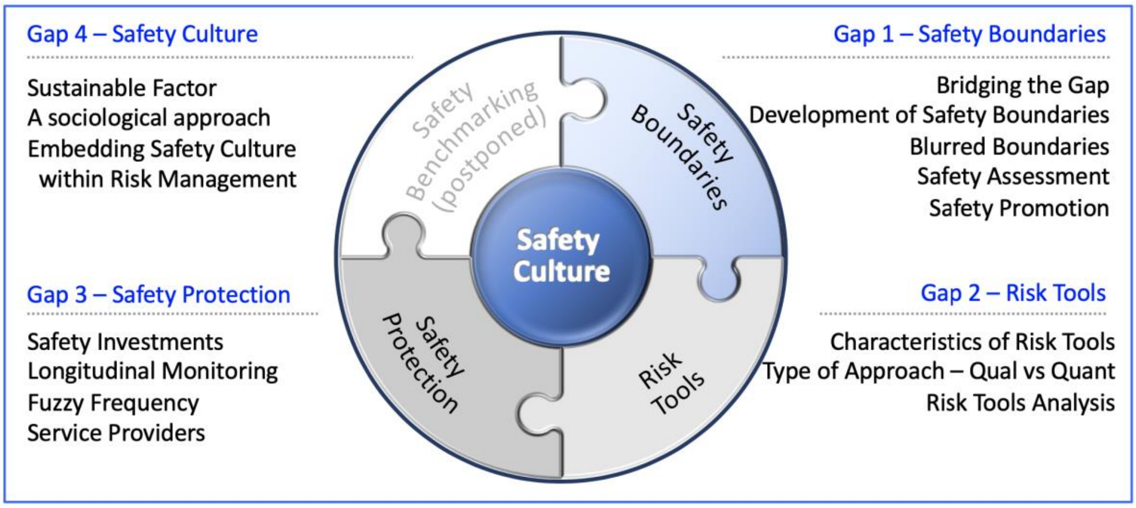

Figure 1.6 – Conceptual Framework: The continuous safety-risk management cycle

2 Critical Literature Review

The critical literature review takes the broad concept of safety risk-management as its starting point. Employment of the methodology offered by Hart (1998) facilitated the identification and connection of the core ideas, themes and theories to support the objectives of the research: to develop a structured commercial aviation risk-management model – the “Oyster Model” – to promote an efficient definition of risk level and its analysis, evaluation, monitoring and resource allocation.

Figure 2.7, below, illustrates the orientation of the research into four main areas.

Figure 2.7 – Map of the relevant literature

2.1 Introduction

The primary objective of a commercial airline is to control the company’s risk exposure to a level commensurate with their activities. However, as Arthur Rudolph – the scientist who developed the giant “Saturn 5” rocket that launched the Apollo missions and delivered the first manned mission to land on the surface of the moon – posits: reality, most of the time, is somewhat removed from an organization’s actual desire. According to Rudolph’s account (see Saxon 1996):

> "You want a valve that doesn't leak, and you try everything possible to develop one. But the real world provides you with a leaky valve. You have to determine how much leaking you can tolerate."

The importance of the organization's ability to define its level of acceptable risk exposure cannot be overemphasized; it is highly relevant. Thus, taking the words of Arthur Rudolph, the establishment of a "safety boundary" never will be seen as the final solution to the challenge, but a component of an approximate model that certainly will help organizations to distinguish the acceptable level of risk exposure from what is considered a dangerous level [SQ3]. Organizations must gauge and calibrate the safety boundary consistently over time, but the effectiveness of this will be dependent on the mitigation measures they can implement in the field.

The model – the tenets of which lie in the author's professional knowledge of the airline industry and his experience as a pilot – and which responds to and has resulted from the research, is based on the idea of continual improvement through questioning and inquiring into earlier models and theories, and this is supported by the evidence obtained from the interviews. The model (presented in Chapter 6) aims to reduce the gap that the research has identified exists between academic developments and implementation of new models and theories put forward by operational staff (Underwood & Waterson 2013; Swuste et al. 2019). Therefore, to reduce the challenges of implementing the requirements of the model, it is crucial to understand the commercial aviation environment and note the findings from the extant literature on risk-management theories. Section 2.2 provides an overview of the main concepts that constitute complexity theory; scrutiny of systems thinking will also help to identify the best approach to follow for risk management to be most effective.

2.2 Organizational Safety Environment

The development of safety boundaries implies that stakeholders understand the system in which they are actors. The purpose of this section is not to develop a comprehensive review of the commercial aviation environment and its characteristics, but rather to review the general concepts and gain an understanding of which approach would most adequately embrace the risk-management process. As Robert Pirsig posits, "there's so much talk about the system. And so little understanding" (see Meadows 2008, p. xv). Therefore, the initial aim is to frame the main concepts and open up the research avenues to develop a risk model suitable for the needs of commercial aviation.

Complexity theory and systems thinking convey relevant insights that could explain the intricacies of the aeronautical system. The underpinning assumption is of an abstract concept where the whole is greater than the sum of its parts (Cilliers 1998). Under the lens of complexity theory, systems are perceived as integrated entities with a rich and diverse set of characteristics, which can only be understood by patterns and principles (Tosey 2002).

Complexity theory relates to an ontological understanding of the world rather than a form of working with scientific models (Tosey 2002; Kurtz & Snowden 2003; Snowden & Boone 2007). It embraces a cluster of different forms of thinking. The “edge of chaos”, also known as the “zone of complexity”, is one of them, whereby the system is conceptualized as the frontier between stability and instability, or as a space of operation amid chaos and the domain of traditional management approaches (Zimmerman 2001; Tosey 2002). In this domain, where production reaches its pinnacle, agents enjoy a greater degree of freedom, which is equivalent to saying that this represents the most creative and effective place to operate (Tosey 2002; Dekker 2011). This is a conceptual place, where the system maximizes its capacity to adapt and respond to modifications in the environment. The system can be contrasted with the simple and complicated stasis stage and the chaotic domain.

Figure 2.8, below, from Zimmerman (2001), based on Ralph Stacey’s matrix, identifies the most appropriate management approach.[12] It bases its analysis on the degree of “certainty” and the “level of agreement”. The “close to certainty” side identifies an environment where managers have a high degree of confidence in their decision-making. Here, however, while experiences from the past allow extrapolations in order to predict the outcome with a high degree of confidence, in the opposite pole of “far from certainty”, experiences from the past do not allow for the existence of cause-and-effect linkages. The vertical axis reflects the level

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[12] The “simple” domain represents a context characterized by stability whereby cause-and-effect relationships are perceptible to all agents. In this context, past data may be used to predict the future outcome. The “complicated” domain belongs with experts in the subject matter. Thus, there is also a clear relationship between cause-and-effect, although not every agent understands this. It is the space of a high level of negotiation, where agreement about the best solution is not consensual, and company values play an essential role. The “complex domain” is discussed throughout the text. In short, one can say that system understanding emerges in retrospect. Therefore, instead of imposing a course of action, managers should induce the system, and patiently let the pattern reveal itself. The “anarchy” domain is a context of great turbulence, where it would be impossible to determine the relationships between cause-and-effect (Zimmerman 2001; Snowden & Boone 2007).

of agreement among stakeholders.

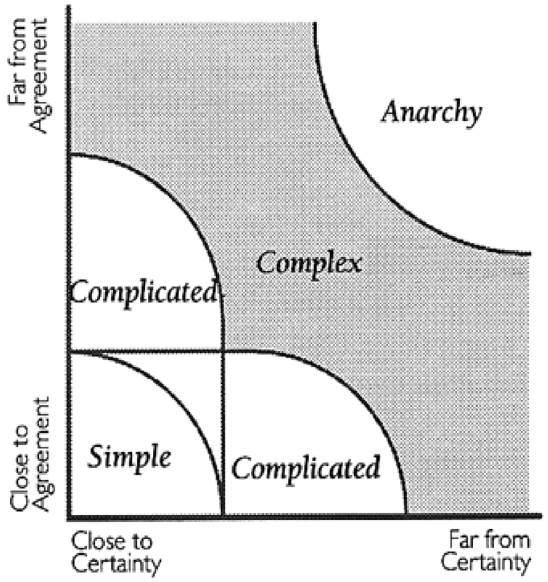

Figure 2.8 – Diagram of the "Edge of Chaos" / "Zone of Complexity". Source: © Zimmerman (2001). Schulich School of Business, York University, Toronto, Canada. Permission to reproduce for educational purposes only.

Within the complex grey area, a system may present emergent, dynamic, adaptive, self-preserving and even evolutionary behaviour,[13] which will be reflected in its performance. However, understanding of a system cannot be achieved by studying the parts individually (that is, using a reductionist methodology[14]), since all the parts interact dynamically, presenting non-linear relationships between the elements (Cilliers 1998; Snowden & Boone 2007; Meadows 2008; Checkland 2012). Compounding variability and unpredictability, systems are embedded within neighbouring systems, evolving, influencing and being influenced by external (adaptive) factors, leading the boundary system to present a fuzzy behaviour (Meadows 2008; Plsek & Greenhalgh 2001; Tosey 2002). Nevertheless, the unpredictability of complex systems can be minimized by constant monitoring of system behaviour (Plsek & Greenhalgh 2001; Senge 2006).

Complexity theory has its foundation in contesting reductionist methodologies. Although acknowledging the explanatory power and accomplishments achieved by the traditional reductionist approach, many authors point to the limitations of its philosophical stance.

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[13] Evolutionary behaviour is termed as "learning" in Tosey's (2002) taxonomy.

[14] Cause-and-effect reasoning was inherited from the ideas of Isaac Newton and René Descartes, whereby understanding of a system is attained by reducing the system to its parts (Dekker 2011); by identifying the separate parts of a system, one is able to learn and explain how the whole functions (Gilbert & Sarkar 2000).

Scholars defend their position by stating the fact that the world does not present machine-like behaviour; it is not understandable through its constituents either, but assembled within organic and holistic systems whose properties are challenging to uncover through an understanding of its parts (Lewin 1999; Gallagher & Appenzeller 1999; Dekker 2011; Nisula 2018).

Complexity theory makes the distinction between complex and complicated systems (Cilliers 1998; Urry 2005; Meadows 2008; Dekker 2011). A system with a large number of components and the ability to perform elaborate tasks that can be analysed and predicted accurately by mathematical equations is seen as a complicated one. Complex systems, Cilliers (1998, p. 3) asserted, are formed by "intricate sets of non-linear relationships and feedback loops[15] that only certain aspects of them can be analysed at a time". A large aircraft is considered a complicated system. It is composed of a myriad of components; however, the study of its parts produces an understanding of the whole functioning without losing its machine character[16] (Mikulecky 2001). Complex systems are related to social and living things, namely a cell, the brain, language, social systems, and the like. For instance, safety culture cannot be devised by a rule, nor can it even be implemented by adding components to develop the desired culture within a specific organization (Nisula 2018). The same constraints would apply if one thinks in economic terms.

Meadows (2008, p. 11) asserted that a system is "an interconnected set of elements that is coherently organized in a way that achieves something." She posits that a system must contain three different types of things – "elements, interconnections, and a function or purpose". She also argues that systems have a behaviour, which is reflected in their performance over time. In this regard, Senge (2006) asserted that people are driven by events, which are distant in time and space. In an attempt to understand these events, people tend to get distracted from the underlying invisible threads of interconnected actions and miss the longer-term pattern of changes, losing the explanatory and predictive power of system behaviour. Systems thinking gives rise to a shift in the mind-set of (risk) managers, driving

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[15] A feedback loop represents a measurement from a system's output that is fed back and used as a basis for controlling the process that originates the output (Hollnagel 2012).

[16] Supported by evidence from several commercial airline accidents, Dekker (2011) argues that complicated systems such as modern commercial aircraft may become complex when exposed to cultures that derive significantly from design and engineering assumptions. Moreover, although the operation may be known exhaustively, in a dynamic environment, several parts may present unforeseen and uncertain behaviours, which are characteristics of complex systems.

them to look for interrelationships rather than straight cause-and-effect chains, and to seek processes of change to the detriment of snapshots of events.

All elements of the system are relevant. From a risk-management point of view, the capacity to influence a system depends on the type of intervention. For Meadows (2008), a significant change in the system would be expected were it possible to modify the purpose, even if the remaining constituents remained unaltered. However, while the interconnections play an essential role, any modifications to them are unlikely to impact greatly on the system, but might be reflected at the level of its behaviour. Finally, the elements are the most visible parts of the system, but (most of the time) they are the least important component to define the features of the system.

Within systems thinking, the universe is systemic, meaning that events are perceived as an emergent property of an interrelated system (Cilliers 1998; Flood 2010; Dekker 2011). Undesirable events “go up and out”, encompassing concurrent factors such as political and sociological conditions, and do not concentrate “down and in[side]”, that is, taking a mechanical perspective to find why a specific part is broken or functioning deficiently (Dekker 2011). This stance is relevant to commercial aviation risk management: safety analysis through a systems thinking lens acknowledges the non-linearity and the dynamic nature of system interactions. Accident and incident prevention go beyond the simple failure of single parts and are the result of the system’s dynamic nature [RQ 2.1]. For an accident to occur does not require a system failure, but results from the concurrence of a set of events (Perrow 1994; Hollnagel et al. 2006). The recent Boeing 737-800 accident of Pegasus Airlines is a good example of a system’s interactions. Although performing a landing in severe weather conditions, allegedly nothing was wrong with the aircraft that could justify the accident (Hradecky 2020).

There are many more descriptions of complex systems. However, it is relevant to understand what makes them unique or differentiates them from other domains. The most relevant characteristics were obtained from the analyses of Cilliers (1998), Le Coze (2005), Snowden and Boone (2007) and Dekker (2011). The properties of these will help elucidate why complex systems are unlikely to be studied using linear, deterministic and positivist philosophical approaches [RQ 2.2]:

- Organizations are open systems. As they interact with surrounding systems, this leads to difficulties in framing the boundaries of the system [SQ 1]. Organizations evolve, adapt and drift throughout their existence; understanding the dynamics and future behaviour of them is only possible with constant monitoring [SQ 3].

- Feedback loops mean the existence of multipliers. The result of an input can be feedback on itself, resulting in reinforcement or attenuation of the input. Cilliers (1998) framed this as recurrency. The crumbling of morale and stamina throughout the management hierarchy could be used as an example of one of these loops.
- Linear cause-and-effect relationships and interaction do not explain organizational behaviour. Non-linearity explains why minor changes have the potential to produce disproportionate outcomes.[17]
- Complex systems are composed of a plethora of elements. Quantity is a necessary characteristic, but not sufficient per se. Elements must interact dynamically, whereby it follows that quantitative models are incapable of predicting an organization’s behaviour, as the number of independent variables and their interactions are too excessive to be expressed as equations [RQ 2.2].
- An organization’s parts are ruled by complex interactions, supported by the internal culture, social interactions, power relations, strategies and the like. Complex systems have a history, and their evolution reflects past experiences, it is a path-dependent system.
- No agent can fully understand the system or the outcome of its action. Complexity emerges as the outcome of multiple interactions of simple elements with access to limited information.

Reflection on complexity theory’s main characteristics as summarized above, recalls many organizations, especially those where many entities regulate their activity (a hierarchal social-technical system). These organizations tend to be dependent on the interaction of a plethora of stakeholders making autonomous decisions about their actions, and have a structure made up of a significant number of units, such as in the case of commercial airlines. Commercial

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[17] A consequence of a non-conforming oil feed stub pipe, installed in the no. 2 engine, a Rolls-Royce Trent 900, A380 VH-OQA sustained an uncontained engine rotor failure (UERF). Debris from the UERF impacted the aircraft, which resulted in significant structural damage and a multitude of systems damages (ATSB 2013). Another example comes from the Columbia accident, which was the result of a breach in the thermal protection of the left wing, which resulted from the release of a mass of iced-up foam hitting the leading edge during the re-entry. The breach led to the loss of Columbia (NASA 2003).

aviation has all the characteristics of a complex industry as presented by several authors (Perrow 1984; Dijkstra 2006; Dekker et al. 2011).

Dynamic interactions and their systems non-linearity explains the emergent properties that characterize complex systems. The exact set of conditions leading to an undesirable event (e.g. an accident) is something that cannot be fully replicated (Dekker 2011). Thus, the restricted knowledge of each agent is what makes decisions rational, but given the goals, local circumstances and the interactive complexity of the system, this can generate unpredictable pathways that are challenging to anticipate (Leveson 2004; Dekker et al. 2011). Therefore, the understanding of safety events – accidents, incidents and their precursors – cannot be analysed, prevented or explained through a reductionist approach [RQ 2.2]. Models based on linear approaches, where the dynamic relationship between systems is ignored or simplified, cannot explain how contributing factors concurred together to create an undesirable event, particularly when agents are exposed to a set of different effects all at the same time (Dekker et al. 2011).

Having discussed the concepts of complexity theory, it is appropriate to revisit the Zimmerman (2001) matrix presented in Figure 2.8, which presents a gradient transition between and within domains. Zimmerman (2001) identifies the existence of three different degrees of emergence within the complexity domain, which represents distinct stages in management intervention:

- “Convene and intervene”, a stage where leaders develop structured plans for intervention involving all representatives from the surrounding complex adaptive systems (CAS).
- “Convene”, the stage at which leaders restrict themselves to identifying the potential for self-organization in the expectation that this will emerge within the system.
- “Examine and describe”, a stage where patterns in CAS move beyond the leader’s ability to intervene.

Snowden and Boone’s (2007) analysis of the Cynefin Framework[18] provided guidance on how managers should diagnose their current situation and adapt appropriately to the different

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[18] The Cynefin Framework has its roots in a Welsh word (pronounced “ku-nev-in”), which “signifies the multiple factors in our environment and our experience that influence us in ways we can never understand” (Snowden & Boone 2007, p. 2). The framework is composed of five domains: simple, complicated, complex, chaotic, and disordered.

domains. There are obvious similarities with the Zimmerman matrix, which turns out to be a quite relevant contrast. While the latter perceives the transition between domains as a gradient evolution, the Cynefin Framework shares that perception only in the order domain of simple and complicated. The conversion to the complex and the chaotic[19] domains is perceived as a phase shift involving the release or use of energy.

The A380 (ATSB 2013) and the Columbia (NASA 2003) accidents are examples that could be explained by the Cynefin Framework, whereby a non-linear event explains why minor changes had the potential to produce such disproportionate outcomes. However, within the commercial aviation industry, which is composed of an array of different types of stakeholders, ranging from small vendors to big airlines and from national and regional regulators to transnational entities such as the IATA and ICAO, the complexity of the industry is better represented by the Zimmerman matrix, where different levels of complexity can be found. Even incidents and accidents could be better explained by a smooth decremental transition between and within the complex domain (Dekker 2011). The Asiana accident (NTSB 2014), the Boeing 737 MAX in Indonesia (KNKT 2019), or even the Emirates Boeing B-777 (GCAA 2020), are all examples that resulted from the concurrence of a set of events that interacted continuously, increasing the degree of complexity to the point where flight crew could no longer manage the situation. Either the Cynefin Framework or the Zimmerman matrix play a key role in explaining the conditions that pushed the limits until an accident occurred. The navigation of risks is perceptible within several domains [SQ 3], which leads one to speculate that risks do evolve in a dynamic “space of possibilities” (Rasmussen 1997).

In summary, complexity and systems thinking theories provide valuable insights in order to acquire an understanding of how the complex and adaptive environments, in which the commercial aviation sector develops its activity, impact upon flight safety and, consequently, accidents and incidents. Thus, it is essential to consider its characteristics and subtleties during the development phase of the risk model, specifically:

- Complex systems interact dynamically with neighbouring systems, present adaptive and self-preserving behaviour, and evolve throughout time. Their unpredictability can

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[19] The Zimmerman matrix identified the chaotic domain as “anarchy”.

be minimized through long-term monitoring of system behaviour and by following patterns [SQ 3].

- The simple implementation of barriers and redundancy features, associated with a reductionist approach [RQ 2.2] – linear cause-and-effect chains – will not stop undesirable outcomes from occurring (Reason 1997; Hollnagel 2008; Dekker 2011).
- Mitigation measures must be brought in to tackle critical aspects, specifically the development of non-linear relationships and interactions within the system [SQ 3].

Complexity theory and systems thinking theories are undoubtedly useful tools to both conceptualize the commercial aviation environment and provide robust explanations for most contemporary accidents. However, both theories are difficult concepts to implement in the field (Tosey 2002), with neither able to detail system interactions or define how boundaries should be framed (Dekker 2011; Williams 2011). Thus, they provide limited explanation and guidance at the organizational level.

The development of a mental model of how accidents occur influences the way accidents are investigated and prevented as much as identifying the causal factors (Leveson 2015). Therefore, the focus of section 2.3 is on the general thinking about accident prevention and how risk models have incorporated the prevailing stance; whereby the review of these will seek to understand how adaptable they are to the complexity of the commercial aviation environment and how robust they are at explaining and prospecting accident causation.

2.3 Safety Linear Risk Models

From an operator’s perspective, accidents and incidents could be explained as a set of barriers that have failed. The reason for the failure might be either that the barriers are not fit for purpose or because they are absent or dysfunctional. The accident investigation lens is purposed with having universal applicability, thus all causes are identified as contributory factors (Hollnagel 1999). In this regard, the analysis component of risk management is an important element of understanding what type of outcomes could result from a specific hazard or the interaction of hazards with agents (BSI 2019). With this knowledge, mitigation barriers should be carefully chosen to address the required objectives; although, potential event analysis can never be exhaustive (Leplat 1997). Nevertheless, this will constitute a continuous improvement, where the lessons learned from the operation will be reflected in the enhancement of the barriers’ ability to prevent the occurrence of undesirable events. Rasmussen (1997) and Leveson (2004) saw this as an intrinsic characteristic of a social system, whereby, in response to local pressures and cost-effectiveness cutting policies, barriers are inclined to degenerate systematically over time [SQ 3].

For Tailor, barriers are “equipment, construction, or rules that can stop the development of an accident” (see Hollnagel 1999, p. 5), whereas for Svenson (1991, p. 501) a barrier represents “a function which can arrest the accident evolution so that the next event in the chain is never realized.”

Hollnagel (1999, 2008) and Svenson (2001) identified four types of barrier that could be implemented: physical, functional, symbolic and immaterial.[20] A combination of barrier functions are necessary to achieve any given purpose and gain an effective defence-in-depth. Enhancing systems safety by implementing a set of mitigation barriers, identifying those that are broken, exploring how these can be improved or replaced by more efficient ones, or even closing the existence of gaps in the system, is quite relevant and has contributed indelibly to current safety levels in commercial aviation. However, the aforementioned view reflects a deterministic stance, whereby accidents are seen as logical sequences of events with a cause-and-effect correlation between them (Hollnagel 2012). Seen through an alternate lens, the system could be understood by analysing their parts individually, but this standpoint overlooks the potential for dynamic interaction and non-linear relationships between the elements within the system (Cilliers 1998; Meadows 2008; Checkland 2012).

Many models have reinforced the misconception that accidents and incidents have a root cause, and that this root cause can be identified by looking backwards from the event through the sequence of triggers that precipitated it (Hollnagel et al. 2006).

The review below is far from exhaustive, but it meets its objective to outline the theoretical concepts that support accident theory by looking at three recognized models. The first two of these are said to be the best known models in the industry (Hollnagel 2014), while the third is also referenced by renowned researchers of the subject. Of these, the Domino model is from the pioneer safety researcher Heinrich (1931); the “Swiss Cheese” model is from the

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[20] In his second paper, Hollnagel (2008) changed the designation of “immaterial barriers” to “incorporeal barriers”.

renowned psychologist James Reason (1997, 2016); and the Accident Evolution and Barrier Function (AEB) is cited by Svenson (1991, 2001) and Hollnagel (1999).

Supported by 10 axioms, the Domino model reflects a deterministic stance, which attempts to formulate a theory of safety. The first axiom states that:

> “The occurrence of an injury invariably results from a complicated sequence of factors, the last one of which being the accident itself. The accident in turn is invariably caused or permitted directly by the unsafe act of a person and/or a mechanical or physical hazard.” (Heinrich et al. 1980, p. 21)

In the Domino model, accidents are explained as a linear sequence of causes and effects, whereby accidents are the result of unpredicted events that result in a disruption of a stable system. The model implies that the absence of an element (a domino) would prevent the accident’s spread. Taken from a different perspective, however, one could assert that accidents and incidents are avoided by breaking the cause-and-effect link. Although the domino concept was helpful in offering a practical approach to understanding events, its support of the linear reasoning stance to explain why accidents occur weakens its appeal. The model provided the underpinnings for accident prevention aimed at avoiding unsafe acts and conditions, which is the basis of the Accident Evolution and Barrier Function (AEB) model.

The AEB model is another example of linear accident representation. Here, accidents occur (or are modelled) as a series of interfaces between the agent and the technical system that result from a sequence of events belonging either to a technical malfunction or failure of a component, an imperfectly performed function, or a barrier function that has not performed adequately. The ultimate objective of the analysis is to implement improvements in the barrier functions to arrest the propagation of an accident with greater probability (Svenson 1991; Hollnagel 1999; Svenson 2001).

The reasoning that supports the development of the AEB model considers the influence exerted by the organization internally, but as it omits the potential influences promoted by the external systems, its explanatory power presents a relevant gap [SQ 3].

Lastly, the “Swiss Cheese” model proposed by Professor James Reason (1997, 2016) considered accidents as a result of tensions between protection and production. This ultimately creates a window of opportunity that results in active failures committed by front-line operators and latent conditions seeded by management personnel. In Reason’s (1997, p. 36) account:

> "We cannot prevent latent conditions from being seeded into the system since they are an inevitable product of strategic decisions. All we can usefully do is to make them visible to those who manage and operate the organization so that the worst of them, at any one time, can be corrected."

Such latent conditions could be perceived as fragile barriers installed in the system, which are represented in the model by the holes in the slices of cheese. The model is more complex than the previous two, with the main focus on the elements and in the structures associated with them. However, it still takes a linear and reductionist approach and neglects the system as a whole as explained by complexity theory (Leveson 2011; Hollnagel 2014). The "Swiss Cheese" model acknowledges that causality can no longer be seen as a single linear propagation of occurrences; however, the undesirable outcome is of a relatively clear-cut combination of events and a failure of a defence can still be perceived as a failure of an individual element or barrier.

The insights brought by the discussion of the three models are relevant to understanding accident causation. However, in light of the more recent concepts conveyed by complexity theory and systems thinking the explanatory power of these models is diminished, since they neglect to integrate other events that concur to bring about the same or similar outcome, as the runway-excursion example in Chapter 6 illustrates.[21] The case of the AEB model exemplifies the deficiencies of linear models. When performing an in-depth analysis, the model may well be complemented with causal tree techniques. But as a static model, these techniques perform poorly in complex situations[22] due to the fact that do not account for the interdependencies, only admit binary states (e.g. failed or successful) and do not incorporate a comprehensive assessment of the main contributory factors (BSI 2019). Furthermore, as a complex system, events rarely duplicate their pattern of occurrence. Thus, to be prepared to operate safely agents must have an understanding of the system as a whole; hence, mitigation barriers should come from all of the interacting systems in addition to taking a wider perspective; for example, training, promotion and awareness should be included in the set of mitigation measures (Rasmussen 1997).

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[21] The AEB model attempts to learn from the "causes and to guide in developing countermeasures to avoid the same event happening again. Also, the analysis can be used to avoid similar events in the future and to find out what characteristics on a higher (e.g. organizational) level could prevent further incidents and accidents" (Svenson 2001, p. 52).

[22] The Causal (event and fault) tree and other sequential techniques may be suitable to risk-assess less complex incidents or minor accidents since they may result from less elaborate causes or simple interactions (Hollnagel et al. 2006; Underwood & Waterson 2013).

This is recognized by Hollnagel (2008), who asserts that irregular threats and unexampled events (Westrum 2006) need to be addressed using alternative techniques beyond barriers alone; analysts and managers should be given the ability of understanding the systems' changing vulnerabilities in what is known as performance variability or resilience (Hollnagel et al. 2006). Section 2.4 scrutinizes five methods and models, referred as systemic accident analysis (SAA), to understand what their added value to the practitioner community is in terms of developing organizations' safety boundaries.

2.4 Systemic Accident Analysis Models

From the two previous sections, arguably one could assert that the models, which base their explanatory power on a linear combination of failures and simple human error, provide little understanding and offer only a fragile explanation of the causes of incidents and accidents. The new set of models, which was developed to address the changed perspective, perceives undesirable outcomes as the consequence of the emergent characteristics of systems, natural operation variability, dynamic interactions and the adaptive behaviour of systems. As a plethora of methodologies to evaluate, risk assess and analyse system accidents already exists (Stanton et al. 2018), a comprehensive review is not offered here, with discussion restricted to only the most representative extant literature identified by several researchers, notably De Carvalho (2011), Underwood and Waterson (2013) and Grant et al. (2018). Although several methods are fairly frequently cited, only five are listed below to verify how they have contributed to strengthening the development of the safety-risk boundaries:

- Leveson (2004), "Systems-Theoretic Accident Model and Processes" (STAMP).
- Rasmussen (1997), The risk-management framework.
- Dekker (2011), Drift-into-failure model.
- Hollnagel (2012), "Functional Resonance Analysis Method".
- Perrow (1981, 1994), Normal Accident Theory.

2.4.1 STAMP – Leveson's Theoretic Model

Leveson (2004) described accidents and incidents as a consequence of the system's emergent properties, which develops from the interaction of physical, technical and human elements, rather than a failure or malfunction of the system's components. Leveson's (2004) STAMP model used a conceptual safety abstraction, according to which accidents occur as the result of external disturbances and dysfunctional interactions that were not adequately supervised by the safety-related constraints embedded in an adaptive socio-technical system. In this regard, safety is perceived as a problem of the inadequate control or enforcement of safety-related measures to restrict the behaviour of the system so that it remains within the boundaries of the safety limits. Leveson (2004) hypothesized that accidents are the result of inadequate (layers of) control. She identifies a set of deficient controls, specifically at the levels of enforcement of controls, execution of control actions, and missing or insufficient feedback.

In her theoretical model, systems are maintained in a dynamic state of equilibrium through the establishment of feedback loops of information and control. However, as systems are perceived to operate in a dynamic environment, this implies the existence of a continuous evolutionary status. Therefore, the STAMP model uses a control structure which is purposed with determining which control measures[23] support operational safety and to identify the ineffective ones. This is a continuous monitoring task (Senge 2006).

Control measures are implemented through a model that represents a hierarchical social-technical structure. In this model, which has its inception in Rasmussen and Svedung’s (2000) risk model, higher echelons control (or impose restrictions upon) the lower ones. The control is divided into two communicative branches: the design stage and the operational stage. The objective of the constraints is to guarantee that the system operates within safety boundaries. The constraint layers can take the form of rules, procedures or limitations, with the ultimate goal of limiting the interaction between the system’s elements.

Based on the underpinnings of the model, Leveson (2004) argued that recent accidents have been judged as the consequence of operator error but, in her perception, they ought to be labelled as the result of systems operation and design flaws.[24] The Three Mile Island accident is a remarkable example of a design flaw in the system and the absence of adequate feedback. Concurrent with other flaws, operators were commanding a valve to its open position and were receiving feedback from their actions as if the valve had been opened, when this was not the case. The only feedback they were receiving was that the power had been applied to

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[23] Control measures may include: managerial, organizational, physical, manufacturing and operational measures (Leveson 2015).

[24] Regarding the complexity and design flaws, in Asiana Airline’s accident report (NTSB 2014), Robert Sumwalt declared the following: “Like most accidents, the causation of this accident is complex and involves the interaction of several elements of the system. It involves a set of circumstances that came together on this day to produce a tragic outcome. […] the HOLD mode is poorly understood by the industry, and absolutely this accident could have happened in any airline.”

the valve, which was not a guarantee of the actual status of the valve. This is representative of inadequate feedback in a complex system[25] (Leveson 2004). These flaws cross-cut the whole social-technical system and cannot be attributed solely to frontline personnel.

Operating and design flaws and the incapacity to control the system's continuous migration towards a state of higher risk – the edge of the safety boundary –, namely during the production phase and periods of financial pressure, reduces the safety margins in a steady fashion [RQ 3.1]. These constitute the reasons for the existence of deficient systems and the occurrence of accidents (Woods 2000; Leveson 2004; Hale & Heijer 2006).

Leveson's (2004) model provided both retrospective and prospective analysis, which justifies its use in either accident or risk assessment analysis. Although reflecting her engineering background, the insights brought by the model make it applicable to a vast range of activities. The notion of control and feedback loops, the dynamic characteristic of the system, which requires continuous monitoring of the controls installed [RQ 2.1] and the hierarchical social-technical structure in terms of design and operations, are relevant concepts to help understand system behaviour.

Were the migration concept incorporated into Leveson's (2011) model to prove correct, it would require the existence of an operating boundary by highlighting the risk level organizations are exposed to, in a form that allows early detection and consequently intervention before an undesirable outcome occurs [SQ 1]. However, as in Dekker's (2011) "drift-into-failure" concept, Leveson's (2004, 2011) theoretical model does not consider such a concept, restricting itself instead to a continuous effort to impose restrictions in order to limit the system behaviour to adaptations and changes. Although bringing a relevant explanatory power to how to prevent and analyse incidents and accidents, in addressing the boundary (or measurement) using an abstract approach, she creates an implementation challenge for practitioners, which relies on safety leading indicators that are managed individually and use a linear reductionism stance, as seen in the previous section (Leveson 2015). These challenges in relation to the development of a risk-exposure stance will become more apparent once the description of the new model is presented in Chapter 6.

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[25] Corey (1979, p. 54). The vice-chairman of the Commonwealth Edison Company, in a brief review of the accident, mentioned that: "A series of apparent errors and equipment malfunctions, coupled with some questionable instrument readings, resulted in loss of reactor coolant, overheating of the core, damage to the fuel but probably no melting, and limited releases outside the plant of radioactive noble gases and iodine."

2.4.2 Sidney Dekker's Drift into Failure Theory

Dekker's (2011) "drift-into-failure" theory does not encompass a specific methodology, approach or a set of procedures to evaluate a system, but instead, is supported by a reasoning, which has its underpinnings in complexity theory and systems thinking, to theorize that systems incrementally and gradually drift into failure. In this same volume, Dekker posited that organizations normalize such deviance, which is a common conduct that applies even to well-run organizations.

Organizations in pursuit of maximizing efficiency start borrowing space from their safety buffer [SQ 1]. The efficiency mandate imposed by managers, environmental concerns, competitors and scarcity of resources is, according to Dekker's (2011) account, the recipe for a drift into failure. The drift described by Dekker and also by Snook (2000), is quite plausible. There are plenty of examples supporting the existence of an identifiable pathway that paves the way to incidents and accidents (Owen 2001; Dekker 2011). Therefore, the question must be raised: Can anything be devised to alert organizations to the existence of such a drift?

According to Dekker's account, safety professionals are moulded by the reductionist stance of cause-and-effect, which was inherited from the ideas of Isaac Newton and René Descartes, and since have developed into a fatal reasoning in modern everyday life. This stance "deflects us from the longitudinal story behind those indications" (Dekker 2011, p. 36), and we lose sight of the drift and rationalize and normalize indicators of trouble.

In Dekker's (2011) concept, order emerges as the result of the sum of the interactions of lower components with the environment, rather than from the imposition of higher echelons. This characteristic of complex systems led Dekker (2011) to assert that actions have a lower degree of control but a higher level of influence. Therefore, predicting the look of the emergent order is difficult to anticipate, but one can assert that a different order will emerge as a consequence of the interaction. The positive feedback produced could generate further decisions that create a path-dependency, which are the contributory elements to the drift into failure. Dekker (2011) identified several features that contribute to the safety drift, specifically: resource scarcity and competition among airlines and decrementalism, driven by the optimization and rationalization of operations, technological reliability and the contribution of protective structures internally and externally.

It turns out that it is difficult to identify a single culprit for the drifting from among the interactions brought by complexity theory in the way the oversimplified (and unjust) view from the Newtonian reductionists would have it. In Dekker’s (2011) view, a diversity of perspectives, embracing the available information and continuous monitoring are the remedy for constructing a resilient system [RQ 3.2]. Nevertheless, apart from those abstract concepts, which are relevant to raise system awareness, scant guidance is provided at the organizational level: specifically, how can managers perceive that the system is migrating to higher levels of risk exposure? Consequently, although relevant, Dekker’s (2011) concept is of little help to manage, perceive and develop the level of risk exposure an organization is willing to accept, that is, to impose the organization’s safety boundaries.

2.4.3 Rasmussen’s Risk Management Framework

Rasmussen’s (1997) risk-management framework presents a highly conceptual model of a dynamic society. The framework is formed of two different components. The first of these represents a hierarchical organization that includes all stakeholders – both individuals and organizations – and all of their interdependencies established within each level of the system. The system is vertically integrated: controls from higher levels are implemented at lower levels and, in return, operational performance feeds upward to the higher levels. While the stance of the framework has its inception in complexity theory, the safety aspect can be viewed as an emergent property of the socio-technical system which is influenced by politicians, regulators, executive boards, managers, practitioners and the like (Grant et al. 2018).

The second component of the framework is Rasmussen’s” space of risk exposure” (see Figure 2.9, below). This represents the dynamic forces that affect each level of the socio-technical system. The components incorporate three constructs: the “boundaries”, “gradients” and “aggregate risk index”. The exposure map is composed of three boundaries of failure: “economic”, “unacceptable workload”, and “(un)safe performance” and three associated gradients. The gradient “towards efficiency” results from the pressures exerted by management and shareholders, who push the economic boundary in an attempt to maximize profitability. The second gradient “towards least effort” represents the adaptive behaviours agents have to pursue in response to the pressures exerted upon them, namely, deviating from procedures, to produce more with less resources, in an attempt to be more cost-effective. These two gradients are balanced by the application of an opposing force composed of awareness, motivation and training campaigns (Rasmussen 1997; Cook & Rasmussen 2005; Miller & Xiao 2007). Safety campaigns to enhance safety culture are identified as another contributory opposing force, which must be consistent and selective to direct efforts towards specific processes (Rasmussen 1997).

The dynamic forces push the “aggregate risk index” away from each boundary, leading the system to move dynamically within these three constraints (Cook & Rasmussen 2005). If the “aggregate risk index” moves outside any of the boundaries, the system will start to operate at a higher risk-exposure level and be likely to fail. To avoid transgressing the limits, Rasmussen (1997) advocated “making the boundaries explicit and known and by providing opportunities to develop coping skills at boundaries”. Making the boundaries more visible in addition to enhancing the safety environment, will raise the effectiveness of the system in the way that increases the system’s efficiency and reduces the number of implemented safety margins, which in Rasmussen’s (1997) reasoning are prone to deteriorating in unpredictable ways when under pressure [RQ 1.2].

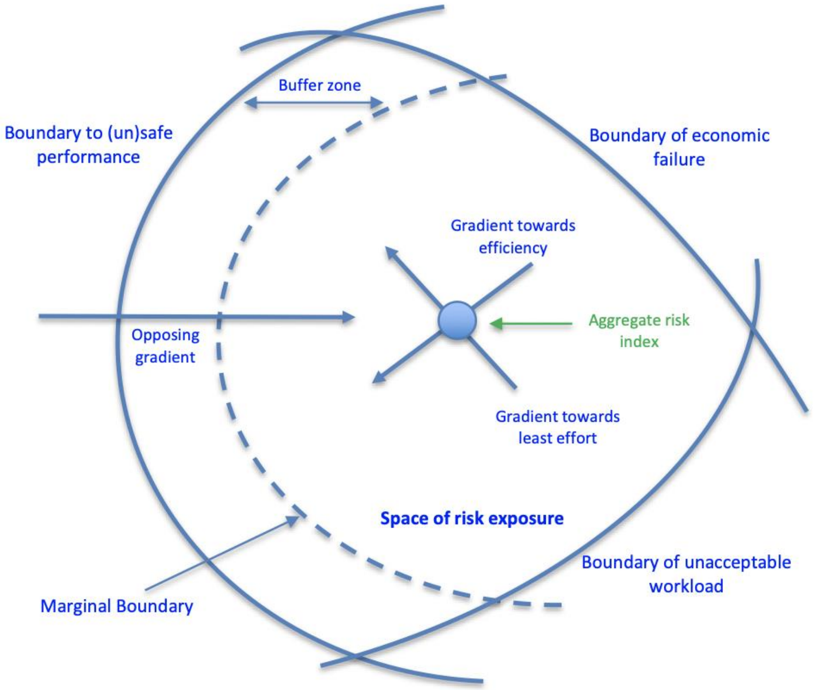

Figure 2.9 – Rasmussen’s “space of risk exposure”. Source: adapted from figure 3, in: Rasmussen (1997, p. 190)

The “buffer zone” (or error margin) represents the ability of the system to cope with disturbances or pressures, allowing the system to operate within the area of minimum risk. Agents set this zone while determining the risk-exposure level the organization is willing to accept [RQ 1.1]. However, the zone is dynamic and subject to inward and outward variations in reaction to pressure (Miller & Xiao 2007). Long periods without significant events, Cook and Rasmussen (2005) asserted, may contribute to an outward creep beyond the buffer zone. Therefore, the system ought to be monitored continuously to understand its resilience and how it is reacting to the implemented mitigation measures.

The explanatory power of Rasmussen’s (1997) theoretical framework is encouraging, providing clarification of how accidents occur in complex sociotechnical systems (Cassano-Piche et al. 2009). Accidents are viewed as a result of the actions of “many actors in their respective daily work context, responding to the standing request to be cost-effective” (Rasmussen 1997, p. 190). Therefore, accidents are not caused by variations in individual agent’s behaviour or performance, but through the interactions of several stakeholders at different levels of the system. In other words, the implementation of safety measures to tackle specific acts or errors will have only a limited impact on the system’s safety.

Rasmussen (1997) conceptualized a framework, whereby managers can perceive and visualize what constraints influence their working system. However, for the implementation to be successful at the organizational level, the boundaries and location of the “aggregate risk index” must be explicit and conspicuously presented, but the framework has not addressed this challenge. Compounding the difficulties, the associated uncertainty in relation to the location of the “aggregate risk index”, its dynamic movement and the current resilience of the system, could mean that the organization unintentionally enter the buffer zone, or even cross into the (un)safe boundary. For this reason alone, there must be a formal methodology in place to guide management decisions, acting as a counter-gradient to the “efficiency” and “least effort” gradients (Cassano-Piche et al. 2009; Cook & Rasmussen 2005).

2.4.4 The Functional Resonance Analysis Method (FRAM)

The FRAM method developed by Hollnagel (2004, 2012) was inspired largely by his disappointment with linear models, whereby accidents are understood to develop from a series of events that occur sequentially, as posited by the Domino (Heinrich 1931) and AEB models, discussed in the previous section, or even by FMEA (Svenson 1991, 2001; Hollnagel 1999).

FRAM assumes an intractable[26] (non-linear) system. This model, which could be used for accident investigation or risk assessment, employs an underlying assumption that has its inception in the work-as-imagined (WAI) and work-as-done (WAD) dichotomy, whereby systems are partly described or underspecified. The model goes beyond the assumptions of complexity theory in that it views systems as having an inherent systemic variation in which unexpected interactions (resonance) may result in undesirable outcomes – incidents and accidents.

The objective of the FRAM model is to develop an explanation of how events have occurred, or may occur, rather than explaining them in terms of the model's constraints. Towards this purpose, the interactions of the functions of the system need establishing by modelling the performance variability and the non-linear dependencies that may develop. By understanding the system's "normal" behaviour it is then possible to extrapolate how performance variability may affect the system positively or negatively. Four principles support the conceptual thinking of FRAM:

- The equivalence of failures and successes – FRAM is based on the principle that failures are the flip side of constant adaptation by the agent to deal with the world's complexities, rather than a failure of the system's functions. Therefore, failures and successes have the same inception, the former being the result of a temporary inability to perform or a performance variation.
- The approximate adjustments – The system's complexity creates a gap between WAI and WAD, leading to an underspecified and unpredictable situation. Derived from resilience engineering, tasks need adjusting, whereby performance variability is seen not as a liability but as a strength, and as an explanation for the functioning of socio-technical systems.
- Emergence – Similar to complex systems, emergence results from the interaction of multiple functions that may combine in unexpected ways, leading to large and disproportionate non-linear outcomes. Accidents do not occur as the result of intrinsic

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[26] Hollnagel (2012) compares a car factory assembly line and an emergency room in a hospital to define a tractable and an intractable system respectively. To differentiate the systems, four characteristics are used. The number of details, the rate of change in the system, the comprehensibility and the characteristics of the process. Analogous to complexity theory, the tractable system is seen as either a "simple" or a "complicated" zone of operation, whereas intractable systems are viewed as "complex" zones of operation. The non-linearity stems from the fact that no one can predict how many interactions occur between the initial event and the outcome, since dependencies between functions are not steady or static.

systematic variability or from the failure of a specific component or components, but, rather, emerge from the interactions of the functions.

- Functional resonance – The system recognizes that not all outcomes can be explained by cause-and-effect relationships – emergence. The variability of a set of functions may resonate; that is, it may evolve to become reinforced and spread by tight couplings (relations), exceeding the limits of the system, thereby leading to an undesirable outcome. FRAM tries to predict the adjustments, which although acquired imperfectly, assumes that variability is not random.

Opposed to traditional diagrams, FRAM representation does not use arrows, but instead shows links to identify how functions can be coupled either in potential or actual terms. Each function is represented by six features: input, output, preconditions, resources, time, and control, allowing the analyst to perceive where performance variability might occur and thereby to forecast where unexpected outcomes may develop from non-linear relations. The graphic representation conveys relevant information, but as a static model it provides limited information about systems behaviour (Grant et al. 2018) – specifically, by itself, it does not allow managers to identify their risk exposure.

Hollnagel sees Safety as composed of two different perspectives – “Safety–I” and “Safety–II”: “Safety–II” focuses attention on what works well to understand how safe an organization is, that is, how resilient it is. This is in contrast to “Safety–I”, where Hollnagel sees safety as quantified by measuring – “what goes wrong will inevitably lead to a paradoxical situation. The (…) safer something (an activity or a system) is, the less there will be to measure” (Hollnagel, 2014, p. 11). The phenomenon, known as the “regulator paradox”, will turn the management of safety into an increasingly challenging endeavour as the number of events reduces continuously. Dissatisfaction with “Safety–I” leads Hollnagel to develop the “Safety–II” concept. Nevertheless, despite being seen as two different concepts, “Safety–I” and “Safety–II” represent two complementary views of safety, rather than two incompatible or conflicting views (Hollnagel, 2014, p. 146).

When discussing the nature of resilient performance, Hollnagel (2012, p. 9; 2018) introduces the concept of resilience potentials. Thus, the analysis and evaluation of a department or organization’s resilience is based on four resilient concepts:

- the potential to respond;
- the potential to monitor;

- the potential to learn;
- the potential to anticipate.

Those concepts are interrelated, and to understand how they function as a whole, Hollnagel (2018) developed a functional model called the Resilience Assessment Grid (RAG). The RAG's implementation is underpinned by a set of four diagnostic and formative questions that can be tailored to any organization. Research into the topic is seen in the studies by Chuang et al. (2020) or Klockner and Meredith (2020). Nevertheless, as the latter authors assert, the existence of scarce research that bridges theory and practice promotes a gap relating to how organizations "can pragmatically measure their current performance against these four resilience potentials using the RAG" (Klockner and Meredith 2020, p.1).

Resilience Engineering is seen as a complementary feature to incident- and accident-prevention to ensure the organization's resilience. However, Hollnagel (2018) recognizes that the potential for resilient performance does not necessarily suggest that organizations perform in a resilient manner. As a new (supplementary) approach to safety, resilience (engineering) seems to have attracted many followers, as the previous authors and the current comment reveal. However, as Hollnagel recognized, it is inevitable that this promotes comparison with safety culture, in as much as bringing to the fore the question as to how the level of resilience can be determined, and how can it affect the organization (Hollnagel, 2018, p. 22)

As opposed to safety culture ("and other monolithic concepts"[27]), resilience is seen as the potential to perform in a way considered resilient. The concept ought therefore to be seen as potential to perform. Similar to the challenges the thesis identified in relation to the operationalization of safety culture, therefore, Hollnagel (2018) does not provide a method to incorporate the resilience outcome within the premises of risk management.

Despite its relevance, operational staff will face the same challenges Kirwan et al. (2019) voiced when discussing safety culture: How ought the results be operationalized and accounted for by safety analysts during their daily practice?

2.4.5 Perrow's Normal Accident Theory (NAT)

Like Dekker's (2011) concept, NAT does not encompass a specific methodology, approach, or a set of procedures to evaluate a system. Unlike linear approaches, the focus of NAT is on

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[27] (Hollnagel, 2018, p. 32)

accidents that occur from system failure, ignoring the common failures associated with procedures and equipment and the like (Perrow 1981, 1994).

Within the premise of complexity theory, Perrow (1994) supported the belief that organizations are far from being perfect. Hence, as the result of the unpredictable, non-linear[28] interaction between components, and tight coupling, safety systems will inevitably experience unexpected failures derived from minor and insignificant errors.

Coupling is described as the interaction between components. Perrow (1994) distinguished between loose and tight coupled systems. A tightly coupled system is often characterized as being highly automated; one task follows another rapidly and there is little chance for human intervention. In opposition to this, a system is loosely coupled when there is a slower process, different outcomes are allowed, and there is sufficient time and opportunity for human intervention to correct potential problems before they escalate into serious ones (Perrow 1984; Hollnagel 2012).

Similar to the previous models, theories and frameworks, NAT identifies the pressures brought by the aims to increase profit, production and growth, and includes the divisions brought by power struggles and even prestige, all of which are seen as factors that will contribute to eroding safety objectives and concerns [SQ 3]. In this regard, when discussing an aeronautical subject, Perrow (1984, p. 196) acknowledged how management is pushed to squeeze the system, stating: “Yet we continue to have accidents because aircraft and the airways still remain somewhat complex and tightly coupled, but also because those in charge continue to push the system to its limits.” Based on a set of close calls and accidents in the US nuclear weapons system, Scott’s (1993) research acknowledged the stance whereby the system is taken to its limit due to management pressure in search for greater efficiency [SQ 1 & RQ 1.1].

In the same vein as the previous examples, NAT presents concepts that are potentially relevant to explain why accidents occur. However, the high degree of abstraction that encompasses the NAT approach limits its explanatory power Hopkins (1999). Kates (1986) identified another obstacle to its implementation, which relates to the absence of a measurement criteria for the “complexity” and “coupling” concepts, which means that the

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[28] “Linear interactions are those in expected and familiar production or maintenance sequence, and those that are quite visible even if unplanned. Complex interactions are those of unfamiliar sequences, or unplanned and unexpected sequences, and either not visible or not immediately comprehensible” (Perrow 1984, p. 78).

theory is difficult to test. In summary, these challenges mean that NAT is difficult to implement at the organizational level, not least by depriving management of a perception of their current risk exposure and rendering them unable to draw their risk boundary.

2.4.6 Summary

A high level of conceptual and theoretical abstraction characterizes the models and theories researched in this section. Apart from Leveson's STAMP model, which bases its predictive analysis on individual leading indicators [SQ 1], the examples discussed provide limited predictive power; as Grant et al. (2018) have asserted, no predictive applications based on the previous models were found in the peer-reviewed literature. The limited predictability leads one to speculate that the models and theories currently available for use do not tackle the needs of practitioners; as the paper by Underwood and Waterson (2013) illustrated, a gap exists between practitioners and academia. Several drawbacks can be identified, but usability represents more than 50% of the challenges faced by organizations.

Beyond the deficiencies identified, the models and theories perused demonstrate the dynamic behaviour of systems and the existence of a continuous evolutionary status towards a state of higher risk exposure [RQ 1.1]. This stance contravenes the reductionist approach, which calculates probabilities, and allows actors to determine the risk level of the organization's systems [RQ 2.1].

Several explanations are identified by each approach, ranging from operating and design flaws to economic pressure exerted by management, and to the existence of inherent systemic variation and unpredictable interactions. To avoid transgression of the defined safety boundary and to ensure that the systems remain in a controllable state, SAA reasoning brings about continuous monitoring of the process [SQ 3].

Similar to the approach conveyed by safety linear risk models, SAA methodologies refer to the existence of controls and barriers. These features have broader applicability, but their ultimate objective is to limit the behaviour of the system to keep it operating within the defined safety boundaries [RQ 2.1]. However, despite previous models and the literature addressing this concept, it is yet to be defined or established, leading one to assert that this is an overlooked subject. Appendix F highlights the research on safety boundaries.

Section 2.5 reviews the risk tools currently in use by the aeronautical industry and looks at what improvements need to be made to them. The objective is to understand the pros and cons of the risk tool features, and to define which are most suited to determining an organization’s risk exposure.

2.5 Risk Tool

Studying risk management, whether from the perspective of human factors (Stanton et al. 2018) or through the risk assessment lens (GAIN 2003; BSI 2019; Marhavilas et al. 2011), one is faced with plethora of evaluation methods and techniques. Deciding which is the most appropriate risk tool (or which could be adapted) for the complex, interactive environment of the aeronautical industry represents a considerable challenge, which goes beyond the premise of the current thesis. Beyond the adequacy of the risk tool, based on research into the use of systemic models, Underwood and Waterson (2013) found that usability, analyst bias and the difficulty of identifying the culprit for the accident (i.e. the incapacity to associate a cause-and-effect reason for the occurrence)[29] negatively influenced the acceptability rate. Therefore, rather than try to impose a completely new method, based on the data collected from the interviews, it seems more reasonable to identify the most commonly used risk tool in the industry and to propose the necessary corrections and amendments to this one – the risk matrix. This approach will allow a seamless transition to the new “Oyster Model” method [SQ 2].

2.5.1 Risk Matrices

Risk matrices are widely used in every field that requires a standardized approach to manage the risk faced by organizations (Thomas 2013; Duijm 2015; Townend 2019). Several international and industry standards make reference to risk matrices: NHS (2018, 2019), BSI (2018b, 2019), ICAO (2018b). Data collected in the field reflects this fact, where interviewees observed that risk matrices are generally the best known and most commonly used risk tool among aviation and healthcare practitioners. Hence, the following paragraphs review the features of the risk matrix and assess its ability to analyse and evaluate safety risks.

As a rule, the purpose of the risk matrix is to provide a perspective by obtaining and describing a measure of risk from an undesirable event by combining probability or

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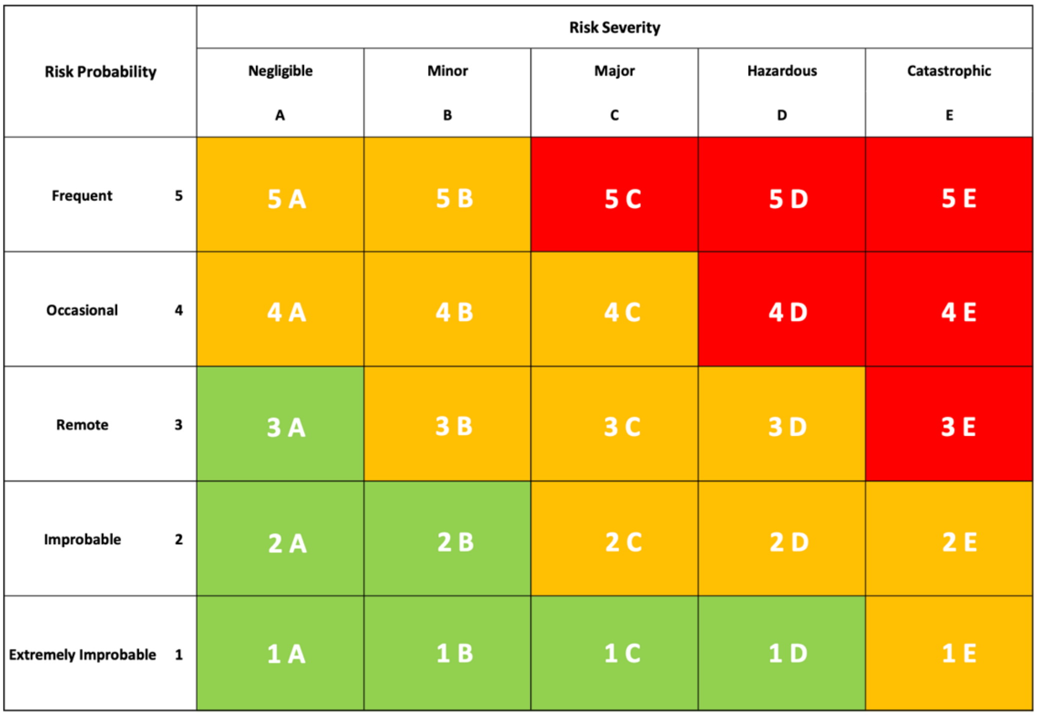
[29] A reflection of the reductionist stance of cause-and-effect inherited from Newton and Descartes.

frequency of an occurrence and the severity or consequence that may occur from it. Figure 2.10, below, illustrates the ICAO (2018b) risk matrix.



Risk Probability		Risk Severity				
		Negligible A	Minor B	Major C	Hazardous D	Catastrophic E
Frequent	5	5 A	5 B	5 C	5 D	5 E
Occasional	4	4 A	4 B	4 C	4 D	4 E
Remote	3	3 A	3 B	3 C	3 D	3 E
Improbable	2	2 A	2 B	2 C	2 D	2 E
Extremely Improbable	1	1 A	1 B	1 C	1 D	1 E

Figure 2.10 – ICAO Safety Risk matrix. Source: ICAO (2018b, p. 2-16)

The risk matrix appears in a variety of shapes and sizes, like for instance that presented in Figure 5.16. It should be acknowledged, therefore, that scale, terminology, scope and output might differ significantly among industry sectors, and the risk tool reflects this, even if matrices appear to be superficially similar (Thomas 2013; Townend 2019). For example, the oil and gas industry’s focus is on the probability of financial loss (Pritchard et al. 2010), whereas the commercial aviation and healthcare sectors focus on the probability of fatalities (ICAO 2018b; NHS 2019). Despite the differences, ultimately the objective of risk matrices is to rank, prioritize, analyse, communicate and assess risks that breach the organization’s risk tolerance (Thomas 2013; Elmonstri 2014; Duijm 2015; Townend 2019) [RQ 2.1]. The outcome of this process will orient the allocation of resources to manage the safety risks identified [RQ 3.1].

One of the reasons why risk matrices are so popular resides in the fact that they do not require complex data input, rendering their use quite intuitive. Moreover, they are a practical communicative medium to demonstrate the results of the risk analysis to the organization’s stakeholders (Thomas 2013). These characteristics lend them a “best practice” label that disregards their limitations. There is extensive research and discussion on the advantages and disadvantages of using risk matrices across a vast array of fields and from many experts in risk management (Cox 2008; Ni et al. 2010; Levine 2012; Flage & Røed 2012; Thomas 2013; Ball & Watt 2013; Duijm 2015). BSI (2019) also provides invaluable insight into its use. The list below summarizes the advantages and disadvantages identified in the extant literature [SQ 2.1].

Advantages:

- Moderately easy to use and quickly provides risk ranking (Flage & Røed 2012; Levine 2012; BSI 2019).
- Conveys a clear picture of the level of risk significance. When using quantitative scales, risk analysis provides management decision-making strong support in identifying where resources are most needed (Elmonstri 2014; Ale et al. 2015; BSI 2019).
- Offers a comparison between different types of risk severity (BSI 2019).
- Promotes open discussion and develops risk awareness (Smith et al. 2009; Townend 2019).

Disadvantages:

- Design – Difficulties in developing a consistent matrix (Duijm 2015; BSI 2019).
- Universal implementation – Matrices cannot take a corporate-wide perspective, scales must be adapted to each area of application (Elmonstri 2014; Duijm 2015; BSI 2019).
- Subjectivity – Qualitative scales have a high degree of bias, creating the potential for subjective decisions (Cox 2008; Smith et al. 2009; Hubbard & Evans 2010; Ni et al. 2010; Budescu et al. 2012; BSI 2019).
- Consistency – The equivalence between qualitative and quantitative risk analysis leads to assigning a higher qualitative risk rating to quantitatively lower risks or vice versa (Cox 2008; Levine 2012; Elmonstri 2014).
- Resolution power – Matrices assign equal ratings to quantitatively different risks. Moreover, unable to discriminate between negatively correlated frequencies and consequences, only a small amount of risk can be compared unambiguously (Cox 2008; Hubbard & Evans 2010; Ni et al. 2010; Levine 2012; Elmontsri 2014; Duijm 2015).

- Risk Aggregation – Concurrent risks cannot be aggregated (BSI 2019; Hubbard & Evans 2010).

From the list above it is strikingly obvious how the extant literature has concentrated on identifying and purposing corrections to the flaws identified. However, as observed during the interviews, the corrections have not repassed to the industry, which is surprising. This leads one to speculate that, having left the deficiencies unresolved, the models and theories do not adequately respond to practitioners' needs (Underwood & Waterson 2013). The following paragraphs peruse the flaws in order to build the foundations for the "Oyster Model" risk tool.

2.5.2 Design and Universal Implementation

The value of knowing the organization's risk tolerance cannot be overemphasized. For the organization to function cohesively, every single entity and department of it ought to be aware of what the appropriate level of risk is [SQ1]. Therefore, the layout of the risk matrix that is used to assess safety risk must reflect the organization's risk boundary or appetite (Duijm 2015), which is why so many researchers consider them as a risk-communicating tool (Smith et al. 2009; Flage & Røed 2012; Levine 2012; Ball & Watt 2013). However, as Kwak and Laplace (2005) and Kim et al. (2019) noted, this task presents challenges, since risk tolerance is rarely successfully conveyed within the organization [SQ. 1.2].

For airlines, the level of risk exposure is based on the organization's safety policy. Endorsed by the executive committee, this supports its safety objectives (ICAO 2018b). Such long-term targets are abstract in nature, and the "safety policy" as a tangible aspect of the organization's safety boundary, turns out to be difficult for employees to perceive (Sackmann 1991).[30] Several organizations use standard risk matrices throughout the entire organization (Ruge 2004; Duijm 2015). The use of a standardized risk tool allows both for the implementation of a common way of performing risk analysis and the existence of a common terminology. Nevertheless, concurrent with the associated difficulties in designing a consistent matrix, BSI (2019, p. 116) advises against extensive use across different areas of an organization,

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[30] Sackmann (1991) termed this type of formal knowledge "axiomatic knowledge", which is used to express company policies such as the "Management System Statement", "Safety Policy Statement", and the like, but these have little significance outside the hierarchy of the top management. This means that what is advocated at company level might not be understood and followed by lower ranking members of the company.

asserting how “It can be difficult to define common scales that apply across a range of circumstances.”

This subject is tackled by Flage and Røed (2012), who noted that what is acceptable for a department may not be adequate at the company level. Developing and designing a risk tool that is consistent across a diverse range of activities requires additional guidance, which will come at the expense of the simplicity of matrices and their user-friendliness (Duijm 2015). However, the presumption that a company’s risk profile is reflected therein, as the research revealed (see Characteristics of the Risk Tool at 5.2.1), proved not to be the case, since risk matrices are perceived as a ready-to-use product. Baybutt (2015) noted how the problem is compounded by the absence of guidelines that address the construction of risk matrices. Matrix construction is deceptively simple, but it is essential that the design reflect the specific risk tolerance of the user, which implies a specific calibration. In the same place Baybutt stresses how different types of severities must be evaluated using different scales and consequently under separate risk matrices [SQ 2].

Taking into consideration the drawbacks of matrices identified above and the implemented practice, where “risk tolerance levels are rarely communicated effectively throughout the firm”, Kwak and Laplace’s (2005, p. 693) caution concerning the promotion of risk tolerance is quite understandable and relevant to RQ 1.2. This is because their insight indicates that the matrices may need adjustment to become a better communicating tool and to reflect the organization’s safety boundaries [RQ 1.1].

2.5.3 Subjectivity

The ability to rank and prioritize risk is one of the main features the risk tool must comply with [RQ 2.1]. Risk measurement is associated with the scales used for the likelihood and severity axes. Risk matrices may present different types of scales: ordinal scales based on textual descriptions (e.g. “negligible”, “minor”, “catastrophic”), as illustrated in Figure 2.10, and numerical scales. Depending on the subject being analysed, the latter may be linear or logarithmic. Duijm (2015) recommended using the same scale – linear or logarithmic – for both the severity and likelihood axes.

The meaning of the ordinal scales should be clear and easy to interpret. This is a communications issue that Hubbard and Evans (2010) held up as highly relevant. For example, several ranking descriptors are considered synonyms when in fact they are used to establish different categories. Budescu et al. (2012) also found people consistently misjudge the probabilistic information conveyed by the scales, he identified significant discrepancies in the understanding of the statements; for example, a misperception of the meaning of probability and severity. This type of misinterpretation is known as "illusion of communication" and is not an error exclusive to laypeople; it also applies to experts, namely safety specialists. It is not uncommon for people during the decision-making process to be affected by cognitive bias or illusions, described by Kahneman et al. (2011) as "heuristics and biases".

As Smith et al. (2009) have demonstrated, analysts using risk matrices follow a pattern described by prospect theory,[31] whereby users tend to overestimate small probabilities and underestimate large ones, and exaggerate the consequences. As several other researchers note, cognitive biases are also very difficult to overcome, as they offer quantitative scales [RQ 2.2] as a solution to mitigate the subjectivity imposed by users' own preconceptions (Hubbard & Evans 2010; Leveson 2015). However, it is argued that the use of statistics in an industry characterized by a limited number of accidents is inappropriate, due to the infrequent nature of occurrences (Leveson 2015; Duijm 2015; Nisula 2018). Thus, the constraints posed by either approach – qualitative or quantitative – seems to offer no satisfactory method as a solution. However, the perspective put forward by the "Risk Aggregation" section (at 2.5.5) minimizes the threat from existing biases.

Risk matrices use "ordinal scales" to measure severity and probability, but in order to preserve the meaning of the two terms, relational comparisons are the only allowable operations: for instance, "high consequence" represents an outcome greater than "low consequence" (Stevens 1946).

Based on Stevens' seminal mathematical work, Levine (2012) argued that the only instance in which an analyst is capable of producing a defensible relational judgment about two risks is when a risk is seen as higher both in terms of likelihood and consequence. In practice, the constraints associated with "ordinal scales" will limit the ranking capacity associated with the qualitative method [RQ 2.2]. This restriction, which is not addressed by ICAO (2018b), is mentioned by the BSI (2019, p. 116) norm, which states that: "it is difficult to combine or

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[31] Prospect theory was developed by Tversky and Kahneman (1992).

compare the level of risk for different categories of consequences”. This might explain the subjectivity of, and the significant variation in risk assessment obtained by, different analysts. This is another point BSI flags up on the very same page, the norm that “use [of matrices] is very subjective and different people often allocate very different ratings to the same risk”.

As Ni et al. have identified, that relational judgment issue is also obscured when different safety risks share the same level or the same cell, on qualitative or on a semi-quantitative matrix,[32] respectively. This situation, which Ni et al. termed “risk ties”, results from the “non-meticulous classification of risk index” – namely, the existence of only three or four colours (2010, p. 1270).

Using the four basic arithmetical operations, Ni et al. (2010) demonstrated a form of obtaining a numerical risk from an ordinal category of numbers. However, to comply with the rule defined by Levine (2012), the results must ensure that the obtained risk function will be a monotonously increasing one. This means that if severity X is higher than severity Y and probability W is superior to probability Z, then the risk (X, W) ought to be higher than the risk (Y, Z), whatever the combination of X, Y, W and Z are. As noted by Duijm (2015), the operation of multiplication and addition complies with the monotonous rule, while division and subtraction do not. Moreover, Duijm observed that the multiplicative operation is more suited to matrices that represent expected loss and have linear scales, which is the case for those used in the commercial aviation industry. In contrast, the additive operation is more suited to logarithmical spaced scales. However, as to the consequences of risk, it is not common to implement a logarithmical approach to loss, specifically loss of human life; furthermore, organizations do not hold enough data to account for their risk at such a scale. This is exactly why the current research will concentrate on the use of the multiplicative operation. Nevertheless, in different contexts, namely the regulatory agencies, one might opt for logarithmical scales, which would produce consistent results as demonstrated by Levine (2012).

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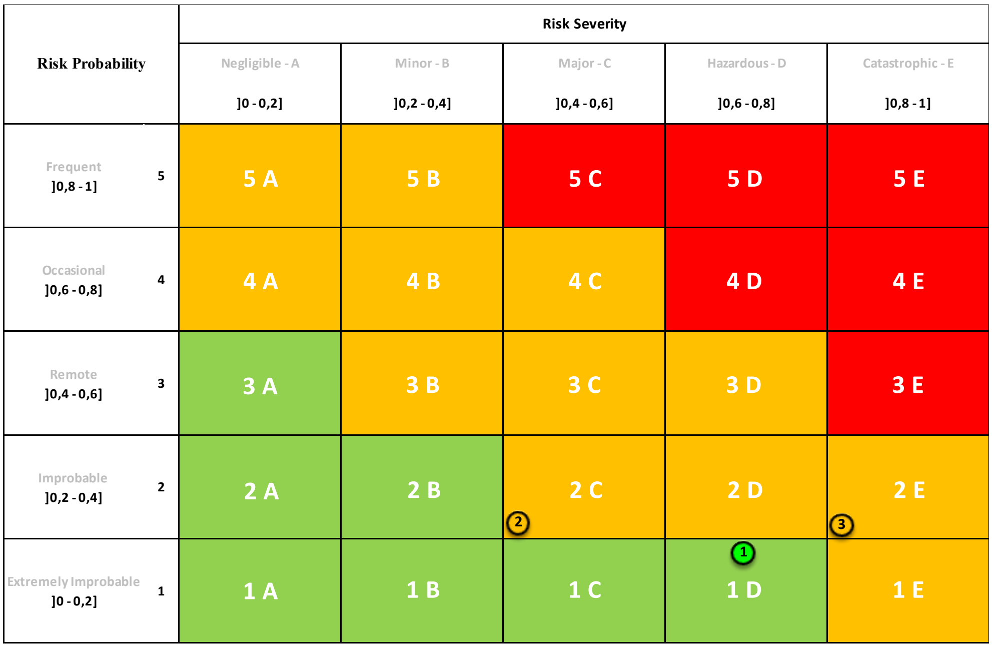
[32] “Qualitative assessment defines consequence, probability and level of risk by significance levels such as ‘high’, ‘medium’ and ‘low’, may combine consequence and probability, and evaluates the resultant level of risk against qualitative criteria. Semi-quantitative methods use numerical rating scales for consequence and probability and combine them to produce a level of risk using a formula. Scales may be linear or logarithmic, or have some other relationship; formulae used can also vary. Quantitative analysis estimates practical values for consequences and their probabilities, and produces values of the level of risk in specific units defined when developing the context” (BSI 2010, p. 13).

Applying the multiplicative operation would transform the traditional qualitative approach into a semi-quantitative method to measure and compare risks associated with each hazard [RQ 2.2]. However, it is not possible to obtain a ratio scale by multiplying ordinal cells such as “remote probability” with “major severity”. Nevertheless, the strict rules presented by Stevens (1946) have been challenged by two researchers, specifically Velleman and Wilkinson (1993) and Duncan (1959, p. 84). The latter states that “both geometric and the arithmetic means are legitimate […] for ratio scales (arbitrary units)”. Thus, as Cox (2008) proposed, when exposing the logic and the mathematical limitations exhibited by risk matrices, one can develop a matrix using two quantitative ratio scales to represent the probability and the severity of a safety risk. Figure 2.11, below, represents this.



Risk Probability		Risk Severity				
		Negligible - A]0 - 0,2]	Minor - B]0,2 - 0,4]	Major - C]0,4 - 0,6]	Hazardous - D]0,6 - 0,8]	Catastrophic - E]0,8 - 1]
Frequent]0,8 - 1]	5	5 A	5 B	5 C	5 D	5 E
Occasional]0,6 - 0,8]	4	4 A	4 B	4 C	4 D	4 E
Remote]0,4 - 0,6]	3	3 A	3 B	3 C	3 D	3 E
Improbable]0,2 - 0,4]	2	2 A	2 B	2 C ②	2 D	2 E ③
Extremely Improbable]0 - 0,2]	1	1 A	1 B	1 C	① 1 D	1 E

Figure 2.11 – ICAO Safety Risk matrix with ratio scales. Source: ICAO (2018b, p. 2-16)

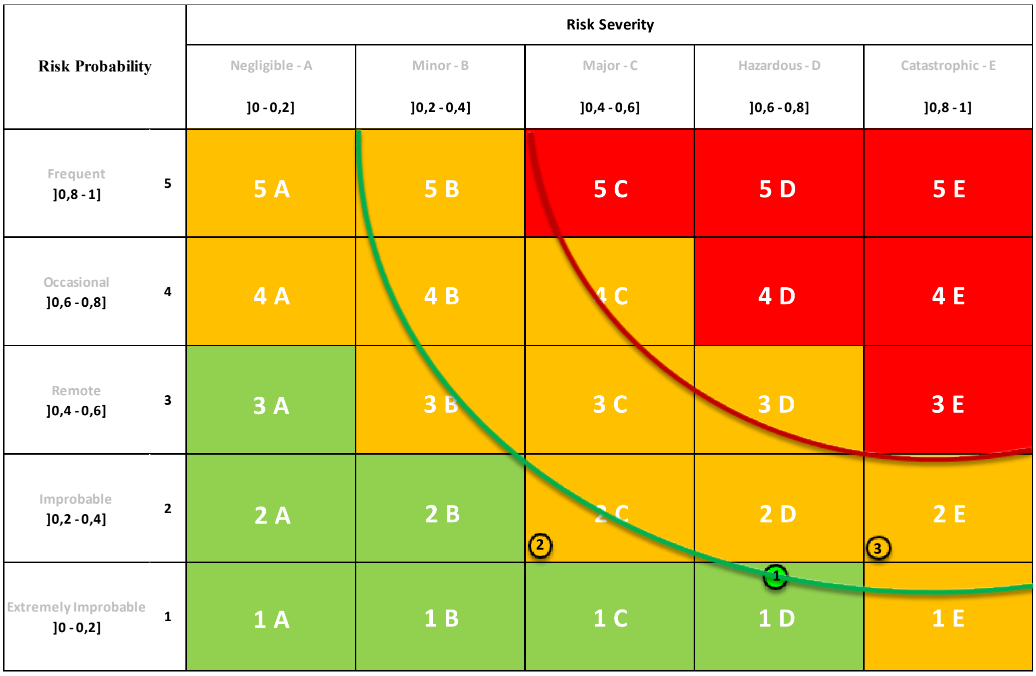
The study of semi-quantitative methods, specifically of matrices, is not a new issue, since academia in some ways has already felt the difficulties brought about by the vagueness of some definitions, as demonstrated by Budescu et al. (2012). In proposing solutions to overcome the drawbacks of matrices, several researchers (Levine 2012; Markowski & Mannan 2008; Duijm 2015) have addressed semi-quantitative methods using risk matrices. However, despite their work, only a few have been used and tested within industry, namely within the commercial aviation industry, which might configure a gap between academia and industry in general, as the research from Underwood and Waterson (2013) suggested.

2.5.4 Consistency and Resolution Power

For the sake of reliability of method, which Cox (2008, p. 501) defined as the “logical compatibility of risk matrices with quantitative risks”, the outcome of a safety-risk analysis should result in an identical outcome, whether using a qualitative, a semi-quantitative or a purely quantitative tool. For Cox, in order for it to be equivalent to a quantitative interpretation, matrices must comply with three axioms: “weak consistency”, “betweenness” and “consistent colouring”. Cox defines the axioms as:

- Weak consistency – A risk in the top-risk category (red cell) represents a higher quantitative risk than one placed in the bottom-risk category (green cell).
- Betweenness – A positively sloped segmented line, which starts at a lower risk category (green cell) and ends on a higher risk category (red cell), will cross at least one intermediate risk category (yellow cell).
- Consistent colouring – Risks with a similar quantitative amount of risk should ideally share the same colour.

Implementation of the three axioms will be a challenging task if it is to comply with the consistent colouring axiom. Although, as Cox (2008) recognized, on a discrete matrix, this condition is impossible to achieve, since the quantitative “iso-risk” contours will not follow cell boundaries, and any cell will be divided into two areas, one with less risk than the other. For example, the safety risk (probability × severity) identified by the number 1 green spot (0.17 × 0.70) in Figure 2.11 (above) is qualitatively classified as an “acceptable risk” whereas the one identified by the yellow spot number 2 (0.22 × 0.42) is qualitatively classified as “acceptable with mitigation” measures; however, the former has a higher quantitative risk (0.12) than the latter (0.09). This problem occurs when two risks are negatively correlated – when the increase of probability implies a decrease of severity and vice versa. This paradox is easily explained when the “iso-risk” contours are superimposed onto the risk matrix, as presented in Figure 2.12 (below). The “iso-risk” curves are rectangular hyperbola iso-risk lines where the product of probability and severity is a constant (Smith et al. 2009); in Figure 2.12, the lines were chosen arbitrarily, with the sole purpose of highlighting the gap between the two spots.



Risk Probability		Risk Severity				
		Negligible - A]0 - 0,2]	Minor - B]0,2 - 0,4]	Major - C]0,4 - 0,6]	Hazardous - D]0,6 - 0,8]	Catastrophic - E]0,8 - 1]
Frequent]0,8 - 1]	5	5 A	5 B	5 C	5 D	5 E
Occasional]0,6 - 0,8]	4	4 A	4 B	4 C	4 D	4 E
Remote]0,4 - 0,6]	3	3 A	3 B	3 C	3 D	3 E
Improbable]0,2 - 0,4]	2	2 A	2 B	2 C	2 D	2 E
Extremely Improbable]0 - 0,2]	1	1 A	1 B	1 C	1 D	1 E

Figure 2.12 – ICAO Safety Risk matrix with ratio scales and “iso-risk” contours. Source: ICAO (2018b, p. 2-16)

Levine’s (2012) argument is now understandable: an analyst, in producing a defensible relational judgment about two risks, must make sure that one of them is ranked on a higher cell in terms of both likelihood and consequence. In this case, the risk represented by the number 2 yellow spot in Figures 2.11 and 2.12, would need to be placed in the position of the number 3 yellow spot (cell 2E), to ensure that it both matches the quantitative and the qualitative assessment results and can be compared correctly with the risk represented by the number 1 green spot. Using the traditional design for risk matrices, only 12.5% of the risks will be ranked unambiguously (Cox 2008). The drawbacks identified by Cox (2008, p. 500) lead him to conclude that:

> “[…] it is not necessarily true that risk matrices provide qualitatively useful information for setting risk priorities and for identifying risks that are high enough to worry about and risks that are low enough to be neglected or postponed.
>
> [...] risk matrices can indeed be very useful if probability and consequence values are positively correlated, they can be worse than useless when probability and consequence values are negatively correlated.”

The conclusions above elicited from a 2 × 2 matrix seem to be correct when considering risk matrices with a discrete design (see Figure 2.10). However, with a continuum constructed – provided by “iso-risk” contours and based on a ratio scale – it is possible to discriminate safety risks, even if they fall into the same cell (known as “risk ties”) and whether positively or negatively correlated (as the case under analysis – green and yellow spots), and to set the priorities among the risks (Duijm 2015). The limitations of resolution imposed by the reduced number of different colours, an inherent disadvantage of risk matrices, vanishes with the implementation of the iso-risk contours.[33] This aspect would seem to be relevant as well as important, since it demonstrates that safety-risk matrices, based on a semi-quantitative method, might be improved [RQ 2.2], and suggests that the way risk matrices are presented by the ICAO represents a gap in the literature. The iso-risk contours bring other advantages too, which the next section (2.5.5) highlights, and which is illustrated in Figure 2.13.

2.5.5 Risk Aggregation

Using insights brought by complexity theory and systems thinking and bringing alongside these the explanatory perspectives offered by the systemic methods discussed in section 2.4, it seems appropriate to introduce a risk tool capable of processing risk in an aggregated fashion.

In terms of expressing severity, aggregation can take form by adding the different type of impacts caused by a single threat – safety, environmental, financial, reputational – or by combining the risk severity from a set of threats that compete in the same undesirable event (Duijm 2015). The former approach is discussed by Flage and Røed (2012) and Baybutt (2015), who advised doing it in separate risk matrices. BSI (2019) also warned of the challenges of adding different risk categories in terms of severity.

Beyond the difficulties of comparison, which Duijm (2015) also highlighted, the single-risk approach does not reflect the ontological perspective brought by complexity theory and systems thinking. Risk exposure cannot be obtained by studying a single threat individually, even though accounting for the different dimensions, since safety risks interact dynamically and between them present emergent, adaptive, evolutionary, and non-linear relationships (Cilliers 1998; Snowden & Boone 2007; Meadows 2008; Checkland 2012).

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[33] The Borda count methodology, used by Ni et al. (2010) to promote further ordering, uses the severity and probability scales as independent scores. Nevertheless, some arrangements may lead to equal Borda counts. The methodology is not without flaws, when one considers how it gives an equal weight in both scales.

Nisula (2018) proposed a logarithmic scale incorporating three dimensions of severity:[34] human loss, environmental and material/financial damage. To be able to aggregate and compare the total severity generated by individual threats, each dimension's outcome is converted into a numerical figure. Nisula's approach (2018, p. 121) states that: "[T]he reference scale is about the number of fatalities […] and the anchor point is one fatality corresponding to 10,000 points. All other types of severity are transformed into points so that the same single scale can be used." Risk indexes to account for the number of deaths is not new (Fischhoff et al. 1984; Chilton et al. 2002); however, placing human life on the same stand as material and financial goods, there will be occasions when Nisula's (2018) severity scale values a specific risk at the expense of human life. While the approach overcomes the challenge brought by comparing different risk dimensions, it nonetheless has potential to raise ethical[35] and appraisal challenges (Ale et al. 2015).[36] Baybutt (2015, p. 165) criticized the existence of scales that establish logarithmic factors to compare impacts on human beings – ranging from hospitalizations to fatalities –, asserting that the practice is "highly subjective and involves a value judgement that will vary for different people". Therefore, as noted by Flage and Røed (2012) and by BSI (2019), within commercial aviation, it would probably be more plausible to develop a severity scale that accounts uniquely for the safety-risk exposure in identifiable outcomes or levels of severity, independently of the total number of casualties and financial losses.

Aggregation presents another challenge in the method it uses to calculate the number of occurrences – in terms of either probability or frequency – of a threat materializing. Up to this point, the concepts of likelihood, probability and frequency have been used interchangeably. However, in ultra-safe industries like commercial aviation, characterized by a minimal number of occurrences, where accidents account for less than one event per 10 million operations (Amalberti 2001), statistics or quantitative methods do not seem to be the most appropriate measures to reflect risk exposure. In this regard, Duijm (2015) affirmed that

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[34] Nisula (2018) considered the inclusion of more than three dimensions of severity, converting them with the same, established unit of points.

[35] "[E]valuating life is inherently problematic. It is problematic as it presupposes an already existing framework by which to judge all instances of life. And as Nietzsche rightly observed, to be able to evaluate something without prejudice one has to occupy a position from where everything is visible; a position elevated above or beyond the social world. In a way then, an impartial evaluation of life seems impossible from a human point of view" (De Lucia Dahlbeck & Dahlbeck 2015).

[36] "As put in landmark (Dutch) judgements about airports, in which fatality figures were given alongside noise levels: such a presentation seems to imply the answer to the question of – 'how many dB a dead person is worth?'" (Ale et al. 2015, p. 236).

because of their infrequent nature, events do not lend themselves the characteristics to be described statistically as the number of accidents, which is why many practitioners prefer to use ordinal scales to express uncertainty. In the same vein, Nisula (2018, p. 13) asserted that: “probability is only one way to try to address uncertainty, and often not the recommended one”, while Leveson (2015) stated that probability is not suitable within highly reliable systems,[37] and identifies a myriad of accidents that took place although probability calculated a less than 10^{-9} chance of their occurrence. Another example came from Follensbee’s (1993) report on probabilistic risk assessments, in which five major transport accidents and one serious incident, where the probabilities indicated less than 10^{-9}, were identified. Hence, from these examples, one can speculate that numerical probabilities appear unsuited to the environment of the commercial aviation industry [RQ 2.2]. Therefore, the second axis should be transformed into a frequency measure as several researchers have advised (Ale et al. 2015; Baybutt 2015). Were this the case, events could be replaced by precursors, since accidents and serious incidents are scarce in commercial aviation. The EASA promotes replacement of events for precursors, once they can be used as a proactive measure of risk exposition (EOFDM 2020). The same reasoning could be used if one uses the insights offered by the FRAM method, whereby the system’s performance variability can be used to anticipate one’s own personal risk exposure (Hollnagel 2012). Figure 2.13, below, illustrates the severity and frequency concept discussed above. Here, the reduced number of identifiable risk-exposure levels for severity and objectively accountable frequency of events are judged as a form able to reduce the cognitive biases identified under “Subjectivity” at section 2.5.3.

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[37] Leveson (2015) identified well-known accidents where the probability was calculated to be less than 10^{-9}. These include Fukushima, Deep Water Horizon, Chernobyl, the Therac-25 accidents, Columbia and the Challenger, among others.

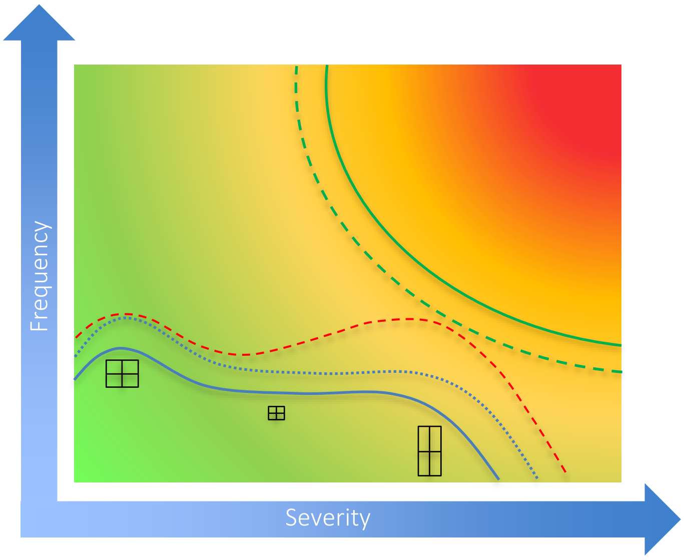

Figure 2.13 – Safety Linear Risk matrix with ratio scales using a continuum "iso-risk" pattern

Figure 2.13 represents an abstract example of a risk tool developed from generating a full set of iso-risk contours. The lower left-hand corner represents the point of lesser risk, whereas the top right-hand corner is the area of higher risk. Opposed to the risk matrix of Figure 2.10, risk uncertainty is not limited to the bounds of each category. The uncertainty of each threat is represented by differently sized and shaped boxes, which incorporate a variation in severity and frequency of occurrence, following Duijm (2015) recommendation. Although regarding a different industry (grocery supply), Stratton (2012) offers relevant insights over variability and uncertainty concepts.

As risk exposure is able to aggregate more than one threat – represented by the solid blue line –, total uncertainty might be expressed as an increase (or decrease) in risk exposure, represented by the dashed blue line, which in this specific example shows an increased exposure to risk. With the ability to monitor risk continuously, the tool will be capable of alerting analysts to potential deviations or, in other words, exceedances of the safety boundaries. Opposed to the static features of the risk registers (Ale et al. 2015; EASA 2015), as illustrated in Appendix G, the dashed red line represents the result of continuous monitoring within a specific timeframe. The longitudinal monitoring feature, which has been proposed to define risk, is in line with the stance espoused by complexity theory and system's thinking, whereby continuous monitoring brings about the explanatory and predictive power of systems behaviour (Plsek & Greenhalgh 2001; Senge 2006; Dekker 2011). Furthermore, as Rasmussen's (1997) framework espouses, this type of safety tool has the potential to allow analysts to make the safety boundaries explicit – seen in the dashed and solid green lines, which constitute the buffer zone,[38] and provides an opportunity for the more judicious management of available resources. Thus, on one hand, the model will increase awareness around risk exposure and, on the other, increase the system's efficiency, thereby reducing the number of barriers that are needed to mitigate the threats.

2.5.6 Risk Tool Summary

The risk tool of Figure 2.13, developed from a continuous set of iso-risks, is derived from the use of multiplicative *ratio* scales. It differs significantly from the traditional risk matrix, its most identifiable features being the following. It strongly promotes consistency between qualitative and quantitative risk, as threats can be plotted in their exact exposure location. The continuum feature associated with the iso-risk contours circumvents the resolution limitations of traditional risk matrices, whereby traditionally risk discrimination (ranking and prioritization) was dependant on a restricted number of colours and featured an inability to discriminate negatively correlated threats. Additionally, uncertainty is not limited to each row and column of the matrix, and it would be possible to customize the risk tool for each threat. The tool can be adapted to specific risk tolerances or exposures (Baybutt 2015) to reflect the characteristics of the scenario being analysed. However, should practitioners persist in their use of ordinal scales, as Duijm (2015) has asserted, the assignment of severity and frequency will remain subjective and the consequence scale will have a lower resolution to discriminate minor injuries from multiple fatalities, which is an issue Nisula (2018) has also tackled.

Risk aggregation allows a threat-integrated analysis to develop into a "risk-exposure" map capable of conveying a high degree of explicit explanatory power. Based on precursor analysis, practitioners would then be able to proactively manage the available resources and be better equipped to maintain control of the threats [SQ 3.2]. Moreover, aggregation of contributory factors will allow organizations to monitor hazards identified by regulators and to transform data into manageable and workable indicators.

As identified in both the linear risk and systematic models, organizations protect themselves against threats by implementing mitigation measures. Leveson (2004) identified these as

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[38] The buffer zone resonates with the concept conveyed by Rasmussen's (1997) framework. The marginal and the (un)safe performance boundaries act to warn of a drift in the system, allowing the risk tool to cope with disturbances and pressures.

controls and barriers; Rasmussen (1997) viewed them as opposing forces; while Dekker (2011) saw them as measures to avoid decrementalism and drift. Therefore, somehow, the safety-risk tool must account for all the features implemented in the field [RQ 2.2]; for, should it fail to do this, the comparison with the defined safety boundary will not reflect the reality and nor will investment decisions be efficiently oriented. Moreover, to develop a continuous safety-enhancement routine as required by the ICAO (2018b), the effectiveness of these measures ought to be evaluated against the daily occurrences (BSI 2018b). The current research has verified this gap with the majority of the other research on the subject. The authors seem to give little or no consideration to the defensive measures implemented in the field, or to the exposure level or safety boundary, yet these factors have a significant impact on the level of risk exposure that needs to be accounted for during the risk analysis.

The cultural factor ought to be integrated into a more comprehensive and wider-reaching risk analysis, particularly as this is recognized universally as a major factor in the risk exposure of an airline (Rasmussen 1997; Ale et al. 2015). BSI (2018b, p. 4) also takes this stance, asserting that “Human behaviour and culture significantly influence all aspects of risk management at each level and stage.” Although this fact is recognized by every single researcher that studies risk management, and each gives due consideration to it, they do so by separately discussing the subject so that the final risk analysis ends up not accounting for it. This represents a gap in the risk-management process [SQ 4]. Hence, the risk tool must be capable of handling the influences exerted by safety culture [RQ 2.1]. Section 2.6 revisits the subject of safety culture to look at what its contribution might offer risk management.

2.6 Safety Culture

2.6.1 Introduction

An article by Bouwer et al. (2019), about how to transform an airline, observed how preparedness for the competitive environment of the industry requires carriers to be more agile, efficient, and more able to improve their cross-functional decision-making processes more than ever before. These same authors warned that in order to compete “they [airlines] must also tackle some of their most deeply ingrained behaviours”. Airlines that invest in cost-cutting measures and cultural aspects will outpace those that focus on performance measures alone. Hollnagel (2012, p. 73) took a not dissimilar view, stating how performance can be influenced via different means, namely "effectiveness of communication, authority gradient (lack of), trust, organizational memory and organizational culture."

The important role that culture plays in risk management, specifically how it influences the behaviour of every actor, poses the following question: Do analysts take into consideration "safety culture" when analysing a specific risk? Or, from a different perspective: Is the risk-management outcome influenced by the organization's (safety) culture? Although the majority of the studies scrutinized recognize that culture has a significant impact on the organization's risk exposure, in the main, the safety-management processes did not consider the factor systematically. As the analysis of risk is dependent on each analyst's personal sensitivity, it is important to explore this illusive concept, which is seen as underpinning aviation safety and forms the keystone of the European Aviation Safety Agency (EASA 2018b) and the International Civil Aviation Organization's (ICAO 2013a) safety-management systems (SMS). In practical terms, what impact does safety culture have on risk management? [SQ 4] The shortcomings presented by the studies are not new and have been around for a long time. Lee (1995) has argued that the practical usefulness of safety culture as a concept to obtain safety-related improvements has not yet been established in offshore environments. Reflecting the difficulties in operationalizing the concept, Kirwan et al. (2019) published an article that investigated the results of a survey performed over four years. In it, the authors raised a [provocative] question about the purpose of the safety culture assessment, asking if "there [is] something credible, tangible and manageable [stakeholders] can do with [it], or is this simply meant to be inspirational?"

The purpose of the current research is not to develop a comprehensive study of the theories that support safety culture; instead, the objective is to perceive how safety culture could be managed from a risk-management perspective. Thus, in the paragraphs that follow, an attempt will be made to understand what the main constituents of safety culture are, how it emerged and has evolved, and how practitioners can make use of such data – specifically, how risk management could benefit from taking account of safety culture.

Section 2.6.2 surveys evidence from the extant literature to understand the important role safety culture plays in risk-management activities.

2.6.2 Safety Culture as a Sustainable Factor

The concept "safety culture" was first used by the International Atomic Energy Agency (IAEA) to explain safety breaches[39] (Cooper 2002). The concept became increasingly popular after publication of the two safety series publications by INSAG (1991). Although its purpose was for use in this specific context, interpretation of "safety culture" was left open for each stakeholder to define and there was an absence of guidance about how safety culture should be managed. Efforts to standardize its application were made in several industries, namely, the offshore, nuclear and shipping industries (Cooper 2002; IAEA 1991). Since its inception, the "safety culture" concept has generated a lot of interest from industries that must consider the risk-management component of their operations (WHO 2009; RSSB 2003; INSAG 1991).

When applying the concepts of "safety culture" to the aviation industry, it is no exception, and follows the same philosophy. The recently revised ICAO risk-management framework dedicates a whole chapter to safety culture. According to its understanding, safety culture mirrors how employees perceive and manage safety [SQ 4]. The degree to which safety values are enshrined in the behaviour of management and operational staff, it is suggested, is impacted directly by how well organizations implement their safety programmes (ICAO 2018b).

A positive safety culture, it is suggested, is the foundation of a robust Safety Management System (ICAO 2018b; Roelen & Klompstra 2012). This culture contributes directly to the reduction of accidents and serious incidents; it ensures that safety matters receive appropriate attention; it increases employees' awareness of safety issues; and, ultimately, it reduces the organization's risk exposure (ICAO 2018b). In his seminal work on the "organizational accident", Reason (1997, p. 16; 2016) suggested that corporate culture[40] affects management decisions, "[…] processes will be coloured and shaped by the corporate culture, or the unspoken attitudes and unwritten rules concerning the way an organization carries out its business", he says. Moreover, in his findings, Cooper (2002) argued that there is strong evidence to support the thesis that risk perception is culturally determined, and to suggest that

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[39] The IAEA advisory body and the International Nuclear Safety Advisory Group (INSAG) carved out the term for the post-accident Chernobyl summary report. The agency published the report as Safety Series no. *75-INSAG-1*, in 1986, and two years later the concept was further elaborated as the third *Safety Series* publication (INSAG 1991).

[40] The concepts of corporate culture and organizational culture are synonyms used interchangeably.

all levels of management ought to be involved in the risk assessment process.

A supporting finding came out from the longitudinal survey carried out by Gravina et al. (2019) in a chemical manufacturing plant, where interventions at the employee behaviour level had a positive impact on reducing injuries among employees. These findings reflected the perception of ICAO (2018b, p. 3-1) which stated that a positive "safety culture has a direct impact on safety performance." A different approach to the same topic is seen in the research about the criminalization of safety culture by Lawrenson and Braithwaite (2018). They also identified poor safety culture as a key contributing factor in high-profile accidents. However, as Roelen and Klompstra (2012) suggested, the constituents of "safety culture" are still not entirely clear. And, having found 18 different scales to measure safety climate, Flin et al. (2000) held similar concerns about the clarity of the concept.

For gaps to exist between scholars and practitioners is not an uncommon occurrence. In research about the implementation of a sustainable safety culture across the railway industry in Great Britain, the recommendations produced by Cross & Papayannakos (2017) suggested that further detail and clarity about how to implement "safety culture" was needed. They recommended that values to support safety culture ought to form part of the organization's vision, and that they should be incorporated into each role and support the rest of the organization's activities.

With evidence to support the premise that safety culture should be viewed as one of the most influential and sustainable factors of managing the risk exposure of an organization, section 2.6.3 will attempt to characterize its features. The objective is to understand, measure and manage it, as safety culture will play a major role in the risk-management model that results from the current research.

2.6.3 Understanding Safety Culture

The concept of "culture" embraces a vast array of disciplines and backgrounds. Its widespread use and different ontological faces make it an elusive and, therefore, challenging concept to understand. As Mutch (2008) noted, the meaning of "culture" has shifted over time: used in the past to describe the "high culture" associated with classical music and painting, currently, in its democratized form, it is associated with ideas and meanings.

As Hofstede et al. (1990) explained the "corporate culture" debate emerged in the management literature in 1964. Based on the notion of an "organizational climate", it entered academia in 1979 in an article by Pettigrew[41] entitled "On studying organizational cultures"; and subsequently, in 1982, the term was used in the seminal book by Peters and Waterman, *In Search of Excellence.*[42] This boosted the subject's academic credentials, and ever since then the subject has generated an extensive literature.

Safety culture can be seen as a subcomponent of corporate culture (Cooper 2000, 2002), which in any high-risk industry should be understood and viewed as a top priority (Cullen 1990). As a consequence, the concept should be seen as the dominant characteristic of an organization's corporate culture (Cooper 2002). Further interesting insight into the concept's meaning is offered by Sinha (2008), who highlights how focal concerns in relation to professional roles, and the interactions of the workforce, make up the constituent elements of what is the organizational corporate culture.

Nevertheless, there are dissenting positions: Apostolakis & Wu (1995), for example, argued that safety culture cannot be dissociated from corporate culture. In their research looking into safety culture at a nuclear power plant, they suggested that it would be more appropriate to adopt a concept of "quality culture". For these authors, working in a highly structured and standardized environment, where plant operation and power production are as important as safety, they did not feel it was possible to separate the two concepts. Therefore, they argued, the broader subcomponent of quality culture should dominate. Although, allegedly, their findings stand opposed to the established knowledge (Lawrenson & Braithwaite 2018; Reason 1997), their research suggests that the predominant component could be representative of the established corporate culture. This is a highly relevant conclusion for the current research, since the research interviews showed that safety culture was a paramount concern of the commercial aviation and healthcare industries.

The accepted view is that safety culture is a concept which affects how risk is managed at all levels of an organization, specifically in the areas of the identification, assessment and mitigation of risk (Pidgeon 1991). Culture, therefore, is conceptualized as a component that affects the gaps identified by the research [SQ 4], rather than taking the traditional view that claims culture is the binding agent for the entire organization (Cooper 2002).

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[41] Pettigrew, A., 1979. On studying organizational cultures, *Administrative Science Quarterly*, 24(4), Qualitative Methodology, pp. 570–581.

[42] Peter, T. and R. H. Waterman R. H., 1982. *In Search of Excellence*. New York: Harper and Row.

Before advancing the discussion, it is important to make a distinction between “safety culture” and “safety climate”. The latter of these is a concept that regularly turns up in the literature, but, as Wiegmann et al. (2002) noted, the term has the potential to generate confusion with “safety culture”, as there are a lot of similarities between them. Although some definitions of “safety climate” are identical to safety culture, and Guldenmund (2000) provided a wide range of these, there are certain differences that should be underlined: Safety climate refers to a psychological perception of the level of safety that is confined to a specific period, associated with intangible matters, and relates to a mental snapshot assessment. It is, therefore, a relatively unstable concept that is subject to variation. Supported by the definitions used by several different industries, Wiegmann et al. (2002, p. 10) derived a general understanding that:

> “Safety climate is the temporal state measure of safety culture, subject to commonalities among individual perceptions of the organization. It is therefore situationally based, refers to the perceived state of safety at a particular place at a particular time, is relatively unstable, and subject to change depending on the features of the current environment or prevailing conditions.”

This is to say that safety culture could be understood as an enduring perception of the organization by itself, whereas safety climate is seen as an individual short-term state of safety culture that is influenced by specific circumstances. Using an analogy, safety culture may be seen as a film (of the organization), while safety climate should be perceived as a still from that film. The safety climate can be identified, confined, at a certain level, which lends it a tangible focus to assess the organization’s safety culture characteristics (Loughborough University 2002; Health Foundation 2011). Therefore, to incorporate this key concept into their risk-management process, organizations must track the safety climate continuously, ultimately to understand and perceive its safety culture [SQ 4].

Taking the ontological perspective brought by critical realism, the safety climate is value-cognizant (Krauss 2005), leading reality to be subjectively construed by each agent and thus conceding to the existence of multiple interpretations, which are imperfectly acquired (Healy & Perry 2000). Safety culture is construed in a hierarchical fashion, being the aerial view of the reality of the organization produced by each entity that exists in lower layers; safety climate, on the other hand, gives a temporal perspective that results from the interaction between entities, is mediated by an array of mechanisms, and is influenced by the surrounding context (O’Mahoney 2011). Although representing different perspectives, and therefore realities, safety climate and safety culture ought to be seen as two different layers of the same reality.

Other researchers have explained culture by using a different narrative layer, making a distinction between visible and subconscious traits. Ahmed (1998) perceived culture as having two distinct layers: an explicit and an implicit one. The explicit layer of culture is visible to an outsider, is associated with symbols and artefacts, and manifests through standard behavioural patterns, while the implicit layer of culture is related to the beliefs, values and principles that are enshrined within the organization and which determine people’s behaviour (Sinha 2008). In their study, Hofstede et al. (1990) suggested that symbols, and heroes – which includes people who are seen as models of behaviour – as well as rituals – which can be subsumed as “daily practices” – also represent the visible external layer of the organizational culture. Thus, although visible, explicit culture might not be perceived in its entirety by outsiders. At the other pole, implicit culture has an unconscious existence that is rarely discussed by peers, but as Hofstede et al. (1990, p. 291) asserted, it is “demonstrated in alternative conduct”.

In order to emphasize the extent to which it is easier to change the values of explicit culture, such as when adapting the organization to a new standard, it is important to differentiate between the explicit and implicit traits of culture. When trying to sensitize employees to risks for instance, their attention can be drawn and certain behaviours can be elicited through education. At the level of an implicit culture, however, a change would hardly be noticeable.

As Hofstede et al. proposed in their empirical study (1990, p. 311), “shared perceptions of daily practices” determine and shape the implicit culture of the organization. This new standpoint is essential in the context of the current research, as leaders will take an essential role in positioning the organization to deal with risks [SQ 1, SQ 3 and SQ 4]. To Hofstede and his co-authors, “key leaders’” (and founders’) shared practices, namely their conventions, habits, mores, and usages or customs, are essential to moulding corporate culture, and ultimately to shaping safety culture.

Several other researchers agree on the influential role played by leaders, affirming that employees are influenced by management’s commitment, personal involvement and adherence to established safety procedures and rules (Zohar 1980, 2000; Kapp 2012;

Leemann 2016). Emphasis on issues like quality versus efficiency, working safely versus working rapidly – the old jargon: "Safety works until we are busy" –, and management's approach to errors and violations, set the tone and create the link between safety climate and employees' attitudes and behaviours (Fogarty & Shaw 2010; The Royal College of Nursing 2020).[43]

Safety climate and (consequently) safety culture is, then, related both to attitudes and behaviour (INSAG 1991) as well as to structures that comprise individuals, groups and organizations. Safety climate is associated with both an individual and collective, shared set of perceptions of the organizational environment in relation to its procedures, practices and accepted behaviours in the workplace (Bosak et al. 2013). Hence, it relates to not only identifying safety concerns but also acting upon them adequately (ICAO 2002). As suggested by, for example, Flin et al. (2000), Sinha (2008), and Kim et al. (2019), values are the foundation for setting the guidance for everyday behaviours and practices. This means, therefore, that values can be used as a form of knowledge to forecast employees' safety performance. The safety climate can be associated with safety practices (Zohar 1980), compliance with the prescribed safety practices (Goldenhar et al. 2003) and with the reduction in the number of occurrences in the workplace (Zohar & Luria 2003; Bosak et al. 2013).

The Columbia Accident Investigation Board (CAIB) reinforces this link between safety culture and employee performance. The report suggests that safety culture is a powerful force that persists within the organization. The report classifies it as a "silent safety" system, describing it as:

> "[A] pattern of acceptance prevail[ing] throughout the organization that tolerated foam problems without sufficient engineering justification for doing so." (NASA 2003, p. 178)

When identifying the remedies that needed implementing, the report's synopsis goes a step further by expressing that:

> "Organizational culture had as much to do with this accident as foam did. By examining safety history, organizational theory, best business practices, and current safety failures,

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[43] The Royal College of Nursing (2020), acknowledged that safety culture reflects in employees' attitudes and behaviours. On their website they make the following statement:
"A workplace culture is the product of the attitudes and behaviours that exist there. A safety culture is the product of the attitudes towards safety issues and the way work hazards are managed." [SQ 4]

> the report notes that only significant structural changes to NASA's organizational culture will enable it to succeed." (NASA 2003, p. 12)

Zohar (1980) gave the behavioural aspect of culture more strength and, consequently, foregrounded the notion of performance associated with safety culture – specifically, the safety climate –, by saying in broad terms that safety culture is meant to predict how workers behave in relation to safety in the workplace. Since this seminal work published by Zohar, the study of safety climate has grown to cover a range of topics. A stream of research endeavour is dedicated to improving measures to characterize the safety climate (Flin et al. 2000; Mearns et al. 2003; Hahn & Murphy 2008), while another avenue has focused on developing models to explain the interaction among variables and their influence on safety performance (Zohar & Luria 2005; Fogarty 2004; Zohar 2010; Kim et al. 2019). Another research source that is significant concerns the degree to which safety climate variables affect safety outcomes, with variables listed at either the organizational, group or individual level (Zohar et al. 2007; Piers et al. 2009).

Supported by the Theory of Planned Behaviour (TPB), Fogarty and Shaw's (2010) study into the link that exists between organizational climate and behaviour at the individual and group levels, provided a promising perspective on how to account for safety culture in risk management. The same authors took the view that individual behaviour is mediated by "behaviour intention" and "perceived behavioural control". Intention, in turn, is shaped by "attitudes", "subjective norms" and "perceived behavioural control". Fogarty and Shaw suggested in the same volume that determinants depend on individual supportive belief structures that are construed by individual attitudes, the belief by the individual in their ability to perform such behaviour and the beliefs and behaviours of "relevant" others. The socialization phenomenon that plays a part in the working environment, have managers and co-workers as a significant source. The influence exerted by the "subjective norms" creates a sense whereby agents tend to perceive themselves as members of workgroups, and in turn, their behaviour is constrained by the norms developed by these groups. The presence of group-level factors in safety climate research is reinforced by studies into the role played by group norms in contributing to the safety performance of the organization (Hofmann & Stetzer 1996; Zohar 2000, 2010). In a study about leadership styles that was published concurrently with the aforementioned studies, Kapp (2012) concluded that leadership is relevant for motivational reasons to achieve the consistent safety performance of the group. This is in line with the empirical study of Hofstede et al. (1990), but found a stronger correlation in the influence exerted by the role of higher-ranking groups of the safety climate. In the lower ranking groups, Kapp found, leadership seemed to have less influence on group behaviour. In the same vein, in a study on the interaction-effect of leadership engagement with safety and the SMS in terms of safety performance, Kim et al. (2019) found an absence of support. Their results diverge from the current perception, whereby, through leadership, organizations implement strong drivers to enhance safety performance (Zohar 1980, 2002; Flin et al. 2000; Fruhen et al. 2014). However, the conclusions of Kim et al. (2019) may have been negatively influenced by the characteristics of the construction industry, because this is a sector that relies on contractors who do not participate in the implementation of the SMS. However, the conclusions overall do reveal the strong influence exerted at the group level, with examples that suggest the extent to which the socialization effect has a significant impact on workforce behaviour and contributes to the development of an implicit group culture (Soeters 1986; Zohar 2010). Other researchers have found a similar phenomenon: for instance, Pascale's (1985) model of socialization defended the position that people also adapt themselves to the workplace through daily practices; or Ahern et al. (2014), who found positive peer effects were attributed to the desire to conform to the existing culture [SQ 4]. Nevertheless, it is worthwhile noting how the group effect diverges from Hofstede's (1990) conclusions, whereby all differences were justifiable by looking to the national culture (McSweeney 2002).

The safety culture of each group does not mean there is a standardization of attitudes and behaviours. Wallerstein (1990, p. 7) was sceptical about the ability of the inference, in which culture could be seen as a set of characteristics that discriminate in favour of different groups. As he noted, he was suspicious that one could "[…] operationalize the concept of culture […] in any way that enables us to use it for statements that are more than trivial". His sceptical stance is based in the fact that no one can ensure that every single member of a group will act similarly among themselves and differently from other groups as claimed by Hofstede (1990). The only acceptable claim one could make would be on the basis of a statistically significant inference, which could then be used to predict the uncertainty of group behaviour. However, the ability to develop an interpretation is itself pertinent to the current thesis, as one may account for culture either as contributing positively or negatively to risk exposure quantifiably and continuously [SQ 4].

From this section, for the purposes of the current research, safety culture could be seen as:

- A holistic environment that influences employees' attitudes and behaviours.
- One framed by a cognitive and externalized appearance.
- With an enduring perspective that is difficult to mould.
- Continuously moulded by socialization and leadership phenomena.
- Able to affect the performance of the organization, which is reflected in its daily practices.

Culture, and specifically safety culture, is demonstrated in employees' attitudes and behaviours. Therefore, section 3.6.4 will review the most important tools to understand how organizational safety culture is perceived within industry [RQ 4.2] and how this important factor could be accounted for in risk-management activities [RQ 4.1].

2.6.4 Safety Culture Evaluation Tools

In contrast to physical parameters such as distance, speed, weight and the like, there is no single unit of measurement for safety culture. In terms of an analogy, certainty that one is measuring safety culture is about as easy to sustain as measuring the weather. There is no single unit to measure or evaluate the climate of a specific place. Nevertheless, physical conditions like wind direction and intensity, humidity, rainfall, temperature, cloud base, and other related features of meteorology could be used to describe the weather. Equally, in the case of safety culture, it is possible to identify attributes that can be measured (Cram 2015). A similar reasoning might also apply to an individual health condition.

As emerges from the previous paragraph, understanding the content of (safety) culture is a challenging endeavour, which researchers have yet to reach much consensus over (Guldenmund 2010; Edwards et al. 2013). Researchers leverage different attributes to describe and measure it; however, no one has been able to provide a complete picture of it, as safety culture encompasses both intangibles and individual traits. Respectively, Verbeke et al. (1998) and Flin et al. (2000) found a plethora of climate scales and definitions, making it difficult to reach a consensus among researchers. Nevertheless, individual behaviours and procedures of organizations do lend themselves a measuring capacity (ICAO 2002). Regarding this, Toellner (2001) asserted that although it might be difficult to quantify safety attitudes,[44] the creation of leading indicators allows a real-time measurement of individual

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[44] Attitudes have been described as "mental states which may exert an influence upon individuals' responses to particular objects and situations" (Loughborough University 2002).

safety behaviours (Leveson 2015).

Toellner’s (2001) case study, which studied worker’s behaviour after a management intervention in an oil and gas platform, revealed that the organization’s safety performance greatly improved throughout the project’s initial period. Enhancement of the safety culture was observable in the reduction of accidents; specifically, in the reduced risk exposure of the organization [SQ 4]. Therefore, it seems that in order to realize a realistic risk assessment, the enhancement to safety the intervention provided should be reflected in the organization’s safety data. Additionally, in contrast to traditional surveys based on climate questionnaires, leading indicators provide a continuous flow of data (Toellner 2001; Leveson 2015).

Moreover, as academia recognizes as much as industry, culture is not homogeneous: An organization encompasses numerous groups, and although there are similarities among groups, one can find a plethora of nuances and variances (Cox & Cheyne 2000; Health Foundation 2011). Reality is not as straightforward as many models try to present. This is a view Gary-AS’s experience suggested:

> *“[... I have] seen many models, graphics, and dashboards, but everything is quite [similar]. [...] [The] result is presented as quite reliable, but the assumptions are fragile. Instead of having a clear picture, it would be preferable to have a blurred vision that compels us to try to understand it.”*

Clearly, this practitioner would rather have the areas of concern that deserve further analysis shown as “a blurred vision that compels us to understand it” rather than the “clear-cut picture” that suggests clarity, but from which he is supposed to identify weakness.

As discussed above in the previous section, efforts were made to develop a framework to establish the attributes that could be used to assess safety culture. In an attempt to provide guidance for an organization to understand the strengths and weaknesses of their “safety culture”, Piers et al. (2009) suggested a framework supported by a survey grounded on domain-specific questions. Founded on a set of practices available both in the literature and in the field, six dimensions or characteristics were proposed to characterize the organization’s safety culture, specifically: “commitment, behaviour, awareness, adaptability, information, and justness”. The characteristics were then further broken down into indicators and items, enabling, respectively, to define features that were more measurable and aiding the development of a questionnaire. The objective of the framework from Piers et al. (2009) was to provide a common tool for the whole aeronautical community. However, despite the detail of the framework, similar to the models (Flin et al. 2000) scrutinized, no operational guidance was provided. So, how does the result have an impact on the risk exposure of organizations?

Despite the drawbacks in operationalization, in the fourth revision of its Safety Management Manual, ICAO (2018b) used characteristics from the framework of Piers et al. (2009)[45] to identify the enablers and disablers of the development of a positive safety culture. The ICAO Doc. 9859 manual also identifies the benefits of evaluating safety culture; however, similar to the framework of Piers et al., no correlation is made between this and the risk exposition of the organization – meaning that there is no guidance about how to operationalize the safety culture concept. This problem goes back to the very inception of safety culture (INSAG 1991).

Traditionally the evaluation of safety culture in industry is carried out using surveys that are based on questionnaires (Halaj 2017). Loughborough University (2002),[46] in partnership with the offshore oil industry, developed a user guide and toolkit for the assessment of safety culture. The method used data from three different and independent sources to assess the safety climates of the organizations. In addition to the traditional approach of surveys to gauge employee attitudes, data was also obtained from face-to-face interviews and focus group discussions, as well as from structured observations using direct and indirect methods. The assessment, based on the 17 characteristics[47] from the three independent sources, expressed the results in a radar (or spider) diagram, where the higher scores of each attribute represented a better mark. Hence, in a longitudinal comparison, a larger plotting area would mean a better safety climate profile. Although a structured presentation, again, no operationalization of safety culture was suggested in terms of risk management, which gives credit to the arguments of Lee (1995) and Kirwan et al. (2019).

Gauging attitudes of employees to safety through surveys and interviews will provide relevant information concerning the organization’s safety climate (Zohar 1980; Bosak et al.

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[45] Although no significant difference was identified by the Piers et al. (2009) framework, in the ICAO taxonomy, the “justness” characteristic was renamed “trust”.

[46] See also the paper by Cox and Cheyne (2000) about the user guide and toolkit for the assessment of safety culture.

[47] Loughborough University’s safety culture assessment is based on 17 characteristics: Management commitment, communication, priority of safety; safety rules; work environment, management style, managing change, systems compliance, supportive environment, involvement, co-operation, accidents and incidents, appreciation of risk, personnel priorities, shared values, competence, and safe behaviour.

2013; Kim et al. 2019). However, as safety is acknowledged to be a multifaceted and complex concept, naturally, would therefore be influenced by many variables in their daily practices that would have bearing on their causal reasoning (Verbeke et al. 1998; Flin et al. 2000). The question included in the Loughborough University (2002) survey: “I am sure it is only a matter of time before I am involved in an accident”, which related to a “personnel appreciation of risk”, when answered without any kind of bias, would allow development of a reasonably good perspective across the safety climate at that point in time. However, safety climate, as discussed above, offers a transitional perspective that could well be influenced by recent events, which might well affect individual perception (Wiegmann et al. 2002). This disadvantage is recognized in the user guide of Loughborough University (2000, p. 29) when commenting on the quality of data obtained from the attitude questionnaires:

> “Attitudes have been described as mental states which may exert an influence upon individuals’ responses to particular objects and situations. In short, the attitude an individual has to a particular thing or situation may influence how he or she deals with it. […] In the present context, attitudes to safety are not going to give the definitive measure of safety climate but rather they provide us with some indications of how people view their work and work environments, value safe working practices, and the extent to which they work safely or unsafely.”

ICAO (2018b) also acknowledged that there are problems with questionnaires, pointing to the potential existence of bias that may unintentionally encourage interviewees to pursue the desired safety behaviours instead of trying to identify and improve their own compliance with the safety culture. Moreover, surveys incorporate a degree of subjectivity in that, that may reflect people’s temporal perceptions at a specific time, rendering an unstable result.

Cram’s (2015) thesis agreed that questionnaires introduce an array of factors that render surveys an ineffective technique to assess safety climate. Among his criticisms, the author identified certain features of questionnaires that can affect the validity of surveys: the order of the questions, culture/language, rating scales, bias, sample selection, and the specific features of safety culture.

In a survey about the available tools, The Health Foundation (2011), an independent UK charity organization, reviewed the main tools available to assess safety culture/climate. The review scoured more than 33,000 pieces of theoretically relevant research and centred on the main databases.[48] Over 100 studies were scrutinized by the study, which concluded: the main values brought by safety climate studies is to expose the [patient's] safety profile and to promote the safety debate; therefore, the specific kind of tool used is less important than its implementation and how the feedback obtained is used thereafter. There is narrow evidence of a relationship between safety climate and its operationalization. Few studies test the relationship between the intervening variables and patient outcome; that is to say, their impact on safety performance (Beus et al. 2010; Bosak et al. 2013). The safety attitudes questionnaire (SAQ) was the only one that consistently established links between patient safety and outcomes, namely as reduced healthcare-associated infections (Robb & Seddon 2010). Moreover, the survey for the evaluation of safety tools suggested that organizations which are performing well have the potential to develop a false sense of security, which leads them to be less likely to develop improvement measures (Noord et al. 2010). Finally, when assessing the applicability of methods developed abroad, the study suggested that use of surveys outside the specific geographical context should be carried out with caution, and appropriate validation was advised before extending their application, explaining the differences in the variables chosen to characterize safety climate and culture. A revision of previous studies from Molenaar et al. (2009) had found five variables[49] that could describe corporate culture in the construction industry, which contrasted with the framework of Piers et al. (2009). A similar result was observed by Verbeke et al. (1998), who found a myriad of safety climate scales.

As Halaj (2017) asserted, the evaluation tools he scrutinized approached safety culture assessment through the use of surveys based on questionnaires. The objective is to target employee attitudes in order to predict behaviour in frontline operations. However, surveys and questionnaires are time-consuming tasks, which do not reflect the temporal perspective of safety climate. Therefore, to maintain the constant monitoring of safety culture, a constant vigilance via implementation of continuous monitoring leading indicators (Toellner 2001; Leveson 2015) is suggested.

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[48] The databases included: Embase, MEDLINE, Ovid, the Cochrane Library and Controlled Trials Register, Google Scholar, PsychLit, the WHO library and the Health Management Information Consortium.

[49] Molenaar et al. (2009) used five variables to describe corporate culture, respectively: the company's safety commitment; safety incentives; involvement of subcontractors (which could translate into service provider involvement according to aviation jargon); safety accountability; and disincentives for unsafe behaviour.

2.6.5 Safety Culture Summary

While safety culture and safety climate are widely recognized as essential concepts for risk management, there has been little agreement on their cause, content and implications in the working environment (Verbeke et al. 1998; Flin et al. 2000; Zohar 2010; Guldenmund 2000; Bosak et al. 2013). In an attempt to characterize and measure safety culture in organizations, researchers have developed variables and models that can help explain their interaction. Nevertheless, despite the plethora of research, there is a general lack of models defining either the relationship between the two principles with risk management or their impact on safety performance – namely, in terms of operationalization of the concept –, which could also be associated with the broadness of the subject (Guldenmund 2000; Cooper 2002; Cross & Papayannakos 2017). Moreover, it has been pointed out how safety climate might constitute a reliable performance indicator (Zohar 2010; Guldenmund 2000). Although recognizing the importance of the safety culture and climate categories identified,[50] these being based on longitudinal surveys and questionnaires, the challenge will be to reflect the evolutionary nature of safety culture. Therefore, in order to maintain constant monitoring of the concept, it is suggested that a permanent vigilance is maintained through implementation of continuous monitoring leading indicators, which are able to survey subjects that may reflect employees' operational behaviours. This research views the absence of safety culture in the risk-management process as a gap, whereby the aim of the thesis is to bring some clarity to its form and to introduce it into the premise of risk management.

Chapter 3 outlines the conceptual framework – the continuous safety-risk management cycle – that represents a theoretical safety model as an alternative to the current risk-management vision. The second part of the chapter details the strategic questions and research questions that support the research~~.~~

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[50] Verbeke et al. (1998) identified 10 categories of safety-climate indicators within 32 definitions, and 17 categories for safety culture within 54 definitions.

3 Conceptual Framework and SQs and RQs

3.1 Conceptual Framework

“The modern world was built by risk-takers.” (Trump 2020)

Thoughts uttered by politicians are often loaded with controversy, depending on the angle one takes to scrutinize them. The quote above belongs to US President Donald Trump’s Kennedy Space Center, SpaceX launch commemorative speech. Independently of the political message, the thought conveys a stance whereby risk-takers work to develop frameworks to evaluate their risk exposure. Risk-taking, whether financial, reputational, environmental or the like, means that one can define the amount of risk exposure one is willing to accept. Thus, it is speculated that one can measure risk, protect against it, and, in an organizational set-up, understand if the workforce is sufficiently mature to manage it.

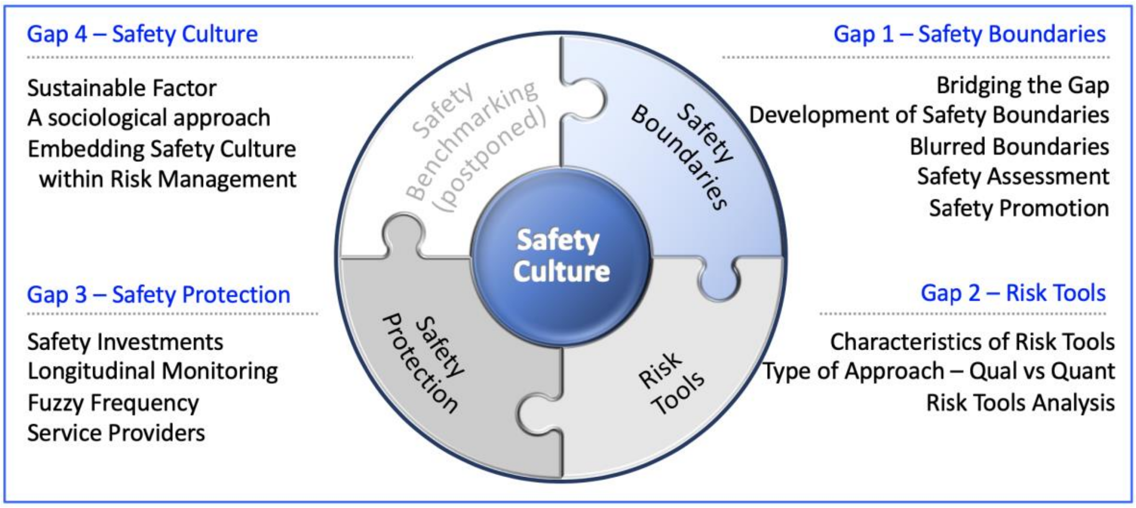

Figure 3.14 – Conceptual Framework: The continuous safety-risk management cycle

The conceptual framework depicted in Figure 3.14 is titled “The continuous safety-risk management cycle” because it reflects the constant and incessant analysis that safety professionals must enact in their daily activities in order to manage risk. For the current thesis, risk management is “a systematic set of coordinated activities undertaken within an organization with the aim of identification, analysis, evaluation, mitigation, and monitoring of safety risks to a level defined by the organization or imposed by the stakeholders.” The ultimate goal is to allow the organization to manage strategic and operational decisions.

Risk management in a complex organization, such as an airline, which interacts with various related systems and with other stakeholders within a hierarchical social-technical industry, is open to a myriad of factors and precursors that must be uncovered and considered during the risk analysis process, as sections 2.2 and 2.6 illustrate. Organizations are affected by:

- Other systems used in dynamic interactions, which evolve, adapt and drift throughout their existence. Dynamic unpredictability and future behaviour are possible to manage only with constant monitoring, which is why defining exposure limits is essential.
- Non-Linear cause-and-effect relationships and interaction; therefore, risk tools need to incorporate as many threats as viable to develop credible scenarios.
- The constant need to trim risk exposure, implement safety investments or, on the contrary, relax protective measures.
- Internal culture, social interaction, and power relationships.

Complex environments imply that individual agents neither fully understand the system nor the outcome of its actions. Complexity emerges as the outcome of multiple interactions of simple elements along with access to limited information. The conceptual framework reflects each phase of interaction with the risk-management process and the associated factors/practices that contribute to their robustness. This action generates new theoretical support to develop a flexible risk model, allowing stakeholders to improve the management of their risk exposure and carry out proactive risk-based analysis.

The conceptual framework incorporates reasoning that is built on the four interlinked stages that any organization, which manages its risk well, must be aware of. A gap is identified at each stage alongside the associated components that are aggregated with it. Underpinning the backdrop of the conceptual framework is the fact that for every hazard[51] a risk level or exposure is defined upstream as section 5.1 suggests. Organizations can measure the risk level at the monitoring phase, which incorporates an efficient allocation of resources, and this risk exposure can also be benchmarked against similar organizations' risk levels. The assumption is that safety culture is a sustainable factor as section 2.6.2 supports, but this is only so from the perspective that it influences the other four stages, whether positively or

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[51] Examples of hazards include runway excursion, loss of control in flight, controlled flight into terrain (CFIT), and the like.

negatively. The continuous cycle’s starting point at the definition of safety boundaries evolves continuously, as defined below:

- Safety Boundaries Gap 1
- Risk Tools Gap 2
- Safety Protection Gap 3
- Safety Benchmarking: Postponed to future research (as explained on pp. 74–75)
- Safety Culture Gap 4

The definition of safety boundaries has its inception in the definition of risk management – “a safety-risk exposure defined by the organization or imposed by the stakeholders”. The management of the safety risk requires the establishment of acceptable limits – safety boundaries – thus what is needed is a standard definition of what is acceptable in contrast to what is not acceptable. Such directives could be interpreted as a directive from the board,[52] which must therefore be reflected in the risk tool (or a set of tools) used by the operational (safety) staff to measure the safety risk.

The “safety boundaries” associated with Gap 1 are a means by which organizations could define their risk tolerability or risk exposure. However, as Kwak & Laplace (2005) and Kim et al. (2019) claimed, risk tolerability is rarely communicated and implemented effectively throughout the organization, as section 2.5.2 identifies. In particular, within the SMS framework, airlines rely on their safety policy, which is often composed of a set of commitments and objectives to be achieved over the long term (ICAO 2013a). These intentions are difficult to perceive and convert into measurable goals by operational (safety) staff. For the majority of airlines, the most they can do to evaluate their risk exposure is to develop statistics based on the frequency of individual hazards, with all the drawbacks section 5.3 highlights. Moreover, risk tools can be used as a risk-communicating instrument as their layout should reflect the organization’s safety policy, that is, they work as a way to overcome the identified difficulties. However, risk matrices (and ARMS) do not reflect the organizational safety policy and suffer from drawbacks as identified in the CLR.

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[52] Equivalent to a “Safety Policy”.

The risk appetite, which should be customized to reflect each specific hazard, should be borne in mind as organizations embark on the second stage to measure their exposure to each hazard. Using reasoning provided either by the framework proposed by Rasmussen (1997) or the drifting theory suggested by Dekker et al. (2011), discussed in section 2.4, airlines should be able to determine where they are in terms of their risk exposure, how close they are to the "marginal boundary" and "how fast are they drifting".

The "risk tools" stage, which interlinks with Gap 2, addresses the method used by airlines to assess their risk. The tool(s) selected should reflect the organization's risk policy (appetite) and, at the same time, be capable of ranking and prioritizing risk as well as identifying those risks that are drifting into the safety boundaries (Duijm 2015). Nevertheless, although the literature identifies many techniques (BSI 2019), the risk matrix was the tool adopted (or proposed) by the International Civil Aviation Organization (ICAO), which is used widely by organizations as a way of measuring their safety risk, as section 2.5 exemplifies.

Considering the widespread usage of matrices (Flage & Røed 2012; Levine 2012), the CLR concentrated its analysis on these tools. However, while there is a sheer diversity of literature about the use and identification of the drawbacks of risk matrices, as the CLR discusses and as witnessed in the qualitative research (section 5.2.3), authors have tended to concentrate on single deficiencies and thereby underestimated the overall problem and its ability to be implemented. This in turn has led to speculation that these models and theories do not adequately respond to practitioners' needs (Underwood & Waterson 2013), thereby leaving the deficiencies unresolved.[53]

The third stage of the continuous safety-risk management cycle – "safety protection" – feeds into, and intertwines with, the two previous stages. The level of protection will depend on the definition of the safety boundary and on the ability of the risk tool to assess the risk exposure.

Within the premise of this research, safety protection is a concept broader than purely making decisions about financial investment, supported by return on investment (ROI), cost-based analysis (CBA) studies and ALARP[54] thresholds. Reducing risk exposure and improving safety performance is a remit mandated by the ICAO (2018b), which all organizations aim to

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[53] The deficiencies of risk matrices were discussed in the critical literature review (CLR) under the section headed "Risk Tool". Several drawbacks are scrutinized in the section: subjectivity, consistency and resolution power, and risk aggregation.

[54] ALARP stands for "As low as reasonably practicable".

accomplish. To achieve this objective, of utmost importance is to have the data to hand to compliment understanding of the magnitude of the risks at stake and their potential consequences (Sunstein 2002). Unfortunately, risk cannot be entirely eliminated. Hence, organizations are faced with the question of how much risk they can live with and what the best strategies are to handle it.

Although the body of literature on ROI and CBA in high-risk industries is vast, little research in this regard has been done in the aviation industry (Lercel et al. 2011). Historically, the costs associated with incidents and accidents have not been accurately tracked by the aviation industry, but there are several other reasons why research lacks in this specific area. While it is possible to demonstrate the negative impact on the airline's stock value according to the outcome of an accident or serious incident, the same cannot be said for a single event. At the micro-level, in a multilayer structure of costs, it is a challenging task to associate specific financial gains to an identifiable safety intervention. A communication campaign or concerted efforts to raise awareness about a specific hazard is difficult to associate with a measurable figure (Lercel et al. 2011). These actions have the unique objective to reduce the risk exposure of organizations, and like weather, culture, economy and other similar concepts, risk exposure cannot be represented by a single variable. Moreover, associating a gain or a reduction of occurrences to a single activity is challenging in a complex system.

CBA and ROI make a comparison between costs and benefits. Nevertheless, there are intangible contributions within these that are challenging to quantify, raising difficulties in assessing the actual value of the risk reduction. Therefore, making a comparison based on financial grounds leaves significant contributions outside the realms of the equation (Baybutt 2014; Ale et al. 2015). Moreover, such a correlation implies an accuracy that these numbers do not hold, since every aspect that cannot be accurately accounted for or compensated with a financial value is neglected (Ale et al. 2015). Therefore, more important than establishing an (economic) value for each action, safety practitioners need to be able to identify and compare the threats that pose a higher risk exposure, as sections 2.5.5 and 5.3.1 stress. An evaluation on this basis would enable them to decide which threats to allocate investment to out of the available resources. Further, this indicates why these financial-led approaches are deemed inadequate, and why the risk-driven principle to determine which threats pose the higher risk-exposure has been adopted.

Mitigation measures come permanently associated with the decision about allocation of the available resources, a decision whereby managers have to choose where and how much they will invest (Reason 1997; Pierobon 2012). Without a comprehensive analytical model, management decisions are doomed to the arbitrary outcome of pure luck. Hence, for the current thesis, the concept ought to be understood as a management model that is used to either allocate or relocate available resources, decide on new investments, and pinpoint where they are most needed (EASA 2018b). The safety-protection concept encompasses a set of protective practices depicted in the conceptual framework, as the research has observed, and which is supported in section 5.3. Depending on how they are used, a risk-efficiency is associated with each measure. Performance depends on how the measures are employed; and, consequently, highlights the utmost importance of correctly managing them (Lu et al. 2016).

The fourth stage identified in the framework – “safety benchmarking” – takes the scope of the research to a different angle; it shifts the focus from the airlines to the regulatory perspective.

Similar to the predecessor regulation, the European common safety rules in the field of civil aviation (European Parliament and Council 2018, p. 1) – known also as the “New Basic Regulation” – on its first recital, mandates that “[a] high and uniform level of civil aviation safety should be ensured at all times by the adoption of common safety rules […]”. Broadly, EU law mandates the establishment of a uniform safety-risk exposure, which is applicable within and throughout the European region. The “safety benchmarking” stage/gap also relates to the “safety-protection” perspective. However, in this specific case, instead of the airline defining the risk exposure, the EASA, the European regulator, establishes it. The purpose is to implement a (hierarchical) “benchmarking” policy, customized to each type of operation, and adjusted to the size of the airline. The ultimate goal is to limit the possibility of having an operator exposed to a high level of risk, namely those supervised by the EASA, as illustrated in Figure 1.5.

Since its inception, the “European Plan for Aviation Safety” (EPAS) has remained a non-binding document, and implementation of its directives is still voluntary through the supervision of each EASA Member States’ Safety Programmes and Plans (EASA 2017, 2018b, 2020b). Moreover, with the exception of Air Traffic Management (ATM) guidance, the approach taken by each other “safety risk portfolio” does not offer a uniform risk-exposure perspective within Europe; in fact, the agency is yet to define or agree to the safety performance targets for European region safety risks (European Commision 2015). However, this objective is within the EASA’s radar.

EASA (2020b, p. 82) is taking a step in the right direction with affirmation of its intention “[T]o develop a common set of indicators and targets on effective implementation of SMS, an agreed methodology for assessing SMS, as well as a method to score and aggregate related assessment results […].” However, it is recognized that many hurdles have yet to be overcome. Therefore, although the fifth gap “safety benchmarking” is acknowledged, close engagement with it as part of the current research seemed superfluous. However, having already mentioned the interdependence between the gaps, the removal of “safety benchmarking” from the research should not suggest that it has been forgotten about. Thus, Figures 1.6, 3.14, and Table 3.1 show “safety benchmarking” as a tint rather than a colour specifically to indicate that it has been postponed for future research, which points to the expectation that the findings from the current research will contribute to the enhancement of the European SMS.

Finally, interrelated with all the previous stages and gaps, the framework incorporates organizational culture or, in aeronautical jargon, safety culture. As suggested during the CLR and confirmed throughout this research, safety culture affects and impacts the risk exposure of each organization. Safety culture is considered an influential and sustainable factor in risk management. However, it was observed that management responsible for risk in each organization does not consider its risk systematically; the outcome is dependent on the sensitivity to risk of each safety analyst.

Safety culture is perceived to correlate with employees’ performance; it is seen as an intrinsic behaviour or attitude towards safety, which ultimately allows employers to predict how workers will behave in the workplace. Despite the mountain of research in this area, there is a general lack of a model to establish the relationship between safety culture or safety climate and risk-management and the impact of these on safety performance. Namely, there is no model to show the operationalization of the concept, which constitutes a gap in the literature, as section 2.6 highlights.

The purpose of the current research is to understand how safety culture could be integrated into the risk-management process, and to explore how practitioners could make use of such data, specifically how risk management could benefit from taking account of organizational safety culture.

The absence of safety culture in the risk-management process is considered a gap, which the current thesis aims to clarify by taking risk-management as part of its premise.

The "continuous safety-risk management cycle" starts at the definition of risk level and runs through all four stages while acknowledging the relevance of safety culture at each stage. The cycle provides a conceptual framework to promote enhancement of the following areas:

- Definition of risk exposure within each organization, leveraging the characteristics of the operation and the specific threats the airline faces.
- Understanding the current risk-exposure level and assessing whether they are drifting into their "marginal boundaries" will ultimately promote a healthier risk awareness.
- Allocate available resources more efficiently and enable wise judgements to be made about further investment.
- Allow the European regulator to establish a high and uniform level of safety within the European region.

In summary, the continuous conceptual framework is based on a cycle – safety boundaries, risk tools, safety protection, "safety benchmarking", and safety culture –, which represents a theoretical safety model as an alternative to the current risk-management vision. The perspective brought by the conceptual cycle, based on a definition of the risk level already established upstream and on continuous monitoring of the safety-risk exposure, promotes a smooth transition to a proactive risk-based approach. At the same time, it also acknowledges the need to use the available resources judiciously and incorporates the influence exerted by the organizational culture.

3.2 Strategic Questions and Research Questions

The strategic questions (SQs) and research questions (RQs) are intertwined with the four stages of the risk-management process and safety culture, a factor that influences the management of each phase. The SQs and RQs presented in Table 3.1 reflect an evolutionary process that began with a scoping document to support the identified gaps and incorporated the adjustments brought by the CLR and the research methodology discussion (Encarnação 2015a, 2015b, 2016). Although these were the guiding light for the research, their broad structure allowed alternative avenues of research to be opened up and explored as they emerged during the data-collection phase (Bryman & Bell 2011). Two main changes were introduced throughout this process: The “safety benchmarking” gap, associated with a “high and uniform level” of risk exposure, as discussed in the conceptual framework section, was postponed for future research. The second change was in relation to the introduction of a new gap: It seemed the CLR took for granted the belief that safety analysts would account for “safety culture” during their risk-management process but, surprisingly, the research revealed that this was not the case.[55] Safety culture was not managed systematically and, therefore, the conceptual framework and the research questions had to be adjusted. Appendix C illustrates this evolutionary process.

The SQs are entwined within the four stages of the conceptual framework and safety culture, as Table 3.1 illustrates. The research, which assumed the flavour of an “exploratory work”, provided both insight into how stakeholders handle and overcome the identified gaps and an understanding of how procedures provided by the ICAO (2018b) are not adequate to the industry needs, as detailed in Section 2.5.

SQ 1 asks the question “*How are the safety boundaries defined and communicated?*” The first SQ is highly relevant to the risk-management process because managers need to have a reference about the risk exposure they are willing to accept. Moreover, the method used to define “risk appetite” works as a directive for operational staff. Therefore, it should be communicated unambiguously and allow a common understanding amongst all internal and external stakeholders. To support the research, two RQs were developed:

- *How is the actual safety-risk exposure defined?* [RQ 1.1]
- *How is the actual safety-risk exposure communicated throughout the organization?* [RQ 1.2]

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[55] Section 5.4.3 presents several examples to support this claim.

STRATEGIC QUESTIONS	RESEARCH QUESTIONS
GAP 1 – SAFETY BOUNDARIES	
SQ 1: How are the safety boundaries defined and communicated?	RQ 1.1: How is the actual safety-risk exposure defined? RQ 1.2: How is the actual safety-risk exposure communicated throughout the organization?
GAP 2 – RISK TOOLS	
SQ 2: What risk tool or combination of tools should be used to assess safety risks?	RQ 2.1: What characteristics should risk tools have to assess safety risks effectively? RQ 2.2: What methods best suit airlines?
GAP 3 – SAFETY PROTECTION	
SQ 3: How could companies achieve a balance between production and protection?	RQ 3.1: How are the safety investments decided? RQ 3.2: How can the organization's safety-risk exposure be minimized?
GAP SB – SAFETY BENCHMARKING (POSTPONED FOR FUTURE RESEARCH)	
SQ SB: How can regulators define a minimum safety-risk exposure for major safety threats?	RQ SB 1: What safety indicator should airlines use to standardize a measure? RQ SB 2: How should national regulators adapt their procedures to monitor the performance of airlines?
GAP 4 – SAFETY CULTURE	
SQ 4: How does organizational safety culture impact on the risk-management process?	RQ 4.1: How can safety boundaries account for the impact exerted by safety culture? RQ 4.2: How can risk tools incorporate the influence exerted by the organizational culture?

Table 3.1 – Strategic questions and research questions interrelated with the research gaps

The second SQ considers the characteristics of commercial aviation, and from this standpoint asks: "*What risk tool or combination of tools should be used to assess safety risks?*" Commercial aviation is a dynamic industry that interacts with many stakeholders, develops its activity within a complex system, with many variables, and where safety analysts ought to be able to process information at a fast pace with a high degree of accuracy. These characteristics demand a risk tool or a combination of risk tools that are capable of handling a large amount of data while providing continuous feedback about the current risk exposure. In this regard, it is important for the research to be able to identify what features such a tool should incorporate and what the best approach for the commercial aviation sector is, an industry that is characterized by an ultra-safe record in terms of accident events (Amalberti 2001). With the objective of SQ 2, two RQs emerged:

- *What characteristics should risk tools have to assess safety risks effectively?* [RQ 2.1]
- *What methods best suit airlines?* [RQ 2.2]

Within the scope of SQ 2, to gain an understanding of airlines' level of support for one or other of the two philosophical schools of thought (the quantitative or qualitative risk-management stance) was extremely important. The extant literature offers a myriad of different solutions (GAIN 2003; Marhavilas et al. 2011; Stanton et al. 2018; BSI 2019). This is why the focus of the current research is on a limited number of risk tools that are already in use, and alongside these proposes the integration of corrective measures to adapt the risk tools to meet the challenges faced by the industry today and in the near future.

The debate about the allocation of sufficient resources emerged in the literature, particularly in Professor James Reason's seminal book (1997) about organizational risk management. The allocation of adequate resources, specifically the ability to manage efficiently those already available, while simultaneously attending to the most critical hazards, was the purpose of the third SQ, which asks: "*How could companies achieve a balance between production and protection?*" To guide the research, two RQs were developed:

- *How are the safety investments decided?* [RQ 3.1]
- *How can the organization's safety-risk exposure be minimized?* [RQ 3.2]

Safety protection should not be perceived as a "one-shot" cost-based analysis; it should be a continuous hazard/risk-based analysis aimed specifically at protecting the organization from the threats as they are exposed. In this regard, Gap 3 is intimately associated with the two previous sets of SQs and, consequently, the associated gaps, because, since not all hazards threaten organizations in the same way, it is essential to understand whether the measures implemented are effective. The intention of RQ 3.2, therefore, is to verify the various interactions that contribute to the protection of the organization, at both internal and external levels.

As mentioned above, the “safety benchmarking” gap is quite relevant overall to the implementation and robustness of the SMS and has been postponed for future research. From the perspective of the regional regulators (e.g. EASA and FAA), it is possible to attain an integrated picture and then predict significant concerns. This type of forecasting is not achievable by individual organizations, but aggregate identification of this sort, which points to where more dedicated attention is needed, will work well as a proactive and reliable protective measure. Although the previous section has explained the reason behind temporarily putting aside the “safety benchmarking” gap, the current research still sheds some light on it; hence one SQ and two RQs are seen here as a guide for future research.

The final gap emerged from the research interviews. Safety culture was integrated into the conceptual framework from the research’s inception. All risk researchers acknowledge the influence culture exerts on the workforce – a stance that echoes through the interviewees’ discourses. Surprisingly, however, practitioners do not systematically account for safety culture in their risk-management process; rather, each analyst refers to their personal sensitivity to deal with organizational culture. In this regard, the SQ associated with Gap 4 explores what influence this critical factor exerts, asking: “*How does organizational safety culture impact on the risk-management process?*” To orient the research, two RQs were added:

- *How can safety boundaries account for the impact exerted by safety culture?* [RQ 4.1]
- *How can risk tools incorporate the influence exerted by the organizational culture?* [RQ 4.2]

Chapter 4 is dedicated to delineating and articulating the research methodology that underpins this research. It discusses the philosophical stance espoused by the researcher, the research method and design strategy adopted, as well as the ethical stance the research takes.

4 Research Methodology and Ethics

4.1 Introduction

Chapter 4 leverages the discussion presented in Document 3, in which the main philosophical traditions[56] were contrasted with the purpose of identifying which would be the most appropriate methodology[57] for the current thesis. This debate is discussed at length by Encarnação (2016), so the argument is not repeated at any length here, but on occasion is brought in to emphasize fundamental differences. Appendix D illustrates a summary of the research traditions studied. The context of the research is within what has been defined as a complex system and, as such, the thesis adopts the philosophical stance of critical realism, employing semi-structured interviews as its method in the pursuit of the research objective. The ethical issues considered during the research are discussed in section 4.6.

4.2 The Nature of Social Science

The philosophical tradition frames the assumptions researchers espouse about their understanding of the world (Burrell & Morgan 1979; Bryman & Bell 2011). Kuhn (1970) sees paradigms as a source of pre-accepted rules and assumptions that guide a specific way of

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[56] Some authors write paradigm as a synonym for tradition, which was coined by Kuhn as a “set of common beliefs and agreements shared between scientists about how problems should be understood and addressed” (see Anderson 2013). The main traditions discussed in Document 3 (Encarnação 2016) are likewise identified using different designations, either because they overlap, include other positions, or because they originated in different schools of thought, specifically:

- Positivism – “empiricism”, “naturalism”, “behaviourism” or “scientific approach” (Hughes & Sharrock 1997); “objectivism” (Morgan & Smircich 1980); “sociological positivism” (Burrell & Morgan 1979); “post-positivism” (Creswell 2009).
- Interpretivism – “subjectivism” (Morgan & Smircich 1980); “constructionism” (Healy & Perry 2000; Fisher 2010); “German idealism” (Burrell & Morgan 1979); “idealism” or “relativism” (O’Mahoney & Vincent 2014; Van de Ven 2007); “phenomenology” (Fisher 2010).
- Pragmatism – “Symbolic realism” (Goldkuhl 2012).
- Realism – “critical realism” (Hunt 1991); “postpositivism” (Denzin & Lincoln 1994); “neopostpositivism” (Manicas & Secord 1982), as discussed in Krauss (2005).

[57] In the literature, the words “methodology” and “method” are used frequently as synonyms, which can create confusion about the meaning of the two concepts. It is important, therefore, to clarify their meaning here. For the thesis, “methodology” refers to “the study of a whole academic field” (Fisher 2010, p. 50), taking a broader and deeper perspective, whereas “method” refers to the techniques used to collect the data required in order to answer the research questions. Methodology, here, is the thorough analysis of the “means of obtaining knowledge from the social world” (Hughes & Sharrock 1997, p. 14), encompassing aspects such as the philosophical stance of the research, the chosen methods of research, the required sampling, the elected method of analysis, and the like (Hart 1998).

conducting research. According to Kuhn (1970, p. 5), research is a “strenuous and devoted attempt to force nature into the conceptual boxes supplied by professional education”. Although paradigms, described as boxes, can provide a useful foundation for the advancement of science, they can also work as a barrier in the development of science.

The chosen methodology of the researcher moulds the approach she or he will employ while seeking knowledge about the social world. However, this does not mean that the methodological tradition will frame the research, but rather, more as Holden and Lynch (2004) assert, the frame of the research will be as a consequence of the philosophical stance taken by the researcher and the subject of the research. The focus of the current research is on safety risk management – more precisely, the idiosyncrasies of safety-risk management – and it is this focus that dictated the most appropriate methodology (Falconer & Mackay 1999).

The research process raises several philosophical questions that the researcher should address thoughtfully, specifically assumptions about the nature of society and the nature of science (Burrell & Morgan 1979). The sociological argument over the “order–conflict” views of society in the same volume by Burrell and Morgan suggested different terms to define the two opposing poles: the “sociology of regulation” and the “sociology of radical change”. According to the former view, society progresses rationally and in a cohesive and unified way, and developments are seen from a continuum perspective. According to the latter, society is seen as being in a constant state of (radical) change, based on a latent conflict, where agents face a constant struggle to free themselves from the control of societal structures. The “sociology of regulation” perspective closely matches the research stance used in the current thesis, where the conceptual framework and the “Oyster Model” – “The continuous safety-risk management cycle” (Figures 1.6 and 3.14) is seen as contributing to enhanced management of aviation safety risks.

The second set of assumptions – the nature of social science – introduces analysis of the core concepts that underline the main philosophical paradigms. Burrell and Morgan (1979) suggested that a set of opposing-yet-interrelated assumptions constructs social science. The hypotheses consider ontology, epistemology, human nature, and methodology from an opposing subjective/objective perspective.

Ontology, a branch of philosophy that studies the existence of “different opinions [...] on the nature of reality” (Hart 1998, p. 81), creates the ground for a fundamental (ontological) question of “whether the ‘reality’ [...] is external to the individual” (Burrell & Morgan 1979, p. 1). It asks whether reality should be seen from an “objective” perspective in nature or as the result of individual cognition. The former view, defined as “nominalist”, considers that only humans are real and that the surrounding social world is the result of human cognition, which uses names, concepts and labels to structure that reality. The opposing view – “realism” – assumes that the external social world consists of rigid, measurable and fairly unchangeable structures. For the realist, the social world exists irrespective of an individual’s cognition. For example, the gravity law will persist independently of human knowledge (Lane 1999; Johnson & Duberley 2000).

The second philosophical stance – epistemology –investigates “how knowledge can be acquired of that reality and therefore, what counts as valid knowledge” (Hart 1998, p. 81). The “positivist” view of this conceives that knowledge is acquired by prepositions in a search for the regularities and causal relationships that can be observed objectively by an observer. In opposition, the “anti-positivist” view is that knowledge is constructed by human experience and interpretation; it is not revealed by directed observation, but instead is constructed through human interaction (Lane 1999).

Related to the previous assumptions, although theoretically independent, is that human nature entails taking a dichotomized view. Human beings are seen either as controllers of the environment – as in the voluntaristic approach –, holding autonomy and free-will, or seen as being controlled – as in the deterministic approach –, where the activities of actors are determined either by the situation in which they find themselves or by their environment.

Lastly, as defined above, the philosophical stance of the researcher is reflected in his or her ontological and epistemological viewpoint and methodological assumptions. Whichever stance is taken will indicate how the researcher has approached the investigation to obtain knowledge about the social world; whether using an ideographic approach, thus, interacting directly with the subject being researched and taking note of the subjective accounts, or by way of the nomothetic approach, which is one based upon systematic techniques and protocols (Burrell & Morgan 1979, p. 1).

The different views of the world held by social philosophers are the product of a long tradition of intellectual debate by their advocates, which have the support of different schools of thought. The objective pole of the “strands of theory” conveys a more positivist stance, whereas the subjective approach is associated with a more interpretative view of science. These two schools of thought have dominated social science for the last two centuries.

4.3 The Critical Realism Philosophical Tradition

As already stated above, ontology relates intimately to epistemology. Different ontological world views involve distinct foundations for knowledge concerning the social world and consequently about social research (Morgan & Smircich 1980). Realism incorporates elements from both positivism and interpretivism (Krauss 2005). In its genesis, historically realism has been concerned with the existence of unobservable entities. Thus, in ontological terms, realism posits the existence of an objective world that exists “despite or regardless of our current state of knowledge” (Mutch 1999, p. 328); one that is beyond people’s perception, consciousness and language. This stance differs from the positivist tradition, which limits the world to empirical facts (O’Mahoney & Vincent 2014), or the interpretivist tradition, which restrains the understanding of the social world through discourse (Bryman & Bell 2011).

In contrast to the “value-free” presupposition of the positivist paradigm and/or the “value-laden” concept accepted by the interpretivist tradition (Holden & Lynch 2004), realism is rather “value-cognizant” (Krauss 2005) while critical realism (CR) acknowledges the way that perceptions have a certain plasticity. Realism, therefore, concedes that reality is subjectively interpreted, allowing for the existence of multiple perceptions, although imperfectly acquired (Healy & Perry 2000; Bisman 2010). This dichotomist recognition of an objective–subjective ontological reality led Leplin (1984) and Van de Ven (2007) to assert that realism is partly empirical and partly metaphysical, a novelty that filtered through to social science research, whereby the position of the tradition is that it goes beyond experience but can be tested through experience (Leplin 1984).

Although seen as a middle ground between the two opposing philosophical traditions – positivist and interpretivist (Krauss 2005; Van de Ven 2007) – the realism developed by Roy Bhaskar (2015), known as critical realism, or CR, attracted some dissent due to the standpoints it took (Mingers et al. 2013). Acknowledging human beings’ fallibility when acquiring knowledge from reality, and recognizing that reality is “conceptually mediated and theory-laden” (Van de Ven 2007, p. 61), CR rejected the philosophical stance of foundationalism, which was a view shared by the interpretivist tradition.[58] On the other hand, from the positivist philosophical paradigm, CR acknowledged empirical validation as a means to confirm theories. Nevertheless, assuming reality as an open system, where events are ultimately the result of the interactions among entities, hierarchically organized and mediated by mechanisms, it rejected the generalized view of an experimental outcome. For realists, reality cannot be considered in isolation of its context (O'Mahoney & Vincent 2014). Open systems, such as organizations, seen by James D. Thompson as based on "complex and unpredictable feedback loops" (see O'Mahoney & Vincent 2014, p. 6), preclude events being regarded as predictable or predetermined. In Mutch's words (1999, p. 329) CR places:

> "[…] emphasis on the search for generative mechanisms, which might operate at a deeper level than the superficial constant conjunctures which positivists mistake for cause and effect. That is, realists look at each level for the causal mechanisms which are at work, knowledge of which might be without the grasp of participants."

Therefore, in the tradition of realism, positivist correlations are seen as a narrow account of reality, isolating social phenomena from their context, and leading proponents to assert that its accounts describe rather than explain their causation. CR, in conceptualizing the characteristics of the complex environment faced by commercial aviation, provides a robust explanatory power to pinpoint the intricacies of risk management.

According to a CR perspective, reality is construed in a hierarchical fashion; entities exist at many different levels and these may be material or immaterial (e.g. Aviation Law). For example, an organization can be seen as an entity composed of different stratified entities; that is, one made up of divisions; divisions are made up of people; people are made up of organs and tissues, and so on. Thus, the capacity to understand how different entities relate to each other as part of a greater whole gives CR the edge in terms of its capacity to explain the reality. Therefore, the concept of a "laminated system" (Elder-Vass 2010), whereby social systems are made up of distinct layers, should be seriously considered when attempting to explain reality. However, according to CR, the topmost entities are not dependent on the lower entities (O'Mahoney 2011).

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[58] According "foundationalism" (Hughes & Sharrock 1997), epistemology requires empirical knowledge in order to overcome the sceptical doubt that "we can never understand anything about the real world"; and, in turn, leads to the argument that "we can never claim with full confidence to know anything".

Under the terms of CR, entities may possess causal properties, known as “emergences”. These properties might be perceived as essences and causal powers (O’Mahoney & Vincent 2014). The essence of something is what makes it distinguishable from something else (O’Mahoney 2011), while causal power is a concept associated with (social) change; yet entities may have features that might be exercised or even actualized, which often results in changes that see interaction with other entities. To exercise the power of entities requires the existence of (at least) one mechanism to relate one entity with another. And as Chapter 2.2 makes clear in relation to CLR, these interactions are an intrinsic characteristic of complex systems (Cilliers 1998; Snowden & Boone 2007; Meadows 2008; Checkland 2012), which denotes the explanatory power of taking the CR stance.

The capacity attributed to entities – of possessing, exercising and actualizing causal powers; a conceptually stratified ontology that has mechanisms, and which, therefore, can generate a sequence of events – allows CR to be brought to describe the social world more accurately. CR’s ability to do this without assuming the existence of mechanisms or causal powers as either determined or predictable, contrasts starkly with the positivist and interpretivist traditions, where, respectively, reality is frozen in recordable events or where ontology is reduced to discourse (O’Mahoney & Vincent 2014).

For positivists, what cannot be perceived cannot exist: This “epistemic fallacy” derives from the attempt to reduce “the ontological domain of existence to the epistemological domain of knowledge” (Mingers et al. 2013, p. 796). For realists, the existence of causal powers denotes the existence of a “phenomenon” beyond perceptibility. This intransitive perspective of reality conveys a sense of stratified domains among mechanisms; these are known as “real”, “actual”, and “empirical”. The “real” domain contains the whole reality, while the “actual” encompasses the events that might (or might not) occur and includes the “empirical” domain, represented by observed or by experimental events (Mingers et al. 2013).

The critical realists’ ontological perspective goes deeper in order to understand events. For example, in parallel with the activities of commercial aviation, the sequence of events during an aircraft turn-around involves several teams (e.g. crewmembers, cleaning/catering staff and refuelling/handling teams). These teams must be coordinated and routinely comply with their operating procedures in order to release the aircraft within a specific time. In other words, the whole process must be explained beyond what is simply observed. The description of aircraft turn-around based solely on the working patterns that allow it to happen is unlikely to provide a comprehensive explanation of the causal mechanisms that support the sequence of events. As Elder-Vass (2010, p. 49) asserted, the best achievable is a “level-abstracted view of it – a view that considers the effect of the whole entity [in this case, the turn-around] in isolation”. At a deeper level, the causes of events may be perceived beyond the immediate context. Thus, while one may assert the existence of intra-team coordination, which is an essential determinant of observing regulations, other events, such as standard operating procedures, recurrent training and unannounced audits, may also contribute to the observed behaviour (O’Mahoney & Vincent 2014).

This example demonstrates how complex reality is and, consequently, reveals how opaque it is – far more than raw observation may anticipate. On the other hand, the same example also reveals how the underlying causes of events may be hidden. In opposition to the interpretivist and the positivist traditions, which, respectively, support research on discourse and quantification of empirical data, CR “incorporate[s] data of different sources, quantitative and qualitative, historical and current – anything that the researcher (or their research subjects) have good reason to think ‘makes a difference’” (O’Mahoney & Vincent 2014, p. 15). The enduring outlook associated with entities, causal powers and mechanisms, highlights the importance of the historical perspective brought by CR. As Mutch (2014) stresses, many features of CR encourage researchers to be more sympathetic to the historical perspective, for example, paying attention to several (often overlooked) resources such as company annual reports, newspaper advertisements and archival material.

According to the CR tradition, events are seen as “multiply determined” with several mechanisms contributing to the final result (Bhaskar 1975); it implies the researcher’s commitment to delving into the multiple causes, assuming the existence of deeper levels waiting to be discovered. Beyond raw observation, it is possible to assert the existence of other mechanisms that are neither noticeable nor readily visible, but still active (O’Mahoney & Vincent 2014).

Researchers in the CR tradition use two different forms of explanation when moving from the empirical to the real: abduction and retroduction. Abduction is a form of redescribing the reality that commonly is carried out through interviews or observational data in an attempt to describe the sequence of events that support the observed regularities. Retroduction, on the other hand, attempts to describe how the world ought to be in order to support the observed mechanisms. Retroduction denotes the use of multiple theoretical lenses to explain the stratified influence exerted over the observed reality (O'Mahoney & Vincent 2014).

CR seems to be a powerful lens through which to examine the way that the aviation industry currently handles safety risk. A thought-provoking approach, which seems to be attracting followers throughout the industry, is seen in how incidents and serious incidents are put into perspective. Using James Reason's so-called "Swiss Cheese" model (1997), Di Gravio et al. (2015, p. 65) asserted that all of the incidents and serious incidents could be interpreted as an accident "except that not all the holes in [the] defence layers lined up". Currently, the aviation industry is starting to aggregate multiple safety risks into a single value capable of identifying performance trends[59] by identifying those that are common contributing factors in accident reports (NoA 2013; EOFDM 2020). In the same vein UK CAA (2010) asserted that it is preferable to understand a safety objective as a maximum rate of occurrence target, and to identify which events contribute to an incident or an accident. Nevertheless there are some dissenting voices about the use of incidents to forecast the reliability of system safety; Elvik and Voll (2014) being chief among the dissenters. They discuss the challenges posed by a "very safe" means of transportation (the railway in Norway) and the task it poses for investigators. Elvik and Voll assert in the same volume that the growing number of reported incidents has not been linked to an increasing number of accidents, and thereby conclude that the increasing number of incidents is not directly associated to an increased accident risk level.

Flying activity develops in a complex system and is dependent on a countless number of individuals to make it possible. These include state authorities, regulators, design engineers, maintenance technicians, air traffic controllers, managers, support personnel, and crewmembers, to name only a few of the professionals who work in the industry. Any incident and/or accident (and consequently, any risk analysis) incorporates an array of events with underlying hidden causes that require in-depth analysis to identify the entities and the mechanisms that might contribute to their activation. This is why the perspective brought by CR is seen as the most appropriate philosophical tradition to support the reasoning within the premise of risk management in aviation.

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[59] For the current thesis, the concept relates to the level of risk exposure.

4.3.1 Summary of the Philosophical Stance Adopted

As discussed above, a critical realist stance has been assumed for the current thesis. Discussion in each chapter is supported by the scientific assumptions and framework of Burrell and Morgan (1979) and Johnson and Duberley (2000) respectively. The overall stance espoused can be summarized as relying on the following:

- Objective ontology – assumes that the external social world consists of relatively enduring structures. For the realist, the social world exists irrespective of an individual's cognition.

- Subjective epistemology – whereby the world is construed subjectively and the existence of multiple interpretations of reality is acknowledged, but captured deficiently by individual observers.

- Human nature – a stance that favours the voluntarist perspective, where the researcher holds autonomy and free will.

- Methodology – there are multiple subjective (ideographic) interpretations of reality; therefore, there is a requirement to implement a diversified and robust collection of data.

The current research adopted an abduction stance to extract data from the interviews and the critical literature review and used it to develop the conceptual framework and the “Oyster Model”.

4.4 Research Methods and Design Strategy

The success of the research ultimately rests with the methods and analytical processes practised during the course of the fieldwork. In this regard, Bryman and Bell (2011) recommended considering several relevant issues. The following aspects were considered:

- The characteristics of commercial airlines; how safety-management systems are implemented and organized, and the responsibilities and functions of each stakeholder.

- The criteria for selecting interviewees and negotiating access.

- The data sources available, comprising semi-structured interviews, participant observation and how data could be collected.

- How to analyse the data: implementing an iterative process to generate inferences, which reveal the emerging themes.

Several factors have influenced the researcher’s strategy. These include the research subject, the experience and preferences of the researcher, and the target audience’s familiarity with the research methods (Creswell 2009; Holden & Lynch 2004). The objective of the current research is to develop a new risk model; ultimately to contribute to a more effective management of safety risk. In this light, Creswell (2009) advocates a qualitative strategy, allowing greater flexibility and more innovative work.

Fisher (2010, p. 71) addresses the decision-making process while selecting a research method. Opposed to the traditional view, whereby the research methods must be rigidly associated with the philosophical stance espoused by the researcher, Fisher writes that realist research is not compelled to use “quantitative research methods and materials (questionnaires surveys and databases)” any more than interpretive research is obliged to use qualitative methods (interviews and documentation analysis) – any research method might be used for both approaches, he says. While recognizing the existence of variations, Buchanan (2015) identifies three research methods suitable for data collection in order to answer the research questions: social observation, documentation analysis and asking questions, whether using questionnaires or interviews, which might also include panels and focus groups.

The research method chosen might take an “open or an unstructured” approach, or be of a “pre-coded or a structured” form, offering researchers a plethora of potential solutions. However, an evaluation of the advantages and disadvantages presented by both methods (Fisher 2010, pp. 174–181; Bryman & Bell 2011, pp. 424–518), with safety-risk management as the backdrop, suggests that the interview approach might be the better suited method to present a higher degree of plasticity.

Bryman and Bell (2011, p. 467) suggest that the type of interview approach used in qualitative research tends to be much less structured than that associated with social surveys. For these authors, making use of both the “unstructured” and the “semi-structured” methods is well suited to qualitative research as it permits greater focus on the research questions, provides space to corroborate the assumptions the researcher might hold, and helps in the development of new explanatory possibilities for the research questions. The former is based on a list of topics or “aides-memoires”, which the researcher uses to cover a range of subjects, whereby the interview resembles an informal conversation between the interviewer and the interviewee. As to the latter, the “semi-structured” method is supported by a list of questions that cover more or less specific points, but the interviewee still has a great deal of leeway in how she or he answers the questions. In addition, the sequence of questions may not follow the outlined schedule, and additional questions might be added to address any significant issues that surface during the interview or to allow more in-depth discussion of a subject within the topic.

On the subject of open and pre-coded interviews, Fisher (2010, p. 181) adds that an open approach is appropriate on occasions where the researcher does not anticipate the answers or when she or he is “looking for new ideas”, while Oppenheim (2005) suggests that it is the respondent who usually leads the interview. However, the interviewer can steer the course of the conversation somewhat by exploiting the leads and cues presented by the respondent.

The current research will have the flavour of an “exploratory work”: its aim is to provide insight and understanding into how stakeholders handle and overcome the identified gaps. There is a large amount of research identifying the drawbacks of risk tools in the academic literature, as seen in the CLR. However, few studies have been dedicated to either understanding the implementation of the new models in practice or to reflect on the theories of operational staff (Underwood & Waterson 2013; Swuste et al. 2019). For this reason, the semi-structured interview technique was chosen as the most adequate method for this research, providing the interviewee freedom to speak about the subject, while offering the interviewer the opportunity to delve deeper into areas of interest (or pick up on new areas) using diverse modes of inquiry as suggested by Kvale (2007).[60] Low (2013) identifies the advantages of the semi-structured interview technique by specifically looking at how it allows researchers to explore the independent thought of specific stakeholders within the organization and how it gives meaning to or provides understanding of their experiences. Adams (2015) on the other hand asserts that the semi-structured interview method provides

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[60] Kvale (2007, p. 60) proposed nine different types of questions: “introduction; follow-up; probing; specifying; direct; indirect; structuring; silence; and interpreting”.

an ideal way to probe candid views and obtain and pursue useful clues, which would probably not be possible within a group of peers.

As to the type of questions that help to structure the interview, Prasad (1993) suggests using a “grand-tour” and “mini-tour” strategy. Here, the idea is to begin with the exploratory and broad “grand tour” questions, focusing the interviewee on areas and topics of interest, and then to follow up with “mini-tour”, specific and detailed questions when the interviewee touches upon any subject that relates to the research questions. The critical incident technique (Flanagan 1954) is another method used in semi-structured interviews. This approach is based on occurrences that allow the extraction of inferences and predictions about specific performance activities related to the research. The interviewee is asked to support their argument with examples where the output went well or not so well. Bryman and Bell (2011, p. 479) also broached the subject of structure, suggesting that the use of a “doorknob question” at the end of the interview will give the interviewee the opportunity to bring in any issues perceived to have been overlooked by the interviewer, or to put forward a personal point of view. The subject of risk management seems highly suited to these techniques, not least since safety improvements are based on analysis of occurrences viewed from multiple perspectives (Owen 2001). The questionnaire in Appendix E.1 follows the above recommendations.

Challenges may develop in the course of a qualitative interview. Kvale (2007, p. 9) draws attention to the power asymmetry that can characterize the qualitative interview, namely when the interviewer holds a monopoly over the topic, defines the questions, interprets the respondent’s statements, and decides which response to follow up. He warns that this can create a sense of dominance over the interviewee, making the subject “feel like an insect under the microscope”, the outcome of which might be a “counter–control” response. Roulston (2010) also addresses the challenges that the relationship between interviewer–interviewee might create. He recommends that the interviewer prepare the interview carefully so that it is designed to be flexible when dealing with unexpected events; that the interviewer maintains a neutral viewpoint during the interview while also expressing empathy with the respondents; and to be a good listener while also maintaining the ability to carry out a positive sceptical analysis.

Kvale (2007) recommends recording the interviews to give the interviewer the freedom to observe the expressions and body language of the interviewees, catch the subtleties and nuances of the interview, and attend to any discrepancies in the respondents’ answers. Miles and Huberman (1994) support Kvale's approach in relation to the importance of attentiveness, but adverts to avoiding imposing of the interviewer's biases and views of the topic. Kvale (1996) warns against seeing interviewees replies as descriptions of their interpretation of a specific phenomenon; the replies should not be treated as definitive knowledge but as a perception of reality. This perspective proved highly effective for the research, it allowed the researcher to leverage the data from the interviews and develop understanding from numerous sources, while also maintaining a mindful position as to the senior (management) position of each interviewee and in employing a neutral attitude throughout the interview process.

The native language of the researcher, whose first language is not the English, was another subject that deserved due consideration. In this regard, Meriläinen et al. (2008, p. 592) warned that translation often implies a loss of meaning, namely in relation to the "untranslatability of localized voices". Huiping Xian (see Bryman & Bell 2011, p. 488), identified three areas where translation might be hampered by cultural differences: linguistic, socio-cultural and methodological. To overcome the potential drawbacks, rather than back-translating, as initially suggested by Bryman and Bell (2007, p. 496), Xian recommended the use of footnotes as a way of adding contextual understanding to make the translation more meaningful. In addition, maintaining an unbiased approach, translating the interviewees' accounts literally, and the application of all transcription conventions (Kvale 2007), all help to maintain the integrity of the respondents' accounts. Nevertheless, in the current research, expressions that may hold different meanings or convey several messages were retained inside square brackets.

Access to interviewees from among high-ranking officials within the commercial aviation sector constitutes a variation known as "elite interviews" (Welch et al. 2002; Kvale 2007; Fisher 2010). This type of interview raises several difficulties, including obtaining access, power asymmetry, providing feedback and ethical concerns. The subject of access was given due consideration; it was obtained following Aberbach and Rockman's (2002) recommendation of writing an imprimatur letter addressed to the interviewees on university letterhead, explaining the project, and accompanying this with some sample questions for perusal. This certainly helped the researcher gain access (Thomas 1993). The use of social and professional contacts alongside careful planning as recommended by Ostrander (1993) and Fitz et al. (1994) proved to be an invaluable asset, and the snowball technique put forward by Fisher (2010) was also valuable. The standard letter sent out to prospective interviewees is presented in Appendix E.2.

4.5 Research Participants, Data Collection, Aggregation, and Discursive Analysis

Section 4.5 highlights the criteria used in the selection of interviewees who have taken part in the research and provides information on their backgrounds. In addition, it outlines the interview process, data collection and the process of analysis.

4.5.1 Interviewees and the Selection Criteria

The research is divided into two phases: The initial phase focused on drawing a clear framework around how airlines manage risk, the purpose of which was to generate ideas about what should be improved or carried out differently to overcome the identified research gaps. Similar to Sackmann's (1991) approach, the interviews were used to tease out the best strategy to tackle the weaknesses identified in aviation safety-risk management. Then, using this acquired knowledge, the second stage of the research sought to generate a new approach, which is reflected in the "Oyster Model" (see Chapter 6).

The research is supported by a qualitative methodology, with semi-structured interviews deemed the method most appropriate to examine risk management, providing a varying degree of depth, insight and understanding about how stakeholders handle and overcome the identified gaps. The need to obtain a thorough understanding of the field justified the number of interviews that compose the sample.[61] Over a period of nine months, 26 interviews were carried out. Appendix E.4 presents the interviewees' profiles. The interviewees' professional roles range across the risk-management functions, to cover the whole organizational structure, as follows:

- Commercial aviation: Six executive board members, nine safety managers, four safety analysts and one independent researcher. The majority of the interviewees hold

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[61] Several authors have developed formulas to calculate an acceptable number of interviews. Kvale (2007, p. 44), for example, suggests a basic heuristic model – approximately 15 ± 10 – based on available resources and in a diminishing return law. Bryman and Bell (2011, p. 492) have contributed to this area also, suggesting a different approach to qualitative data based on the number of interviews, which allows a "theoretical saturation" to be reached.

extensive knowledge and experience in risk management. The sample distribution range is across nine different airlines, including two that are considered flagship carriers, and six countries.

- Healthcare industry: Two heads of patient safety and two researchers.

The 26 interviews are representative of the commercial aviation sector. The sample includes legacy, charter and regional commercial aviation organizations and the supporting activities of, for example, maintenance and handling. A comparative perspective and the development of benchmarking analysis was developed by including similarly hazardous industries, specifically the business aviation sector and healthcare industry.

The research set out to collect different understandings and cultural nuances within each company by implementing a stratified interviewing criterion. The option is in line with the safety-organization structure advocated by ICAO (2018b, p. 9-8): SRB and SAG. Hence, the plan was to conduct at least two interviews within each organization with executive board members, preferably one responsible for flight operations, along with the safety department director – the safety manager –, or, alternatively, a safety manager and a safety analyst. Where feasible, three management levels were interviewed: on two occasions, this was possible, but only two levels were interviewed in three other organizations. The four healthcare professionals belong to different organizations.

Of the dataset as a whole, six of the interviewees were female, which represents approximately a quarter (23%) of the total sample. While the gender imbalance is recognized, it is notable that this is an issue not restricted to the aeronautical industry; Ferraz (2012, p. 98) acknowledged a ratio of 3.3% of women occupying senior positions in the Portuguese banking industry. However, a comparison within the aeronautical industry, taking the leading European commercial aviation company board members (executive or non-executive) as the interviewee sample, provided a figure of 27%. This ratio is similar to that presented in the current research sample.[62] This sensitive issue has attracted deserved attention from the

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[62] In a survey carried out on 25 May 2020 among Europe's leading commercial aviation organizations, comprising board members from 11 airlines, a *ratio* of 27% women was reported. The survey targeted the following airlines:

- Aeroflot (0 in 11) https://ir.aeroflot.com/en/corporate-governance/board-of-directors/
- Air France/KLM group (7 in 19) https://corporate.lot.com/pl/en/management-board
- EasyJet (4 in 11) http://corporate.easyjet.com/about/management/board-of-directors
- Icelandair (3 in 8) https://corporate.lot.com/pl/en/management-board
- LOT (1 in 6) https://corporate.lot.com/pl/en/management-board
- Lufthansa (1 in 7) https://investor-relations.lufthansagroup.com/en/corporate-governance/executive-board.html

industry. For example, a recent decision approved by Lufthansa (2019, p. 9) noted that: “The Supervisory Board has confirmed the basic target of 30% for the proportion of women on the Executive Board and has set 31 December 2021 as a deadline for meeting this target. Until 31 December 2019, women accounted for 17% of the Executive Board; as of 1 January 2020, they account for 14%.”

The ratio between female and male pilots presents another example of the representativeness of the sample: a recent study of gender disparity on the flight deck, McCarthy et al. (2015) asserted that only 3% of airline pilots are women. Again, this confirms the predominance of male pilots in the commercial airline industry.

Although the selection criteria for the current research had not sought specifically to look into the imbalance between males and females in the industry but, rather, had set out to select specific roles within organizations, nonetheless, it can be concluded that the sample mirrors the status of the gender gap currently within the aeronautical industry.

As discussed in the ethics section below (at 4.6), the welfare, anonymity and confidentiality of the interviewees has been protected when citing the interviewees. Appendix E.4 (Interviewee Profiles) gives details of participants’ pseudonyms. To detail their function alongside their pseudonym, each interviewee is identified using a pair of letters as the legend of Table E.12 explains, and former professional experience is similarly anonymized.

4.5.2 Data Collection, Aggregation and Discursive analysis

Figure 4.15, below, illustrates the process of data collection, aggregation and discursive analysis implemented for the research described in this section.

- Ryanair (4 in 12) https://investor.ryanair.com/directors/
- SAS (5 in 11) https://www.sasgroup.net/about-sas/board-and-management/sas-board-of-directors/
- TAP Air Portugal (2 in 12) https://www.tapairportugal.com/pt/sobre-nos/administracao
- The International Airlines Group (4 in 12) https://www.iairgroup.com/en/investors-and-shareholders/corporate-governance/board-of-directors
- Turkish Airlines (1 in 9) https://investor.turkishairlines.com/en/corporate-governance/board-of-directors

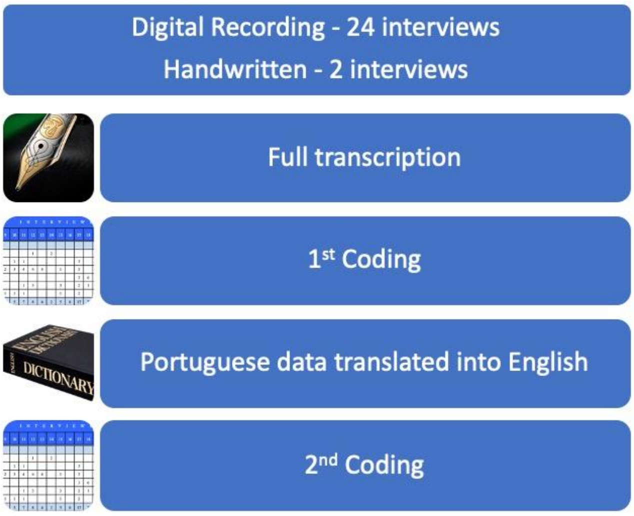

Figure 4.15 – Process of data collection, aggregation and discursive analysis

A summary of the data collected, showing the details of the interviewees, recordings, transcription and language, as well as the word counts, is illustrated in Appendix E.5, Table E.13 (Interview data).

All interviews were digitally recorded, with the exception of two that took place within the same organization. After the interviews were transcribed in the original language, the discursive material was subjected to a content analysis (Hsieh & Shannon 2005).[63] The use of an abduction stance (O'Mahoney & Vincent 2014) allowed the main topics within each gap to be identified (1st coding). Each unit of the recordings representing the interviewees' assertions were matched to a "conceptual element" of the research (Spurgin & Wildemuth 2017). A quantitative approach was used to identify the relevant themes. The absolute frequency of each unit supported the coding selection, whereby all results below 2% were excluded.

The approach described above allowed the relevant subjects within each gap to be understood. An exception to this stance relates to the bow-tie method, this is because, although this is a concept used frequently, users often do not realize they are using it. This explains why the scores in this respect are reduced in the interview coding. Having identified the main subjects, the relevant Portuguese data was then translated by the author into English, using the method discussed at section 4.4 (Research Methods and Design Strategy).

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[63] "[C]ontent analysis is defined as a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns" (Hsieh & Shannon 2005, p. 1278).

Following the initial coding, where relevant statements were associated with each gap (1st coding), the discursive material was then reviewed, annotated, compiled and merged for a second time to obtain the final coding (2nd coding).

The whole exercise, based on "summative content" analysis (Hsieh & Shannon 2005), allowed the underlying meaning of the interviewees' accounts to be extracted and to inform the research questions being investigated. Although a quantitative selective approach supported the first coding, overall analysis of the discursive material extracted meaning from the interviewees' accounts (Zhang & Wildemuth 2017). Appendix E.6, Table E.14 (Interview coding) provides a kind of "coding guide" to show development of the process.

Sections 5.1 to 5.5 discuss the whole dataset obtained from the discursive material once it had been merged. Please note that the discursive material that was unclassifiable within the premise of the identified gaps, but considered relevant to the research none the less, was assigned to the emergent issues of section 5.5.

The findings drawn in a recapping paragraph at the end of each section are brought into relation with the "Oyster Model", associating each finding with its respective gap. To facilitate the identification and numbering of each finding, each was given an identification in order of sequence, thus, for example, [F1.2] is associated with the second component of Gap 1 – "Development of Safety Boundaries". Whenever more than one finding relates to a gap, each is referenced by adding an extra letter, thus for two findings: [F1.2a] and [F1.2b]. A summary with the whole set of findings in included in section 5.6.

Finally, although there is no consensus about the taxonomy used to assess qualitative research (Zhang & Wildemuth 2017), the characteristics put forward by Lincoln and Guba (1986)[64] were considered, and in light of this, the current research can be said to achieve the high degree of quality by which to understand reality, using the philosophical lens of the critical realistic.

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[64] Lincoln and Guba (1986) put forward four criteria to assess qualitative research: credibility, dependability, confirmability, and transferability. Bradley (1993, pp. 436–437) defines credibility as "adequate representation of the constructions of the social world under study"; dependability as "the coherence of the internal process […], and the way the researcher accounts for changing conditions in the phenomena"; confirmability as "the extent to which the characteristics of the data, as posited by the researcher, can be confirmed by others who read or review the research results"; and finally, transferability refers to the extent to which the working hypothesis can be transferred to another context.

4.6 Ethical Thoughts and Moral Considerations

The ethical and moral debate deals with "drawing the line" to distinguish between ethical and unethical research practice; it is a discussion that helps researchers make personal decisions about their activities. Specifically, it ensures that the research addresses worthwhile objectives, guarantees the welfare of participants, and helps to settle any conflicting goals and values (Diener & Crandall 1978). Risk management deals with hazards, incidents and accidents, which may jeopardize customers' fidelity and ultimately could undermine trust in an airline. Therefore, safety is a paramount asset in the commercial aviation industry, which an airline must work hard to preserve, and, consequently, requires that all matters that may breach its integrity are treated discreetly and with reservation. This is a chief reason for advance reflection before engaging in the research proposed.

Bryman and Bell (2011) identified four main ethical principles that should be addressed in business research, specifically: whether participants may suffer harm; absence of informed consent; invasion of privacy or whether there is any kind of deception involved. While Diener and Crandall (1978) asserted that mistreatment and serious harm is uncommon in social science research, nevertheless mitigating risk to ensure minimum harm to participants ought to be the aim of any researcher. Miles and Huberman (1994) believed that any qualitative study has some degree of real or feared harm (damage) associated with it. An array of potential harm or damage could result from the research, ranging from subtle consequences to those of greater magnitude.[65] Moreover, in the same volume, Miles and Huberman alerted readers to the fact that the existence of potential harm will have repercussions which affect both access and data quality. The prospect of causing harm might therefore lead researchers to inadvertently revise or eliminate conclusions or even self-censor them.

Fisher (2010) recommended adherence to academic ethical codes and, where applicable, gaining ethical approval for the project beforehand. In this regard, Bryman and Bell (2011) identified other potential sources for guidance, such as the codes of conduct developed by professional associations.[66] Appendix E.3 provides the informed consent form where these

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[65] Harm to interviewees can range from subtle consequences – emotional harm, blows to self-esteem, tarnishing someone's image or position – to effects with greater magnitude, such as jeopardizing someone's career prospects, or in extreme situations, interviewees being sued, or even arrested.

[66] This requirement is also addressed in NTU's Research Ethics Policy – Section 3 – General Principles (NTU 2019).

issues were addressed. Ethical approval was submitted following Nottingham Trent University's research ethics policy, the Professional Doctorate Courses Ethical Approval Checklist, and the research was approved.

Diener and Crandall (1978) added other relevant ethical principles related to professional matters, including falsification of the research findings and the relationship between science, values and society. The last point relates to the influence that the researcher's values and beliefs could exert during development of scientific research and the impact that science has on society. The project discussed and considered these aspects from the outset and has paid heed to them continuously over the course of the research.

Bryman and Bell (2011) stressed that consent in itself is not sufficient to fully protect the welfare of respondents, specifically when dealing with elite interviewees whose identity can be easily tracked and/or discovered. Unlike surveys where anonymity and confidentiality[67] is ensured by way of computerized statistics, interview-based research raises sensitive ethical dilemmas in relation to the publication of the respondents' accounts (Kvale 2007). Therefore, anonymity and confidentiality form a vital tenet of the research; all records comply with the Data Protection Act (1998);[68] and the interviewees and their accounts are referenced with pseudonyms and codes identify their role within the organization. Appendix E.4 – Interviewees' Profiles – contains the details of each interviewee.

Diener and Crandall (1978) supported anonymity and confidentiality on the same basis, but also added that as this level of confidentiality provides greater security for interviewees, they are inclined to be less inhibited and more likely to answer questions honestly. Complementarily, Kvale (2007) believed that anonymizing subjects works as a protective feature in the researcher's favour in that they gain the privilege of control and the right to publish. However, Diener and Crandall (1978) also warned against the researcher falling foul of "paradigm bias". They pointed out this bias in particular not just as an example of unethical behaviour, but more as the consequence of the solitary work of researchers, who not only have a monopoly over the type and content of the questions to be asked, but also decide which data to collect and how to interpret the results. To avoid this potential problem, the same authors recommended that researchers analyse data critically and from several different viewpoints. In this regard, while Grinyer (2002, p. 1) acknowledged anonymity, he also

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[67] Anonymity relates to the identification of respondents' names and locations, whereas confidentiality relates to the researcher not disclosing his or her sources (Fisher 2010).

[68] See the Data Protection Act online at http://www.legislation.gov.uk/ukpga/1998/29/contents.

recognized that this might develop as a sentiment of emptiness among respondents, creating a sense that they “lose their ownership of the data when anonymized”. This did not occur in the current research: to avoid this potential problem, the researcher analysed the data critically from several different viewpoints and continually considered the data in light of his own biases and beliefs, mindful of how these could adversely affect the research. Therefore, in order to eliminate any potential biases or any conflict of interests that could affect the current project, no stakeholders with whom the researcher is currently working, or with whom he has worked in the last five years, took part in the research. Moreover, the project has been funded entirely by the researcher himself, thereby negating any potential pressure from financial or organizational entities.

Following the aforementioned recommendations, a subsequent internal reflection, and taking into consideration of the subject of the current research, informed consent, anonymity, confidentiality and absence of any kind of deception, applied as safeguards, are viewed as capable of satisfactorily protecting the interviewees’ welfare.

However, this said, the researcher’s academic supervisors will have access to the interview records, and, under extraordinary circumstances, the jury will be granted access also as part of the examination process, but in either situation, anyone with access will be bound in law to maintain strict confidentiality.

Chapter 5 will now introduce the qualitative research, specifically with the aim of deriving support for the “Oyster Model” presented in Chapter 6.

5 Qualitative Research: Analysis of the Interviews, Identifying the Gaps and Arriving at the Research Findings

5.1 Gap 1 – Safety Boundaries

Controlling and understanding risk exposure is the primary objective of any airline. But no matter the industry sector, for any organization to protect itself comprehensively, every single individual, department or division should share the unified vision and understanding of what the acceptable risk exposure for each threat is within the organization. Nevertheless, this is a challenging task; as Kwak and Laplace (2005) have asserted, risk "tolerance"[69] is a neglected subject in many firms, which is rarely communicated effectively throughout the organization. An organization's ability to define its acceptable risk exposure is therefore highly relevant. Section 5.1 now tries to close Gap 1 by delving into what practices stakeholders use in handling the subject of safety boundaries.

5.1.1 Bridging the Gap

Gap 1 is associated with strategic question 1 [SQ 1], "*Safety boundaries: How are the safety boundaries defined and communicated?*" SQ 1 is depicted in Table 3.1. This strategic question incorporates two research questions: RQ 1.1 – "*How is the actual safety-risk exposure defined?*" and RQ 1.2 – "*How is the actual safety-risk exposure communicated throughout the organization?*" The purpose of these research questions is to explore how executive directors establish safety limits in line with the organization's exposure to risk; how do they define which strategies to implement, decide which to communicate, and disseminate the acceptable risk exposure throughout the organization?

The heading to this pre-introductory phase to Gap 1, "Bridging the gap", acknowledges the essential link between executive directors and practitioners and seeks to understand how safety boundaries are defined in organizations (RQ 1.1). Lary-AB, a lecturer and former board member in a flagship carrier, offered a board member's perspective, stating: *"We had a*

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[69] Risk tolerance is equivalent in meaning to risk exposure.

series of indicators; they were basic, but, generally speaking, they performed very well with the available information. […] The number of incidents, the number of aircraft dents per flight, the number of low-fuel reports, and the like.” Tavares-AB asserted, *“We are very much focused on management indicators. […] We have some safety indicators.”* Gordon-AA described how strategic decisions are taken regularly at six-month intervals: *“After identifying and examining a new hazard […], the limits are agreed and approved by the CEO. The approval starts within a specific Safety Action Group – Flight, Maintenance, Ground operations –, where the new hazard is discussed, and then presented at the Safety Review Board, a meeting chaired by the CEO, held every semester, where the strategic safety decision is taken.”* Lary-AB exemplified and corroborated the practice: *“We had a regular meeting every six months with the whole board and with the people who worked [...] in the [Safety] area where we spent all the time needed to uncover everything.”* However, when asked whether the company’s strategy somehow affected the definition of the organization’s risk-exposure level, Lary-AB stated that “[*Even*] *in the expansion* [*period*], *when opening up new routes to more sensitive markets, [...] like Africa and the like [...], no way, we haven’t even considered!”* Lary-AB supported this statement with an example: *“The entry of 100 new pilots at the same time or in a short time in an operation naturally increases the risk inherent in everything else. However, [...] there was no consideration at all. [...] That’s what it was [...]. You would say that ‘this is poor risk management’. […] And if I stop to reflect on it, I would say this is an improper risk-management practice. […] We should have programmed the operation to accommodate 20 pilots every six months, instead of 100 at the same time. This is a significant [labour] force in our company.”* John-AB took a similar stance; although he does not interfere with safety management, he stressed: *“The safety department is undertaking [the performance indicators] and reviewing them […] we don’t go into the details.”* When confronted with a similar question about the impact of the organization’s safety policy relative to its definition of the safety boundaries, Santini-AS replied: *“I will answer in another way. [...] I am satisfied with the outcome. There has never been a time when we have not taken them into account; i.e. failed to ensure implementation of the defences to reduce high risk to an acceptable, or low risk. There has never been a time when I suspected the defences were not implemented and yet the operation went ahead.”* Although not in direct response to the question of how the board defines risk in relation to safety boundaries, the account of Santini-AS, which wisely circumvented the question, indicated that the safety department established and judged risk and this was not something done directly by the executive board with its respective commitment and empowerment. Gary-AS supported the previous claim saying that: *"Our COO [...] has not defined with certainty [...] any levels [of risk]. [...] To copy a matrix is an error."*

Theoretically, the distance that exists between board members and operational staff[70] has its roots in the way the ICAO's safety framework is designed. Strategic guidelines are decided at Safety Review Board (SRB[71]) committees, an advisory board that includes the accountable manager[72] and senior managers, whereas operational implementation is carried out at Safety Action Group (SAG[73]) level. Managers and front-line personnel ordinarily compose part of the SAG committee (ICAO 2018b, p. 9-7), thus rendering operational staff's access to the CEO a challenge.

Still from the perspective of management, interviewees were asked to identify relevant safety concerns or areas where they felt their operation was more exposed to safety risks. George-AB stated: *"So long as the [area] is able to control [a specific] risk, it manages it from the technical or knowledge perspective. When the risk exceeds the areas' capacity, it is escalated to higher echelons."* John-AB, a Chief Operation Officer (COO) and executive director, clearly found addressing the subject difficult,[74] thus he stuttered and fumbled during his reply: *"Well, no, not specifically as far as, yeah [...]. As far as [...] specifically to those departments, is to what [...] of doing [...], I mean as far as ...."* During the interview, John-AB remembered an event he had in operation when a "prolonged loss of communication"

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[70] "Operational staff" and "practitioners" are used interchangeably and both relate to the same or similar roles.

[71] "The SRB is strategic and deals with high-level issues related to safety policies, resource allocation and organizational performance. The SRB monitors: a) the effectiveness of the SMS; b) timely response in implementing necessary safety-risk control actions; c) safety performance against the organization's safety policy and objectives; d) overall effectiveness of safety-risk mitigation strategies; e) effectiveness of the organization's safety-management processes which support:

1) the declared organizational priority of safety management; and
2) promotion of safety across the organization" (ICAO 2018b, p. 9-7).

[72] "Accountable manager" may be used interchangeably with "accountable executive". ICAO's definition is "A single, identifiable person having responsibility for the effective and efficient performance of the service provider's SMS" (ICAO 2018b, p. vii).

[73] "SAGs are normally composed of managers and front-line personnel and are chaired by a designated manager. SAGs are tactical entities that deal with specific implementation issues in accordance with the strategies developed by the SRB. The SAGs: a) monitor operational safety performance within their functional areas of the organization and ensure that appropriate SRM activities are carried out; b) review available safety data and identify the implementation of appropriate safety-risk control strategies and ensure employee feedback is provided; c) assess the safety impact related to the introduction of operational changes or new technologies; d) coordinate the implementation of any actions related to safety risk controls and ensure that actions are taken promptly; and e) review the effectiveness of specific safety risk controls" (ICAO 2018b, p. 9-7).

[74] The question unsettled and embarrassed the interviewee to the extent that it was necessary for the interviewer to help him with possible answers, which, even so, the interviewee did not understand. The interviewer summarized for him: "*So, I have understood that you are complying with and following what the legislation is asking you to do and that you do not have top priorities in terms of hazards, although you are monitoring the operation.*"

(PLOC) was experienced by an aircraft in European territory. When asked whether he was familiar with any kind of metric that could have helped him track exposure to the hazard, he questioned the concern, saying: *"What are you talking about?"* Tavares-AB, general director of a major handling company, identifies his main concerns in relation to individual training and to obsolescence and maintenance of ground support equipment (GSE). When asked to explain how the risk was monitored, he linked the safety concerns to SPI, although his main apprehension related to customer and operational improvement: *"Our company business model is based on specific key processes. [...] All these [three] fundamental processes, linked to the operation, have defined KPIs*[75] *of [...] productivity. All the various components of these are set at the beginning of each year [...], and then we have financial indicators as well. We [also] have performance indicators of our own [...]; on punctuality, regarding each customer, based on [...] the volume, to accompany and to implement some [of the] improvement plans."* Martin-AB, an executive director and accountable manager of a regional airline, mentioned: *"The last time we addressed this issue [of Safety Boundaries] was [...] recently in September. If I'm not mistaken, [...] during the last SRB, a more detailed [...] [analysis] occurred after a hard landing we incurred [...] at XXXX*[76]*."*

From the interview data offered so far, individual board members' difficulty in answering the questions is perceptible. Nevertheless, independently of their commitment, these interviewee accounts demonstrate that stakeholders are not familiar with the safety-management system framework, but rely (totally) on their organization's safety departments to manage the safety. Furthermore, difficulties in pointing to the main weaknesses of their operation, pinpointing where sharper attention was needed, was commonplace. At most, interviewees were able to recollect single events experienced by their organizations, while their ability to convey the current risk level exposure was not obviously forthcoming.

The "Bridging the Gap" phase viewed from the practitioner's perspective – that is, from the standpoint of safety managers and analysts, is also relevant to Gap 1 and RQ 1.1. Gary-AS understood that: *"[The CEO] [...] does not have direct contact [...] with the concerns. [...] I intend to create [...] a way for him to take a clear view of where we are in our operation regarding risk. Not in great detail, but in order for him to be able to understand that our activity [...] presents specific risks [...]. I've been discussing the subject. [...] I started the*

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[75] Stakeholders used the expressions "KPI" and "SPI" interchangeably. These mean "key performance indicator" and "safety performance indicator" respectively.

[76] XXXX represents the ICAO code for the airfield mentioned by Martin-AB.

discussion yesterday about the possibility of [...] developing a dashboard, a simple one, which he [...] can consult on a daily basis [...] [containing what] I consider the most relevant." Kostas-AS recommends that safety should be put on the same level as the commercial branch of the company, stating: *"If a company wants, hypothetically to consider zero risks and wants to ensure no accidents occur, it will stop flying. [...] Safety realistically has to be balanced with commercial and other decisions."* Jeremiah-AS presented a possible reason for the differences in knowledge, in his view: *"Safety is not adapted to employ financial language. [...] It is difficult for safety to demonstrate the concerns it has quantifiably in understandable language [for executive directors]."* Furthermore, he thought: *"that [executive directors] attribute importance [to safety boundaries] if they are translated into language commonly used at management level – that is, to the costs, whatever they are. Typically, financial value, but, apparently [...], cost translates to fatalities, injuries or anything that in the end has an economic or image impact."*

It is also pertinent to the discussion to understand how the risk tools are calibrated and how they are used to measure risk exposure in the organization. Jeremiah-AS states: *"Neither the ARMS matrix [...] nor the ICAO matrix [were] validated by senior management. The five levels of severity and probability [...] should reflect the board's view across [...] the acceptable level of risk. [...] [Internally, the matrix] was taken directly from ICAO documentation. I do not know what assumptions ICAO has [considered]."* Customization of the risk tools is developed further in Gap 2 (Risk tools) under each of the tool's characteristics.

Practitioners acknowledged that executive directors lacked knowledge; frequently admitting that their superiors were not acquainted with the organization's risk exposure, and pointing out how safety data was not adapted to be easily interpreted by executive directors. This lack of knowledge may explain the distance that exists between professionals, even though their strategic decisions have potential to adversely affect the organization's risk exposure.

Thus, the research supports that there is a barrier between executive directors and operational staff. It is suggested that this shortcoming is an influential factor in the safety boundary gap [SQ 1, RQ 1.1, RQ 1.2]; specifically, in the definitions used, the commitment of board members to pursue the delineated safety objectives, and ultimately, in the definition of their risk exposure. Furthermore, the statements shed some light on the unstructured way safety limits [RQ 1.1] are defined, which are in line with the findings of the critical literature review. The main findings from the accounts as cited are as follows:

1.1 Executive directors are concerned with the subject of safety. However, from their accounts, it is perceptible that they are neither familiar with the SMS framework nor with the risk exposure of their organization [F1.1a]. Safety figures differ significantly from the financial jargon, the latter being the language executive directors are trained to understand. Consequently, executive directors neither contribute to nor establish guidelines to help develop safety boundaries [F1.1b]. Moreover, the approach of executive directors' evaluations of the impact a particular strategic decision might have on the risk exposure of the organization is unstructured. Finally, the framework established by the ICAO sets the two hierarchical levels apart by promoting meetings (SRB) only on an occasional basis – normally at six-month intervals – as demonstrated in practice [F1.1c].

5.1.2 Development of the Safety Boundaries

The barrier identified above represents a hurdle that constantly challenges practitioners as they go about their daily activities. The analysis carried out and detailed in this section sought to understand how the safety boundaries are drawn [RQ 1.1].

In this specific area, the research set out to identify interviewees' understandings of the concept of safety boundaries and to learn how this informs the development of them. Lary-AB viewed them as: *"statistic; it related to the number of incidents that were tolerable and particularly the reasons for them."* John-AB took the view: *"As far as the boundaries go […] the objective is […] to set the limits we allow. […] For me, a boundary is [the existence of] clear processes, checklists […]; for example, [at] what point do we raise our concerns?"* India-AS states: *"I understand [Safety Boundaries] as […] the organization's risk appetite – the limits that the organization accepts."* For Charles-AB, the safety boundaries represent a buffer zone, a "red line", to restrict hazards: *"There is the acceptable level […], below or above […] that KPI; if the red line is exceeded, that is a boundary breached. The indicators […] are goals that have been defined […], below or above [this value] marks it is dangerous […] and suggests how we are going to mitigate them."* Gary-AS's reasoning develops the stratified concept as proposed by the ICAO: *"Safety boundaries, I interpret them as the maximum acceptable limit, […] the various levels of acceptance […]; that is, there will be a* *boundary limit from which […] we do not operate, but up to the limit, there will be several boundaries. […] These various boundaries depend on several levels within the airline. Everyone […] must be aware of the limits that are permissible and acceptable."* Peter-AS stated simply: *"My [boundaries] are somewhat associated with [safety] targets."* The safety target (or risk exposure) is relevant to the development of safety boundaries. This subject is discussed below in section 5.1.4 – "Safety Assessment".

In the attempt to develop a methodology of proactive analysis, a significant portion of the literature addressed the occurrence component of the risk analysis as a probability (Cox et al. 2005; Cox 2008; Hubbard & Evans 2010). Nevertheless, the current research has shown that organizations work with frequency data instead. Lary-AB's statement is elucidative in this respect, for he used the statistical concept in his reasoning although his explanation supported the frequency approach: *"[using] a statistic; this is the number of incidents that were tolerable."* Furthermore, in this regard, George-AB asserted that: *"We benchmark, and therefore we accept that for every thousand hours [there may be] a determined percentage of incidents."* George-AB added: *"The objective […] is to reduce the number of technical incidents, […] then there is a series of [associated] metrics, and these metrics are [the] SPI. Some [SPIs are measured] monthly and others quarterly, others twice a year, and others annually."* Jeremiah-AS affirmed this: *"A boundary is anything that […] assumes a specific performance. […] A non-overtaking zone* [where] *[…] objectives [and] performance […] are measurable, below a specific value that each operator will define as comfortable [or] acceptable."* Jeremiah-AS presents an actual mitigation strategy: *"What was done pertinent to known events [was] to improve the occurrence rate […] by reducing it."* Santini-AS explains how his safety boundaries were developed and shows his support for the frequency approach: *"We took statistical data from the last five years and then [developed] the averages of everything in terms [of] absolute numbers and […] cycles, to understand how many [events] we had."* Jeremiah-AS used a similar approach to explain the construction of safety boundaries: *"The starting point is to understand what […] my history is […], what my average number of occurrences is and, therefore, whether this has been the historical reality over the past years; this is then the starting point."*

Frequency can and sometimes is used proactively to predict future occurrences. Charles-AB provides a good example: *"What troubled me about these indicators [was] the form of acceptance. If you have defined a target of six slides 'deployed' throughout the year, and if in* *the first three months you had zero, five, two, it means that the tendency is […] to fill and breach […] its limit in June. [Therefore,] we [can] begin […] to take action in advance."*

Nevertheless, frequency in itself does not provide a solution to determining risk exposure as the previous accounts might suggest. Rates of occurrence are not a synonym for the level of risk exposure. A high (or low) number of occurrences does not necessarily correlate to a high (or low) level of risk. This is not what one would derive from the previous statement, however; although this was in answer to a request to provide concrete examples on changes to the level of risk. When Martin-AB was asked to give an example of a safety risk where the exposure level had been modified, he replied: *"There is a theme we have been debating […] which I believe fits with the question posed [the boundary exceedance], which relates to […] stabilized approaches. […] Our normal operation is defined as green, […] but actually, through FDM, we have seen situations where this requirement is not being fulfilled in its entirety and […] this takes it to another level."* George-AB offers a similar revelation: *"[In a maintenance shop], we cannot accept more than 'a fixed number' of rejections for poor performance due to dust."* All of the interviewees' approaches treated every event as if each held the same level of risk. As this kind of approach lacks the severity of a risk component, it cannot, therefore, be associated with either an increased or decreased level of risk exposure. To evaluate the level of risk, the analyst must be able to take into consideration the level of risk of each occurrence.

Nicholas-AL, a lecturer and safety researcher in the aviation field, has a different understanding that stands in opposition to the frequency approach: *"The classic safety indicators [for me] are […] counting the number of times [events] happened. This I think is a very, very dangerous [practice] because you are just classifying events under certain titles. The problem is that there is no sensitivity to the severity of those events: All […] events that fall under the same category are in the safety indicator at equal value, even when in real life some of these cases could have escalated to an accident while others would not have had the same potential. […] So primarily, whatever sort of performance measure is used, it should be risk-based."*

Kostas-AS agrees with the use of metrics, however, in the same vein as Nicholas-AL, he acknowledges that further data is needed to support the conclusions: *"We [...] act according to the trend and by what is generating the pattern. […] The metrics help us to […] manage safety, but it is not enough to look at the metric and accept it as a […] final goal."* In relation to the issue of simplification, George-AB's account offered depth to the same concept, explaining how the boundary was developed: *"At the level of the significant indicators, we have nine […]. For example, […] the number of […] technical incident reports. But to achieve this minimum […] I have to have a series of controlled precursors. That is the reason for further 'cascading' this important objective."* Gary-AS made a similar statement, identifying the precursors as the main contributors to the activation of the hazards that affected his operation: *"We defend ourselves against three primary risks: loss of control, runway excursions and CFITs, and then we move backwards [to] try to figure out where we were most exposed. […] Our risk is higher when there is a specific airport infrastructure. [The contributing factors] traditionally range from […]: lack of radar control; […] runways of 2,400 metres long [with] reduced lighting, […] served by a [non]-precision approach; […] [operation] with aeroplanes close to maximum weight limits […] and, most of the time during the night."* Louise-HS took a similar approach to monitoring and establishing the safety boundary for risk infection; collecting data from several sources, she stated: *"We monitor the [infection] indicator every day. […] We have a programme that seek[s] information at various points in the patient's process and builds […] the indicator."*

A risk is composed of two main components: probability (or frequency as noted previously) and severity, both of which can be analysed from different perspectives.[77] Therefore, independently of the approach followed, it is intriguing why interviewees have not addressed the second component in their accounts. Nicholas-AL had an interesting explanation: *"There is no one way to say what the limit is, but I think it is more a human judgement. If you go one step further, […] you are not actually saying […] where the limits of acceptable risk are; actually, you are choosing the actions that you take and when you choose [to take these] actions […],a decision that implies which risks you tried to reduce and which risks you didn't try to reduce."* While Nicholas-AL's account could be seen as somewhat too radical, what he is actually saying is not: What he is indicating is that one's judgement should be based at a particular reference point, whatever that reference might be.

The research revealed how interviewees hold a common understanding about how to develop safety boundaries. They all supported development of them around the framework conveyed by ICAO (2018b). They also all supported the evaluation of safety boundaries through a

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[77] Depending on what is being secured, risk can take on different perspectives, namely: reputational, financial, health, environmental, compliance, and the like (Hopkin 2012).

frequency-based approach, whereby each event is considered as a single occurrence and where each occurrence presents a similar level of risk exposure.

It is essential that risk exposure incorporates details about the frequency and severity of any occurrence (Flage & Røed 2012; Duijm 2015); thus, it must be risk-based, as suggested by Nicholas-AL. The difference between the perspective the current research conveys, which embodies the "safety boundary" concept and the "safety objectives" espoused by the ICAO, constitutes a gap in the way practitioners currently assess their organization's SMS performance. This research confirms that a gap exists in respect of safety boundaries, and shows the difference between stakeholders' general understanding of the concept of safety boundaries and the safety-objective concept shared by ICAO (2018b). The current research has shown that when developing their risk boundaries, interviewees associated risk exposure with a concept of frequency. This is chiefly the same as presented by the literature (ICAO 2018b).

The following findings arose from stakeholders' accounts about how they view and develop their safety boundaries:

1.2 Operational staff define safety boundaries [SQ 1 & RQ 1.1] based on frequency. While this lends itself to a proactive perspective, it nonetheless hinders the objective of gauging the risk exposure faced by the organization, which could mean that it impedes the framework's ability to manage the safety risk [F1.2a]. Risk exposure is a complex subject, whereby construing it from one simple indicator is inadequate. In fact, it requires a set of data – such as the contributing factors mentioned by Gary-AS, George-AB, Nicholas-AL and Louise-HS – in order to reproduce, albeit deficiently, the reality faced by practitioners [F1.2b]. The current research suggests that the way safety risk is currently analysed constitutes a gap, which exists as a consequence of the way the safety boundaries are construed.

5.1.3 Blurred Boundaries

While this section could have formed a sub-paragraph to section 5.1.2 (Development of Safety Boundaries), its relevance means that it deserves separate attention.

The requirement set down by ICAO (2018b), which helped decide European legislation and IATA best practices (European Commission 2012; IATA 2019), drives stakeholders to develop ingenious tactics to demonstrate that their approach to SMS meets health and safety legislation, and is commensurate with the scope of their operation. In other words, the SMS submission can form evidence that an organization's safety-management system is improving, or at least show that it is maintaining its protective level. Many industry experts find the efficacy of these measures questionable, and Nicholas-AL's statement is poignant in this regard: *"Administrative […] work – SPI, graphs, audits and the like, where safety professionals develop a bunch of 'nice looking' measures to impress the auditors – does not add much to safety value."* While Nicholas-AL's account relates to the use of the notion of frequency solely to demonstrate SMS improvement, other flaws are worth highlighting too.

High-risk industries are characterized by the complexity of their systems (Perrow 1984; Dijkstra 2006; Dekker et al. 2011), which can create the blurred boundaries this section is discussing. For example, in an effort to cope with all the various scenarios an organization in this industry may have to deal with, the safety objectives, targets and goals frequently phrase things to allow for an extreme range of flexibility on the part of end-users. This type of approach, ultimately, is likely to generate ambiguous guidelines for practitioners, as they can then resort to using common sense sometimes instead (Rasmussen 1997), which could in turn be seen an unsound tool when evaluating the breach of safety situations. Jeremiah-AS's reflection on blurred boundaries calls for more clarity: *"The definition of boundaries […] should be clarified – sometimes not only explained – more robustly, and the way they are written should also intentionally allow for the existence of grey areas […] or less safe ones."* Sabine-HS struggles to define the safety boundaries that guide her practice: *"The patients' safety policy is not precise."* As to the directives' "woolly" phrasing, Jeremiah-AS provides an elucidative example: *"'Taking control' of the aeroplane by not allowing the pilot to fly could have avoided some events; however, the text that [exists] is sufficiently ambiguous to explain the non-action."* The same interviewee provides another example: *"The restriction that we have established with the wide-body fleet, which means we cannot backtrack*[78] *on a runway, is not clear. It says it is forbidden. […] However, immediately afterwards, it mentions that in […] specific cases it might be actioned with authorization from the leadership; therefore, it is forbidden and it should be avoided. […] This approach creates a mixed rule!"*

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[78] Backtrack, also known as backtaxi, is an airport ground procedure that allows an aircraft to taxi on the runway in the opposite direction it intends to take-off, or, after landing, to reverse the movement direction in a 180-degree turn on the active runway – inbound to the terminal.

This may go some way to explain why the industry persists in using the so-called "mixed rules", which the previous account from Jeremiah-AS espouses. Although the rules do tend to be standardized, the differences persist because of the myriad of regulators and, as the previous example mentioned, the number of airport operators, so airlines must maintain a minimum degree of flexibility to maintain operations. Jeremiah-AS alludes to an uncountable number of runways served by a single taxiway – put in simple terms, a unique entrance. The simple closure of an access could oblige airlines to backtrack on the active runway, which would constitute an exception to the rule. While it could be said that the use of an exception, in the belief that it is seldom used, could reduce the risk exposure to runway excursions, one could argue also that the rarity of the manoeuvre means that pilots seldom practice it in their daily routines. Therefore, the pilot's exposure to risk would be higher still and the mitigation measure would reveal the inefficiency, as the incidents Hradecky (2018, 2019c, 2019b) reported demonstrate.

Beyond having recourse to sound boundaries, it is essential that safety professionals also have confidence in the risk barriers or mitigation measures implemented in the system. Sabine-HS's statement concerning her trust in the barriers established in the system is paradigmatic: *"I cannot say […] that if you have a low-risk level it is acceptable. […] Because there are not enough barriers to avoid the incident."* Santini-AS admits to lagging behind in his evaluation of mitigation measures: *"[The Hazard identification list] is not static […], it is a dynamic. Every situation where we see that the mitigation measures are not implementable [or effective], we update the list. The problem is that we are not even in this phase. In some cases, we already know whether or not they are effective."* Sabine-HS expresses a concern about the reliability of the measures implemented in a healthcare setting: *"Inside [our premises] we had introduced another barrier – a purple bracelet for anyone with allergies to medicines. […] I have had […] incidents […] of patients who were allergic, whose intolerance was noted in the clinical process. […] They were wearing the bracelet, but the doctor prescribed a drug he was allergic to, and the nurse administered it; namely, there were no barriers. That is why I say this risk is still not acceptable."* Sabine-HS's account shows how mitigation barriers themselves do not guarantee a lower level of risk exposure, which is why it is important for the effectiveness of safety barriers to be measurable [RQ 2.2].

Mitigation measures may present additional flaws, since they have to adapt to a constantly changing scenario and risk professionals must ensure their applicability in the given environment. Sabine-HS raises questions over the effectiveness of the barriers currently installed: *“Over time, [barriers] have been modified and electronic systems [for] alerts have been introduced. Why do I say that it is not […] a low risk yet? Because the electronic warning systems in relation to allergies have not yet […] migrated to all users. […] I can have a patient who enters the operating room, and the nurse does not have an alert in the electronic system mentioning that ‘this patient is allergic to penicillin’, so he or she will have to ask the question again.”* Yet, although this interviewee questioned the universality of the mitigation measure and admitted that it had not yet reached an acceptable level of risk, still she could not provide a structured means to achieve “low level of risk”.[79] In order to assess the effectiveness of a mitigation measure one must be able to verify a reduction of risk, or show progress towards the desired effect or outcome to reach a specific target. Beyond risk-matrix colour-codes, there is no structured approach available for practitioners to ensure they have achieved the desired level of safety, since a boundary has yet to be set. Safety boundaries are defined based on the abstract concept of an “acceptable level”, understood as “as low as reasonably practicable” (ALARP). Sabine-HS acknowledges her use of the ALARP concept, commenting: *“We always work in this direction [ALARP], in a global way.”* She also acknowledges that comparison with a specific standard would not be possible: *“I think we have to move to a different […] more quantitative and more focused way.”*

Fatigue management is another example of a tool that might need calibration to take into consideration the specific working environment of professionals. Santini-AS’s account is self-explanatory; he confesses to using the fatigue tools as a black box, without understanding what is behind the computations: *“We have a program […] that controls our […] rosters, and we have adopted the […] metric […] that most companies use. Up to 70 (whatever the 70 means) is considered low; [from] 70 to 90 is considered average; from 90 to 120 is considered a high value; and from 120 upwards is considered an extreme risk. […] Each time a crew is employed, one sees the level of fatigue based on what they did before.”*

The challenges identified by the interviewees make it possible to conclude that, in order to enhance safety protection:

1.3 Operational staff must develop a means to evaluate barriers and to correlate effectiveness with the level of exposed risk. Hence, the risk tool needs on one hand to be able to

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[79] When questioned about the risk-of-infection policy, Sabine-HS stated that: *“[In] our policy we do not have [...] that type of definition. [...] Our policy states that [...] the level of risk must be controlled in the manner of ALARP: ‘as low as reasonably practicable’.”*

measure the level of risk exposure and, on the other, somehow incorporate the data provided from the level of protection implemented in the field [F1.3].

5.1.4 Safety Assessment

Having defined the safety boundaries (the “safety policy” according to the ICAO jargon) and established the safety mitigation barriers, this still leaves the question of how, when assessing a safety risk operational staff are to decide on the level of risk against the boundaries set by management [SQ 1, RQ 1.1]. How can management trust that risk assessments meet the limits defined by their own safety boundaries? The discussion that follows points to the relevance of this to consider how actual exposure to safety risk is communicated throughout the organization [RQ 1.2].

Although safety limits are poorly defined (Kwak & Laplace, 2005), the fact they exist holds general consensus among the stakeholders. Every interviewee acknowledged them, although implementing them was done in different ways, ranging from a partly decentralized to a fully centralized policy. Dissemination of indicators throughout the whole organization means that every manager is involved in overseeing safety performance, which is George-AB’s experience in his organization: *“The management sees some macro indicators, but then the indicators are cascaded. […] The directors have a lot […] of indicators that are their responsibility to monitor.”* In some organizations, the management of the indicators are centralized, this is the case for Dimitri-AS: *“The Safety Department regularly produces safety analysis [based] on […] SPI analysis, to be presented to the SAG.”* Nor do the indicators originate exclusively from inside the organization; external entities such as the regulators also impose targets on organizations, as Charles-AB points out: *“[Some] targets are defined [by] the national authority. [On the other hand], the remaining indicators […] are part of our […] manual that is handed over to the authority.”* According to Jeremiah-AS, safety targets have a motivational charge associated with them: *“I think the existence of a limit is desirable. As an operator, I will make efforts to have no more than a [determined] percentage of occurrences of this event. […] It mobilizes and establishes a commitment that, so long as [this percentage] is not reached, management will take no action.”* As seen below in section 5.3 (Safety Protection), targets can be associated with resources, as George-AB confirms when addressing the way these are managed: *“If [targets] are not within limits, I feel obliged to communicate to the management that I have an indicator that may be […]*

outside the bounds. Even to ask for additional resources." However, generally, the executive committee will approve these targets, as George-AB's explanation about implementation of the process in his organization illustrates: *"New indicators are approved in the SAG. We do periodic SAGs with each sectorial area [...]. There are SAGs for engines, for logistics, and for cabin problems."*

As Bentes-AA describes, his organization uses different approaches, based on the level of importance implied by the indicator, to decide at which level of the organization a decision should be made: *"The objectives, depending on whether the SPI is a high-level or low-level one, are defined either in the SRB or at the SAG."*

Safety limits, based almost exclusively on the frequency of events, have developed into a "risk-exposure uncertainty" among stakeholders. SPIs exist to measure almost every operational deviation, yet when Jeremiah-AS was questioned about the status of a specific one, he was unable to evaluate the organization's performance. *"I have no way of responding to what it is to be safe [or] what is it to be in danger [...], because I do not have a limit that tells me: if I have 10 occurrences per month I am fine; [...] what I do know is that I have a reality of exceedances. I have a [determined] percentage of exceedance [...] in the medium-haul, another in the long-haul, characterized by the airport, [...] but in the end, I do not have data that says: I am fine when I have less than [a specific value]."* Santini-AS voiced two major concerns, but he, too, was unable to evaluate their status: *"The quality of maintenance and the [practical] experience of the crews are the two [risks] that concern me the most. [...] I do not measure the experience of the crews, [...] [but do measure] the number of flight hours [...] and the turnover rate above average. [Over the] last year, I clocked up 500 flying hours [...] [but] only flew twice without being accompanied by a student."* Jack-AS can recall no discussions in relation to risk exceedance: *"That type of discussion has never occurred"*, he said. As noted, Charles-AB's organization uses frequency of occurrence to predict future risk, but he was conscious that, when exposed to an event, this method provides no measure of risk exposure, since it is the number of occurrences that defines the risk. He states: *"If you have defined a target of six slides 'deployed' throughout the year and had one in the first month, [when] extrapolating [...] your indicator, [...] [you] will be stuck [...] at 12, that is, one event per month."* Gary-AS expressed a similar attitude: *"The internal SPIs [...] are presented [...] at the [...] SAG. We explain how we intend to monitor them. [There is] tacit acceptance, there is no such process of [...] validating it, [defining] when we shall* *begin to react [...], there is no target defined, we just monitor and present the results to the SAG. We limit [the explanation] to show what is happening accurately."* Nicholas-AL's account also sheds light on some of the challenges that face stakeholders: *"As top management, one is not able to define a specific target; however, you might be able to establish a level of risk."* This statement aligns with Jeremiah's opinion in section 5.1.1 (Bridging the Gap) of how the safety figures do not lend themselves to a management perspective.

The interviewees' accounts are intriguing, revealing on the one hand their knowledge of the safety-management system and, on the other, demonstrating how unfamiliar they are with the framework. Martin-AB recurred to the use of the risk matrix to evaluate a specific risk: *"The hazard is assessed using a risk matrix, and if it is within the desired level it is accepted, whereas a risk with greater [...] criticality [...] will have to be evaluated by [...] flight safety."* Santini-AS seemed unable to identify the status of his two main safety concerns. When asked to elaborate on how he personally evaluated a risk, he chose to explain the method used within his organization: *"We define the level of risk according to its frequency and its criticality, and then with the mitigation measures we are able to implement, we evaluate what the [risk] level [...] achieved would be."* The same interviewee was sensitive to the level of risk generated by each occurrence when assessing spurious events: *"[The system] generated a TCAS ARRAY warning: therefore, the aircraft followed a descent guidance. [...] However, the vertical speed was too low to be able to generate an advisory from above, but there was in fact traffic on top in this case. Nevertheless, on the other two occasions there were no planes around."* Sabine-HS provided another example acknowledging how similar events might generate different risk exposures and, consequently, have distinct outcomes: *"In six hospitals, I have 503 records of patient falls. Of course, not everyone has damage associated [...], usually 70–80% [of falls] cause no injury to the patient."*

From the previous accounts, what emerges is a high-risk industry-wide safety assessment that almost exclusively bases measurement of risk on the frequency of occurrences. This is a consequence of the way safety boundaries are based (merely) on a frequency approach. Although there is a recognition of the need to incorporate the severity perspective when measuring a risk, the reality in practice demonstrates a different approach. The TCAS and patient falls examples provide insight into similar situations that hold completely different levels of risk. Clearly, therefore, not all events are classifiable according to the same risk levels. Section 5.3.2 (Longitudinal Monitoring) will bring other methods for measuring breaches to the fore. However, a speculative inference to emerge at this stage of the research is that the risk assessment challenge has to do with the tools available to measure and handle it, which is to say that, presently, the risk assessment is unable to incorporate the variables and the characteristics of different safety risks.

The gap identified in this section has the potential to develop into an uncertainty-exposure stance among stakeholders, compounded by the poor procedures used to define safety boundaries. Moreover, it would be interesting to research further into what lies behind the scepticism around risk exposure. This may well be one of the root causes that leads managers to question whether the resources spent on safety are worthwhile; in fact, whether the resources should be deviated at all from the productive areas of the organization. Furthermore, what is the difference between 20% or 24% of a specific frequency? This is the challenge that practitioners must overcome. However, were it possible to convert a frequency of occurrence to a risk-exposure perspective, the decision to direct investment towards safety probably would be seen as more reasonable. This is the challenge the current research proposes to overcome, for while one organization's exposure to a higher number of events currently indicates a higher exposure to risk, another might appear less exposed even though it faces a much higher level of risk.

From analysis of practitioners' assessments of their level of risk exposure, it is possible to conclude that:

1.4 Assessing safety risks supported by a frequency approach has the potential to develop into an uncertainty-exposure stance among stakeholders. Therefore, the tools used to assess safety risk must be analysis-based using a risk-based approach – namely, it must incorporate both variables associated with risk: frequency and severity [F1.4].

5.1.5 Safety Promotion

Not surprisingly, the subject of safety promotion generated a large number of concerns among interviewees [SQ 1.2]. Although some organizations revealed their data, only two allowed disclosure under the anonymity and confidentiality terms. Appendix H is a rare example of a set of SPIs monitored by an organization. Nevertheless, according to the interviewees' accounts, dissemination of risk-exposure data – supported by frequency statistics – is largely for distribution among the higher echelons of the organization.

Practitioners, meanwhile, get to see only specific cases that have occurred within the organization. One can only speculate from the interviews why this practice occurs: it seems to be due largely to an inability to associate the results with specific safety measures, yet the lack of data to enable comparison of the measures within a defined set of limits also impedes the process [RQ 1.1].

In support of the current status quo, Jeremiah-AS affirmed: *“You do not communicate a boundary or [a] goal. You describe a procedure that in management terms you understand should be applied. It only works to communicate […] an objective, [or] share one when you […] have been informed of one previously […]; [this is] the reality we are faced with.”* Peter-AS’s statement conveyed a similar viewpoint: *“We have safety news where we disclose some statistical information, but not in any detail. I don’t believe the administrator wants information to come out in this way.”* Gary-AS, acknowledged the presence of so-called “attention gatherers”: *“Some hazards have active campaigns, [namely] RAs, MMOs, non-stabilized approaches, and the like. […] This is possible when you publish a briefing note, or when you issue a specific communication.”* India-AS’s organization represented a rare example of one that perceives the breach, she believes: *“I think employees are unaware of [safety performance]. The reason why areas are increasingly adhering to this kind of […] dissemination – [use of] visual images – is that they […] are immediately perceived.”* Tavares-AB also acknowledged the need to inform the workforce of the results: *“This year, the administration decided to publish […] a monthly communication for everyone.”*

Stakeholders are aware of the important role safety dissemination plays in raising employees’ awareness and improving behavioural culture. However, due to the sensitivity of the subject, data sharing is restricted or available only to dedicated forums. In this regard, Lary-AL commented: *“The subject was not addressed proactively in formal internal communications. The company has an internal portal and newspaper and […] regularly communicates. There was no mention […] of the issue of risk whenever we opened new routes to specific places, [but] what could occur were […] semi-formal meetings [where we] discussed the subject.”* Kostas-AS acknowledged the significance of good communications: *“The success of this new model of SMS depends very much on the level of awareness there is [in] internal communications; hence […] it is almost something […] mandatory, […] which I see as an add-on in itself.”* Paul-HL took the same stance: *“Dissemination [is the] sustainability of the project, [so that] in the end […] hospitals maintain good practices in all that has been* *acquired.”* Jeremiah-AS provided another relevant example: *“We have published a newsletter regarding ‘taxi speeds’. […] The rationale was neither associated with [identifying] our reality nor […] to set a goal for improvement […]. The commitment was […] to exhibit the associated risks. The safety limits were part of the internal improvement objectives, which means they are not explicitly communicated to everyone.”*

The purpose of promoting safety is to foster a positive safety culture to assist the organization in achieving its safety objectives (ICAO 2018b). From the accounts above, however, one could conclude that exposure to the uncertainty stance has a direct impact on the content of the safety message conveyed to practitioners. Practice shows that communication aims to raise practitioners’ awareness of safety risks in the expectation that an improvement might occur. Therefore, one might conclude that:

1.5 The management of safety promotion is not structured. The approach leaves operational staff unable to perceive how far the organization is from its safety boundary or limit. Ultimately, this could act to impede staff as they work to convey the appropriate safety message throughout the organization [F1.5].

5.1.6 Recapping on Gap 1

The purpose of Gap 1 has been to research how executive directors define safety boundaries in relation to the risks the organization is exposed to, and to look into what strategies they have implemented to assess and communicate risk exposure throughout the organization [SQ 1, RQ 1.1, RQ 1.2].

As was perceptible from the interviews, executive directors are not fully acquainted with the risk exposure of their organizations and furthermore their knowledge of the SMS framework of their organizations is inadequate. Consequently, operational staff in the lower echelons of organizations tend to decide the limits of the safety boundaries themselves. This means that not only is there an absence of executive directors’ guidelines, but also that the commitment by the executive lacks [RQ 1.1]. The interviews revealed that executive directors were unable to evaluate the impact of strategic decision-making on the risk exposure of their organization in a structured way. Furthermore, Gap 1 is compounded by the approach set by the ICAO, which promotes meetings with the Safety Review Board (SRB) only seldomly. Commonly, in practice, these SRB meetings occur at six-monthly intervals, thus, twice annually. This has the tendency to set the two hierarchical levels apart.

Setting safety boundaries based solely on a frequency approach [RQ 1.1] does allow a proactive perspective, but as it also degrades the ability of the organization to manage its risk exposure and, ultimately, it will contaminate the performance of the SMS framework. Risk exposure is a complex subject that definitely requires interpretation of the dataset to explain its complexity; namely, it requires a set of contributing factors to reproduce, albeit deficiently, the reality faced by practitioners.

Degradation of the SMS framework could develop into an uncertainty-exposure stance, thereby leaving stakeholders unable to react knowledgeably to the risk uncertainty. This stance was perceptible in the interviews, as in the comment of Gordon-AA which suggested how *"difficulties and hurdles in grasping precise information from FDM data"* led to an incapacity to evaluate the organization's risk exposure. Risk tools analysis, therefore, must be based on a risk-based approach and incorporate both of the variables associated with risk: frequency and severity. Moreover, the risk tools must consider the protective measures implemented in the field and be adaptable according to these.

Safety promotion mirrors the deficiencies addressed previously [RQ 1.2]. Not enabling operational staff to disseminate an appropriate safety message throughout the organization represents a lost opportunity. Yet poor communications of the actual safety-risk exposure throughout the organization, happens as the consequence of the blurred perception of risk exposure the organization promotes.

5.2 Gap 2 – Risk Tools

According to the risk-management process proposed by the BSI 31000, the risk assessment is composed of three stages: risk identification, risk analysis[80] and risk evaluation (BSI 2018b).[81] Although relevant, the first stage – risk identification – as explained in Chapters 6

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[80] "The purpose of risk analysis is to comprehend the nature of risk and its characteristics including, where appropriate, the level of risk. Risk analysis involves a detailed consideration of uncertainties, risk sources, consequences, likelihood, events, scenarios, controls and their effectiveness. An event can have multiple causes and consequences and can affect multiple objectives" (BSI 2018b, p. 12).

[81] "The purpose of risk evaluation is to support decisions. Risk evaluation involves comparing the results of the risk analysis with the established risk criteria to determine where additional action is required" (BSI 2018b, p. 12).

and 7 (pages 184 and 214, respectively), has not been altered in the model’s design. The focus of this research is on the operational staff who reproduce the analysis; pointedly, the people who convert the identified factors into a framework are the actors in the spotlight. Their work, in turn, conveys a perspective of the inherent risk, which, ultimately, compares it with the “safety boundaries” set by management guidelines – the risk evaluation. Therefore, to reduce the variability in the subsequent stages of risk analysis and evaluation, it is vitally important that an adequate risk tool – or combination of tools [SQ 2] specifically for that purpose – be put in place. With the support of the data collected from the 26 interviews, sections 5.2.1 to 5.2.9, which follow, review the practices of operational safety staff and the challenges they face when going about their daily activities. The objective is to identify the answers to the questions: “What characteristics should risk tools have to assess safety risks effectively?” [RQ 2.1] and “What method best suits airlines?” [SQ 2.2].

5.2.1 Characteristics of the Risk Tool

When asked in abstract terms about the main features a risk tool ought to incorporate, interviewees had significant difficulties in replying. During the course of the interviews, it became clear how stakeholders use the tools either as the regulatory authorities present them or as proposed by industry best practices (ICAO 2018b). Sabine-HS presented a good example of this “one-size-fits-all” approach: *“I do not know who defined [the matrix] because it was wholly adopted [from another] National Health Service.”* Santini-AS divulged a situation where the airline had tried to develop its own risk matrix in the past (see his remarks about this below), but now he explained how the organization was using the original tools as proposed by the regulators: *“The matrix used is the same as the one produced and distributed by* ICAO Doc. 9859*. As with the fatigue tool, the administration has not defined a risk policy; it is merely a copy from the manual.”* Louise-HS viewed the risk tools as a ready-to-use product: *“The matrix has not been modified. […] They are matrices that are approved internationally, and therefore we don’t change them.”* Gordon-AA took a similar view: *“The tool has never been modified since its initial development.”* Moreover, if a tool is modified, namely as a risk matrix, stakeholders view it with some suspicion. However, this comes with the risk of creating a strong barrier to improving or adjusting it to reflect the risk appetite of a specific organization. Santini-AS’s account is a remarkable example of an attempt at customization that developed into mistrust among his counterparts: *“I don’t think that the risk matrix […] represents [our] safety policy. […] We* *adapted the EASA's [matrix], but did not keep it […] because we had a lot of trouble explaining it, and our auditors or clients felt that we were [being] permissive."*

These intriguing accounts pave the way to the speculation that operational staff do not recognize the need to discuss the structure of their risk tools. Thus, risk tools do not represent individual airlines' specific risk appetite or the defined risk exposure of the organization. This means, therefore, that the evaluation phase of the risk-management process – that is, the comparison phase, where the results obtained from the risk analysis process are set against the risk appetite of the airline, will be challenging to implement effectively.

For Tavares-AB, user-compatibility presented challenges: *"As each area has its own specifics, the tool must […] be adaptable to meet the various types of public."* Nicholas-AL supported this concern, adding another proviso to suggest that the tools must be *"[…] able to leave the decision up to human evaluation."* John-AB looked to the need for a comparison feature: *"Looking at the data, can [it] help us to understand where we are? You set the metrics, you set the goals, and say that this is what is acceptable, [and] this is what is not acceptable. […] We have to be able to […] know where we are in relation to these."* George-AB endorsed the multi-risk perspective, saying: *"One [feature] I consider important is to characterize risk on multiple fronts, not just the operational one."* Nicholas-AL agreed with this multi-dimensional view of risk, suggesting it must: *"Take other perspectives on board. The analysis should consider not only the operational perspective, for example, but also the financial, the reputational, the uncertainty that we have about the risk."*

The interviewees raised concerns about the capabilities of the risk tools to work proactively. Gary-AS understood that the available tools remain reactive: *"I have the impression that the community is advancing at the same pace. That is, we still do not have […] a tool that allows an […] analytical and predictive analysis of risk."* The same interviewee brought attention to another interesting perspective in relation to the imagery used to assess risk. The development of clear imagery to show risk (see also section 2.6.4) concerned him, he said, as this would not be his preference for raising awareness of a build-up of risk exposure among operational staff. Clear images specifically should not be a feature of illustrating this build-up, because: *"I have seen several models, several graphics, several dashboards, but I think everything appears very [similar]. […] [The] result is very reliable, well defined regarding colour […] but […] the assumptions are fragile. Therefore, I think a clear image is less effective […] than having a blurred vision that compels us to try to perceive [its detail]."*

Nicholas-AL reinforced the proactive perspective, which many in the industry believe is essential for risk management to incorporate, when he affirmed that: *"The risk is the uncertainty about some event materializing […], and in what way. […] The modern perspective about risk is [associated with] the degree of uncertainty or certainty that the operator has about it."* The matter that risk tools cannot, therefore, be static was broached by George-AB, he felt they should be incorporated *"In a map or matrix […] of probability by severity, because it is one of the most used, […] positioning each risk […], and with a process to perceive its current location. Knowing if this risk is in the yellow area and, in a second stage, if it is moving towards the green area. […] Designed as a dynamic tool. […] There should be a tool that could do this in real time."*

In the absence of a continuous flow of data to update the risk analysis, operational staff are tasked with frequently re-evaluating each risk to understand the evolution of the response to the measures implemented. This drawback, discussed in the "longitudinal monitoring" section in Gap 3 – Safety Protection –, creates extra work for practitioners. George-AB stated in this regard how: *"When we analyse a risk we take a snapshot, and then we define a plan to mitigate it in the expectation that it comes to 'D5'; then we agree to put aside a period of time, for instance six months, to re-analyse it."*

Another subject addressed during the interviews related to the prioritization of risks. Ideally the risk tools would tackle this specific feature, but presently the tool itself has an inherent discrimination in the reduced colour palette available. This presents the task of prioritization with a challenge; George-AB explained how his organization implements this feature: *"The implementation is decided at the level of the […] Event Review Group. […] A review is carried out; the investigation is [then] presented to the ERG […] [with] a report [along with] the proposed actions to mitigate the risk, and the expectation is that after the implementation of these actions all the risk will reach a certain level. We do not have a model to [prioritize] yet."* He then added how, *"Currently, […] we look at all [the hazards], but each one has its own timing. [We prioritize] based on the sensitivity the group has decided."* Yolanda-AA also highlighted the prioritization feature and its importance: *"A tool that can be customized, […] that attributes different weights to different events […] and, therefore, to be able to develop [a] comparison, […] seem essential characteristics."* Sabine-HS acknowledged the importance of prioritization and recognized the tool's inherent drawbacks: *"The prioritization is in fact [one] of the evaluations carried out by the teams and the* *services. Sometimes I have to pick up on these evaluations and do a re-evaluation to prioritize."*

From the discussion and thoughts gathered from the interviews, it can be asserted that:

2.1 The standardization imposed on the aviation industry has its advantages. However, standardization hinders the ability to innovate and to adapt the risk tools to reflect individual airline's risk appetite; it also highlights the incapacity of stakeholders to effectively implement the evaluation phase of the risk management. The conclusions to draw from the interviews are that it is essential for risk tools to be adaptable to the environment of their use; that they have the ability to consent to human evaluation; and that they enable comparison between the established safety boundaries and the actual risk exposure. In other words, the risk tools should incorporate each individual organization's risk appetite [F2.1a]. Further relevant features to emerge during the interviews are: the ability of risk tools to react proactively; their capability to anticipate future scenarios, and their ability to improve the system's capacity to receive data in real-time, thus avoiding longitudinal monitoring to assess the evolution of risk exposure [F2.1b]. Finally, in order to orient the available investment resources in organizations, risk tools should be able to prioritize, as appropriate, the analysed risks [F2.1c].

5.2.2 Types of Approach: Qualitative versus Quantitative

Initiating a debate about the most suitable approach or method for airlines to follow [RQ 2.2] to analyse and evaluate a safety hazard seems pointless. The current research responds in line with the literature, wherein it is easy enough to find detractors and supporters for both approaches.

The current research supports the potential advantage of qualitative over quantitative risk tools on the basis that the former performs better. The imprecise and inaccurate, but valuable knowledge held by practitioners offers better insight than the accurate figures offered by the quantitative approach (Cox et al. 2005). As opposed to countable physical variables, risk can be neither measured nor observed. As Nisula (2018) has pointed out, risk does not actually exist in the empirical domain, but rather it only exists in the mind of people. In this regard, Lary-AB's statement supported the use of qualitative methods: *"There is a particular paradox here: the more precise it is the less I see. The assessment is so accurate that I lose* *the notion of the reality that is around me. In other words, when I say that my risk percentage is 2%, I am narrowing [it down] in such a way that I lose the scope of my operation. I think this is a danger. The generalization of such risk-management metrics […] are dangerous, because they tend to make the reader unconcerned."* Gary-AS likewise supported use of the qualitative approach to evaluate and analyse risk: *"It is [about] bringing people together, identifying situations and seeing what is and what is not reasonable. But I think this ought to be done with minimum support of numbers."* Support for the stance of these interviewee statements is in the BSI 31000:2018 standard, which acknowledged that: "Highly uncertain events can be difficult to quantify. This can be an issue when analysing events with severe consequences. In such cases, using a combination of techniques generally provides greater insight" (BSI 2018b, p. 12).

Although the quantitative community criticizes the use of qualitative methods (Cox et al. 2005; Hubbard & Evans 2010) on the basis of "reversed ranking"[82] and "uninformative ratings",[83] operational staff acknowledge difficulties with them specifically during the subsequent phase of the risk evaluation – namely, when comparing the risk exposure to the safety boundaries defined by the airline. Alexis-HL recognizes the need for quantitative means, specifically to enable tracking the results of the interventions or the mitigation measures implemented to reduce the risk exposure: *"It would be important to have quantitative instruments, because […] this would give us a more accurate […] evaluation of the effectiveness of the interventions."* Nicholas-AL takes a similar stance, asserting: *"I think […] numbers are difficult, but text is maybe even more difficult, because if you try to define categories with words […] people's understanding will be even more varied [i.e. subjective]. So that's why sometimes the numbers may work better."* Paul-HL offers an interesting perspective on the robustness of the information: *"I think that the more objective and factual [the risk evaluation is] the better. Independently of being quantitative or qualitative, information should be robust to enable it to support the decision. Therefore, it does not matter whether it is quantitative or qualitative, although I support the former, since it reduces subjectivity. Nevertheless, it is important to provide some context to the numbers, namely a comparison."*

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[82] Evaluating risks with higher qualitative grading with events that have a lower quantitative risk.

[83] Frequently assigning higher qualitative risk to events that have reduced quantitative risks, as well as rating risks with a grading that diverge by several orders of magnitude.

More could be included from the interviews to support one specific approach to the detriment of the other, but, ultimately, the sole objective should be to reduce the subjectivity associated with the risk assessment, which can only be achieved based on a robust methodology.

The previous statements make clear that:

2.2 Among operational staff, there is a division as to whether the quantitative approach would be more appropriate than the qualitative approach, and even a suggestion that a combination of the two methodologies would provide a more accurate picture. To understand which methodology would reduce the subjectivity of the risk assessment most effectively in practice is, therefore, relevant [F2.2].

5.2.3 Risk Matrix

The current research affirms that risk matrices are in use universally among stakeholders as a tool to analyse and evaluate hazard risk. As Appendix E.6 shows, the risk matrix accounted for over 8% of the total relevant statements, of which more than 40% belonged within Gap 2. Nevertheless, stakeholders complimented their analysis and evaluations sometimes with other tools to support the decision-making process [SQ 2].

The choice of tools was a point Gordon-AA thought was relevant. He suggested that the decision about which specific type of tool to use should depend on the purpose of the analysis: *"Two different tools are in use in the safety department – risk matrices and fault tree analysis. The former is used for a reactive analysis whereas the latter is dedicated to proactive assessments."* Bentes-AA's organization used a different combination of tools: *"We have two different approaches, the daily occurrences, e.g. [when] something has happened, and we classify the event using the ARMS method or improvement [processes], where we use the matrices."* Unlike Gordon-AA, Bentes-AA's organization used matrices proactively: *"We apply the concepts of the risk matrix [associated with] the management of change process"*, he says, and then adds *"[…] when […] analysing scenarios where the picture is not completely defined."* Peter-AS's organization used a combination of "control charts" and risk matrices to monitor the evolution of the risk exposure. However, he received little support to implement these tools among colleagues: *"We had no directives to implement the control charts. […] We were looking at the metrics [of other companies], and tried to* *adapt [these] to our business, and we used […] our data. […] The existent documentation to support the [implementation of the Control Charts], is not official.”*

Yolanda-AA viewed the risk matrix as her basic analysis and evaluation tool: *“*[*When faced with a new hazard*] *we try to do a basic risk analysis: matrix five by five, […] probability, severity, […] as simply as possible, to try to assess what level of risk is involved, and to think about what measures can be taken to reduce that risk. And then we make safety recommendations […] of the steps to take which we believe may be appropriate to lower the level of risk.”*

Several drawbacks are imputed to risk matrices, specifically: integrity,[84] subjectivity, and prioritization. The following paragraphs present the main drawbacks identified by the interviewees and provide two mitigation measures considered relevant to overcome the deficiencies discussed.

“Integrity” was an expression coined by the interviewees. It represents the ability of a tool to incorporate the analysis and evaluation, and subsequently it represents its capacity to incorporate the outcome resulting from the mitigation measures.

Martin-AB asserted that: *“The current tool [risk matrix] gives us […] a notion of what measures we will need to implement in order to operate within the green range, the acceptable range. However, as it does not give us […] feedback in an integrated form, we cannot do an integrated assessment.”* Santini-AS also complained about the integrity of the tool: *“The risk matrix, as opposed to what it may seem, […] is a straightforward tool. We check the frequency here, and then the severity, and after joining one with the other, we obtain there [a] risk. […] Then, when [we apply] a mitigation measure, what is the outcome? It is very difficult to calculate.”* Sabine-HS noticed how the mitigation measures would be the same even after implementing the risk outcome: *“It is something […] I have noticed. […] Even with a control measure implemented, I have had situations […] where the assessment has accounted for a high-risk. […] It did make me wonder if this matrix had […] some drawbacks.”* Unlike the FMEA method, evidently, matrices lack a detectability factor or the development of a mitigation method to cope with the identified risks. This could be why practitioners complain about obtaining the same outcome even after implementing the

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[84] As the integrity drawback emerged from the “04.01.01 – Risk Matrix – Pros & Cons” coding, it does not appear in Appendix E.6, Table E.14 – Interview coding, as an autonomous item.

"control measures". The detectability factor, or something similar that accounts for the measures implemented, would go some way to helping the analyst to differentiate between severity and probability before and after applying the mitigation measures.

The second drawback is the subjectivity or variability in the outcome. Complaints about subjectivity was a shortcoming found across the whole range of stakeholders. To compound the drawback, individual analysts can bring a personal stance into the hazard evaluation. Peter-AS considered an extreme outcome: *"Our tool [measures] […] the outcome of the event, […] using a worst-case scenario perspective."* Even with a standard evaluation, Peter-AS assumed a high level of subjectivity, stating that: *"My major concern is the subjectivity of how […] I analyse things."* Sabine-HS's assessment of the hazard looked at it from another perspective that centred around: *"what the probability of this incident happening again is, and if it reoccurs what the consequences could be, […] not the current outcome."* Paul-HL took the view that the data is still useful: *"One of the main drawbacks or limitations [of matrices] is, in fact, some subjectivity that […] might be associated with them. The advantage [of this] is that […] it allows us to maintain visually […] a means to perceive what is happening in terms of risks in an organization, in a department, in a service, and in a ward."* Charles-AB saw his organization's tool as *"a graphic-based matrix […] that depends on the experience of who is doing [the analysis]; […] there is no standardized […] method. [The] outcome depends on the analyst. For now, we have defined the risk matrix, which in my opinion is also a bit outdated, but anyway it is what we have."* He then adds, *"Standardization is an important characteristic not only for us but for the whole industry […]. I would like to analyse one [incident] where we all arrive at the same conclusion."* Yolanda-AA was even more sceptical about the subjectivity of the risk matrix: *"The output is [going to be] […] different, in fact, for a [single] person on different days, according to his/her mood; one day [I am] more pessimistic, the next day [I am] more optimistic, [therefore,] the results will be different."* She then added, *"[For the risk matrix] to be more efficient […] the analysis tool needs to be less subjective. […] It has to have a more objective form to evaluate risk and not depend on the subjectivity (associated) with the person [the analyst]."* Sabine-HS also acknowledged the variability introduced by the human factor: *"I regard the risk assessment in the knowledge that several different teams are evaluating [them], […] and that they were trained within the patient safety office. But then when I analyse [them] there is variability […] in the evaluations for the same risk factor."* She concluded by saying: *"I think [variability] is [at the heart of] the fragility of the system used in healthcare."*

Prioritization is the final drawback to present, which is fraught with compromises. While economic considerations will inform stakeholders' decisions in the knowledge that resources are scarce, a similar theoretical stance needs to apply to the management of hazards. A theoretical approach of this sort would help to guide decision-makers when deciding how to address hazards, whether expediently, immediately, quickly, or to postpone until a future time. Therefore, the tool must be able to prioritize risks efficiently. However, an intriguing finding forms in the accounts of the interviewees, in that the majority of the interviewees had never thought about this prioritization feature of the risk tools.

Jack-AS saw the feature as a relevant one: *"Being able to compare various risks is important. Afterwards, the challenge […] is to be able to reach […] a hierarchy of what […] is more significant and what is [more] influential in risk."* Gordon-AA was sceptical about the ability of the risk matrix to prioritize the risks: *"[Matrices] have limited capacity in prioritizing the risks. The decision has to be supported by a safety analyst's recommendation."* India-AS circumvented the question of prioritization altogether, stating: *"All [risks] are placed in the matrix. They are all treated. […] If we do not have enough resources […] someone has to assume the risk."* Barros-AS admitted that his organization did not consider prioritization: *"We do not discuss [hazard prioritization] much. We try to deal with all of them once we've raised them, we should [manage] the whole range."* Gordon-AA[85] said that his airline was already developing a risk-assessment system in response to the introduction of a new aircraft into service. In the organization, there was an acknowledgement of the existence of a myriad of hazards, yet the notion of prioritization was not on the horizon, simply because no one ever considered it in these terms. Moreover, the same interviewee indicated that his airline's tools reduced its capacity to prioritize the risks: *"Risks are not compared; all of them have to be tackled or addressed by the department."* At first, Gary-AS was unsure about the capacity of his organization's tools. However, his reasoning evolved during the interview and he began to realize the limitations that existed. Thus, initially he stated: *"I think [the risk matrix and the ARMS] can prioritize the risks. […] The limitation does not appear as the number of risks of a situation, but according to the various studies in which we are involved."* Then, in the following stage of his statement, he mentioned how: *"[Tools] do [prioritize] partially, but*

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[85] Gordon-AA did not give his permission to record the interview.

then there has to be a human component to balance [out] or to attenuate the specific gaps of the tool." George-AB agreed that human intervention was necessary to attenuate the incapacity of the risk tool. He then went on to speak specifically about the prioritization associated with the mitigation measures, which are also relevant to the risk-management process: *"[…] Imagine a certain risk that is analysed in the ERG, […] there are 20 actions, and in that meeting […] it is decided that 10 are to go forward and the other 10 are not worth it. We do not do [a] fine analysis, they are all [put] […] on an equal footing."* In opposition to the previous statements, Paul-HL provided an interesting alternative perspective by explaining how: *"The establishment of risk priorities comes from the colour code [of the matrices]. [In a tie], the decision must be on a case-by-case basis. […] It could be interesting to consider other variables, namely, the costs, or what resources are necessary to have an effect."* Jeremiah-AS took a less trusting view of the matrices' ability to discriminate between two risks, suggesting that: *"The majority of [the risks] have the same colour. […] There may be a lack of awareness [between] two yellows, [assume] a more roasted [mustard] yellow. […] But, it is an individual decision and, therefore, it is an unstructured perception. […] I would say that […] this hierarchy makes sense, but the […] matrix [itself] does not allow for it."*

Although stakeholders recognized the main drawbacks, it was clear that the use of matrices is widespread throughout the industry and that mitigation techniques to overcome their limitations were commonplace. Concerning the disadvantages of subjectivity, Sabine-HS, who is an experienced professional, introduced an "overlapping" method, whereby more than one analyst carries out analyses to obtain an average evaluation. On the efficacy of this procedure, she notes how *"The [matrix] is always at the mercy of qualitative analysis of risk perception. That is why, given my experience […], I am called […] to re-assess specific identified risks."* Barros-AS highlighted the relevance of this consensus when he affirmed how: *"Everyone has an opinion. When [evaluation] is done together […] consensus is reached, but when I do not have this opportunity to do it together, I may miss out on assessing […] a risk."* In support of Sabine-HS's "overlapping" method, Gary-AS stated: *"I tackle [this problem of] subjectivity by attempting to integrate several points of view, not only from the operational environment but also from within the [area of pilot] safety, [listening to] two or three pilots."* Gordon-AA shared this view, confirming that: *"[…] risk classification is discussed with more than one safety specialist in order to obtain a weighted consensus."* Yolanda-AA had assessed the method in a training session: *"[With] 10 people*

[…], we were working in groups of three [and four] people, so […] it was no longer just one person's opinion. […] [When] evaluating various cases, […] each […] group, at the end of [the session] provided information about the point in the matrix where [the risk] had arrived. Each group had come up at a different point in the matrix. It was never […] too different, but varied because it had to do with the people's [individual] sensitivities."

Ingenious solutions were evident, such as that implemented by India-AS to overcome the difficulties posed by the scales of severity and frequency. In opposition to the traditional matrices, those in use in India-AS's organization had several scales pertaining to severity and probability (or frequency). Scrutiny of the severity of the risk took a view from several perspectives, with the probability of occurrence evaluated against the nature of the risk and/or the available data. *"Until recently, our risk matrix was exclusively used to assess […] operational interruptions. […] In the* [severity] *part, our criteria […] has 11 fields that we work with. […] In the probability section, [there are] also several available ways of analysing the probability: industry, company events or flight hours. […] Severity follows the traditional five or six levels of consequences. However, instead of being restricted to a single scale, the outcome is verified against 11 different scopes."*

Figure 5.16, below, presents this type of matrix as a schematic.

PROBABILITY		
Industry Data	Airline Data	Flight Hours

5A	5B	5C	5D	5E
4A	4B	4C	4D	4E
3A	3B	3C	3D	3E
2A	2B	2C	2D	2E
1A	1B	1C	1D	1E

					SEVERITY
					Airworthiness
					Assets
					Compliance
					Environment
					Financial
					IT
					Labour
					Operational
					People
					Process
					Reputation

Figure 5.16 – Risk matrix incorporating multiple risk perspectives[86]

The conclusions obtained from the interviews are:

2.3 Risk matrices are the primary tool used in risk management among stakeholders. Nevertheless, using other tools alongside risk matrices would complement their strengths. Matrices suffer from three main drawbacks: the first of these weaknesses is integrity – the reports from matrices draw attention to their incapacity to integrate within the tool the three fundamental risk-management activities of the risk analysis, the evaluation stage,

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[86] A similar type of risk matrix is widely used by the UK's National Health Service (NHS). The 5 by 5 grading matrix uses nine scales for consequence and three scales for likelihood (Elmonstri 2014).

and subsequently the outcome resulting from implementation of the mitigation measures [F2.3a]. The second drawback relates to the variability associated with the risk-analysis outcome, which is dependent on the stance taken by the analyst [F2.3b]. Finally, there is the incapacity to prioritize safety risks in an efficient form – risk matrices depend on the colour palette to discriminate between safety risks, and the reduced number of available colours of the palette turns the task of prioritization into a challenging game [F2.3c]. Recognizing the variability produced by the tool, stakeholders have introduced the “overlapping” method in an attempt to reduce the level of human subjectivity.

5.2.4 ARMS

The methodology of the Aviation Risk-Management Solutions (ARMS) working group was developed 10 years ago [SQ 2]. While the methodology in use by ARMS resembles traditional matrices, a closer look reveals significant differences.

The risk analysis of ARMS is composed of two stages: these are the Event Risk Classification (ERC) and the Safety Issue Risk Assessment (SIRA). In the first stage, ERC evaluates events briefly in terms of severity, taking into consideration the robustness of the safety barriers already installed. Every single event analysed has as a backdrop a perspective that evaluates what would have been the most credible outcome should the event not have been detected by the operational staff, or had it not been stopped by a safety barrier already installed in the system. The objective is both to understand whether further investigation is necessary and to attribute a weight of severity to the event. Providing no outstanding issues are identified, the events are then filed into a database. SIRA is the second stage, which comprises the assessment of any safety issue identified from the aggregate data, taken as a product of four factors: prevention, avoidance, recovery and minimization of the consequences, instead of making use of the traditional severity versus probability product of the risk matrices. The system follows the approach of the bow-tie concept, whereby a recovery plan follows the measures of avoidance and mitigation.

While employing several different approaches, the interviews have revealed that this bow-tie-based method was in use by three different stakeholders. One airline uses it as a stand-alone tool, whereas another uses ARMS in conjunction with the risk matrices, as described above in the previous section. A third user, an aeronautical consultant, also supports the method. A fourth airline had practitioners who were familiar with the method but not employing it. One interviewee remarked that the tool was used strictly in the aviation industry, and another user mentioned his organization used an enhanced version of the method they called ARMS+ (see Appendix I).

Users see the tool as a fast-processing approach to managing the myriad of reports received[87] on a daily basis. Gary-AS commented: *"We examine the potential impact regarding immediate severity"*, and added, *"we just verify [...] the level of severity."* For Jeremiah-AS, *"ARMS appeared as an initial classification criterion for occurrences; it is a way to [...] identify the resources that have [to be] allocated to each event."* Nicholas-AL straightforwardly explained why fast analysis of the reports was essential for him: *"Any airline receives on a monthly basis hundreds of reports or even thousands. This is why there should be an efficient method for processing all the data collected, fast. This was the purpose of the Event Review Classification (ERC) of ARMS. It is kind of an estimative approach, and must be complemented with another method or procedure that looks into the cases that have raised greater concern."*

In light of the similarities, the comparison with risk matrices is inevitable; it is also a useful exercise by which to understand the advantages and disadvantages of the tool. Kostas-AS considered that ARMS reduced the subjectivity of the assessment during the risk analysis phase, and provided an example: *"Analysts, when they were applying the ICAO concept of severity versus frequency, [...] attempted to associate that event with other similar events that had happened in the past. Thus, they made it not an analysis of that event, but a mixture between that event and the safety issue."* Gary-AS stated: *"We use ARMS, [...] [to understand] the most predictable consequence concerning severity; what could have happened. [...] It provides us with not only the actual severity of that event, but also with a perspective of what could have been the outcome."* Bentes-AA highlighted the ARMS methodology's ability to not focus solely on the number of occurrences: *"With [ARMS] [...] we are able to [...] distinguish [...] where the danger is. [...] What happened that represents a more significant threat? Even, if it has happened only once."* Bentes-AA articulated this line of reasoning further: *"Until the implementation of ARMS, we would open investigations for a lot of things that we would then close, with no practical results."* Gary-AS agreed with this statement: *"I think there is a degree of uniformity in how we approach the events.*

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[87] One of the interviewees explained how on average the safety department of his organization processes more than 20 reports a day.

[Another advantage] […] is to define whether [the event] is sent for research or not, and [decide on] what level of analysis is done. […] You have […] a filter, which provides a systematic approach to handling the occurrences, so that they are always approached in the same way." Nicholas-AL reinforced the narrowness of perspective ARMS offered, as he explained: *"ERC is an extraordinary thing. Because in the old days, […] the safety tools […] were asking you to risk-assess the event in two dimensions. One was the severity, and nobody knew what 'severity' was supposed to mean: Was it the actual severity or the potential severity, or what? […] The other dimension was [the] type of frequency: Was it the frequency of this event, or the likelihood of a recurrence? […] The problem there is that […] a single event does not have a frequency."* According to Kostas-AS, the objective is to understand the robustness of your system: *"The ERC, through the two questions it poses, is more focused on what the event was under those specific conditions. That's a significant advantage, because I'm not concerned with doing […] the risk assessment of that event, it does not matter what frequency it is, but […] we want to know how close we were to [an] accident [then]."*

From these accounts, there is a perception from the point of view of the end-users that the analysis method incorporated into the initial stage of the tool takes the edge over the traditional risk matrices, at least potentially. In the following paragraphs, the interviewees provide accounts of some of the tool's drawbacks, which provide a wider perspective of the tool's performance.

Gary-AS pointed out one of the difficulties he has faced with when using the first stage of the ARMS method – ERC: *"It is difficult to measure the failure rate of a specific procedure, therefore […] [the analyst] has to use some common sense."* Bentes-AA provided an evaluation of the performance of the barriers by subscribing to the previous comment but also providing further comment on the drawbacks in an open and frank way: *"The [assessment of barriers] is clearly a disadvantage, because it is challenging to gauge what an […] effective barrier is. Right now, there are not [many] ways to mitigate [this]. […] We try in any case to remove the factor of the individual from the classification. […] Ranking [is carried out] by two [people] to enable debate."*

Another problem the interviewees identified related to the way risk is classified. The ARMS method introduces a weighted number to each cell, whereby the objective is to overcome the difficulties presented by purely qualitative methods and to establish a hierarchy of risks. However, in the first ERC stage, the method restricts the evaluation to the most credible outcome, and then, based on this, the decision is made about whether or not to proceed with further investigation. No frequency data is added to the analysis phase; therefore, in the first stage, the exercise is restricted to hazard analysis. The risk analysis is performed in the second ARMS stage – SIRA, in which repeated events might constitute a concern. According to the ARMS guidance: "The proposed method for carrying out the Safety Assessment is first to identify and analyse the associated hazards and then use the Safety Issue Risk Assessment (SIRA) technique to assess the risks related to the identified hazards. This method works when there are enough factual, quantifiable elements to feed the SIRA" (ARMS, 2011, p. 29).

Although the explanation is straightforward and rational, this is not how operational staff view or experience it in practice. For example, Gary-AS said he used the ERC part of ARMS to classify the events, but then reverted to the ICAO matrix to risk-assess the hazard: *"[…] if we start to have many of these situations, then we have to analyse it from a future perspective. What is the likelihood it will happen again? […] We do this in two stages. We have the […] ARMS, then […] for the risk analysis, we use […] our matrix [of risk, which] incorporates somewhat the bow-tie concept. [That is], you have the hazard, the specific hazard, the defences implemented, then you have the unsafe event, the recovery defences, and the consequence."* This means that Gary uses the ICAO's risk matrix in conjunction with the reasoning provided by the bow-tie concept, and this is present in the second stage of ARMS as well. When asked to describe the SIRA component of ARMS, Nicholas-AL mentioned how *"[SIRA] is a […] really big 'approximation'."* Later, this same interviewee then followed up on this earlier statement to explain why he considers SIRA inadequate: *"Today I don't recommend SIRA, because […] its application is too limited to cases where you [already] know your limits. What you could do, though, is to use the ERC based on your events, and use the cumulus risk values. Then you could see […] what kind of cumulative risks you have on different routes, at different airports, at different times of the year, different days, whatever."*

In fact, after closely scrutinizing SIRA, it is understandable why users feel it is a challenge to determine with a high degree of certainty the failure rate of each barrier, the occurrence rate of each event, and the associated outcome, which partly explains why the interviewees seemed reluctant to use the SIRA part of ARMS. In light of the previous account, the statement from Gary-AS now makes more sense: while Gary-AS acknowledged that a standard method does exist on how to approach the analysis, his explanation showed that the results were not in line with his expectations. He was uneasy with the results produced by the tool, because for him: *"Subjectivity is one [of ARMS deficiencies]. [...] I do not expect much from the tools, [these] are a help, a means to develop some systematization in the assessment, but it is always subjective [...] – it will never be [...] a precise tool."* A statement from Jeremiah-AS raised similar concerns: *"ARMS does not lead to risk classification."*

A question about managing the results generated by ARMS prompted an extremely vague reply from Kostas-AS: *"The ARMS model and the thresholds are the basis of the protocol for both the result that emerges in the ERC and the outcome that arises in the SIRA."*

Actually, although ARMS was developed to overcome one of the deficiencies pinpointed in the traditional ICAO matrices (the prioritization of the risks), it too reveals restrictions in this area. Bentes-AA is an analyst who makes use of the ARMS+ method. His explanation helped identify the drawback of matrices more succinctly: *"The colours give us [...] the actions that we will have to take; that is, everything that is orange and red [are] things that we investigate."* He continued, *"[This means that if the event] falls within the yellow zone it is dubious. That is to say, if there is [...] available time we will try to evaluate [it], otherwise, if we are overwhelmed with work, [it] will just be stored."* Concerning the categorization by a number, which could be indicative of risk exposure, Bentes-AS's statements were at the least peculiar: *"The weight of [...] numbers [...] will allow you to differentiate SPIs by the degree of danger."* However, when questioned objectively about how the ARMS outcome could influence the SPIs, his reply demonstrated the weakness of the method*: "That's a question I cannot answer. [...] It is a process we have to review, [...] we now have more information, and we have to make SPIs better to [...] take advantage of ARMS."* To consubstantiate the difficulty, Bentes-AA gave the following example related to a hazard: *"Because of their recurrence they appear to be a greater risk, when [...] they do not necessarily pose more risk but they necessarily have more recurrence."* This may be why the same interviewee concluded that: *"At this point [the ARMS numbering] does not have much utility."* Therefore, as section 5.2.7 (Control Charts), below, suggests, the frequency that the graphics convey does not necessarily correlate with, or imply, an increase in the organizations' risk exposure; it merely means that there is an increase in the frequency of the event.

The revamped ARMS method allows it to provide more detail for the classification of barriers and to enlarge upon the number of potential accident-outcome scenarios. To overcome the subjectivity associated with purely qualitative methods, specifically the risk matrices, each of the ARMS scales incorporates a figure to enhance the gradation characteristics of the scale. Therefore, from the discussions with the interviewees, it is possible to assert that:

2.4 The first stage of ARMS – Event Review Classification (ERC) – proves to be efficient as an approach to manage a high volume of data. It still presents challenges, however, in relation to implementation, consistency of the potential outcome appraisals, and reliability of each safety barrier, and its results still seem incapable of conveying the actual exposure to risk the organization faces. The first stage creates a false sense of standardization, this is because it is dedicated to reviewing a specific event; while the risk evaluation, if required, is postponed until the second phase – the Safety Issue Risk Assessment (SIRA). At this stage, carrying out the risk analysis involves a set of cascading questions that can prove even more challenging to answer than the first-stage questions. The cause of the difficulty relates to organizations' lack of access to sufficiently robust data to support the decision-making process. This means, in turn, that the analysts tend to abandon the second stage of this method, relying instead on frequency-of-event data upon which they can speculate, but which, in fact, merely represents a re-occurrence. Although users' initial expectations have faded over time, the method's underlying reasoning is relevant: the risk analysis must consider the risk exposition – similar occurrences might generate a different set of risk exposures – and it is essential to incorporate similar events to convey a realistic risk-exposure scenario [F2.4].

5.2.5 The Bow-Tie Method

Among the interviewees, Charles-AB, Nicholas-AL, Peter-AS, Gary-AS, Bentes-AA, and Santini-AS were familiar with the bow-tie method. The concept is in fact widely used without users realizing they are using it, which explains why the method scores so low in the interview coding (see Appendix E.6). In the aeronautical industry, the bow-tie concept is used mainly as a reasoning method to identify causes that might trigger a hazard, to evaluate the barriers in place and, ultimately, to understand the consequences of the risk whether to the process or organization. Figure 5.17, below, illustrates the concept [SQ 2]. Surprisingly, the four interviewees from the healthcare sector were either unfamiliar with the concept or failed to mention it when asked to describe the tools used in their daily activities.

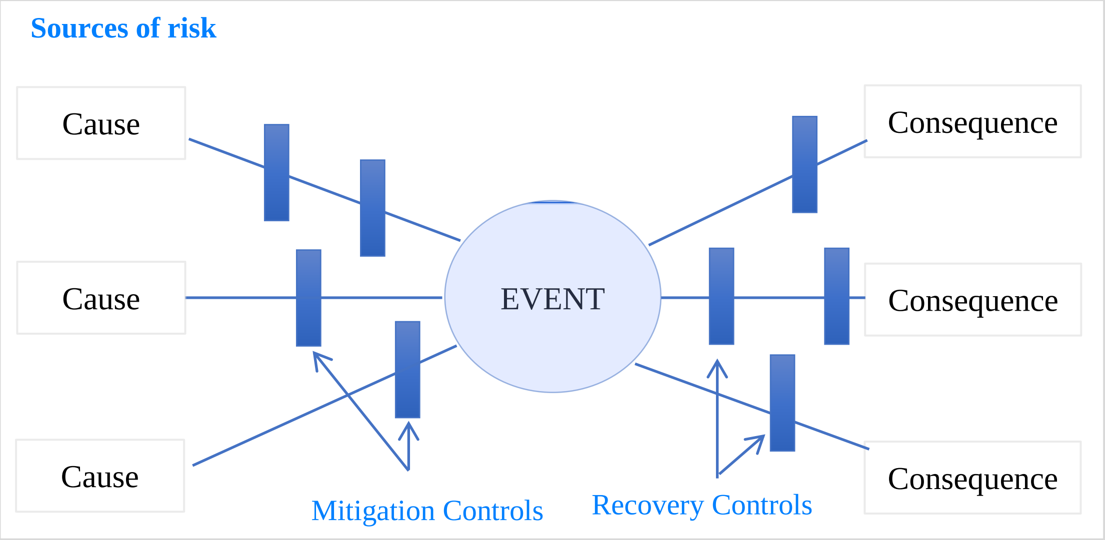

Figure 5.17 – The bow-tie risk evaluation method

The barriers or mitigation features installed in either the process or the system will reduce the organization's exposure to risk. The same features will ensure that the severity of the risk is diminished should the organization be exposed to the hazard, as Peter-AS pointed out: *"It is creating some barriers that somehow unequivocally allow you to push [the risk] to the [left] side of the matrix."* Alternatively, as Gary-AS suggested, it is possible to replace the second-stage SIRA approach of ARMS with the ICAO matrix using the bow-tie concept that is also a feature of SIRA: *"[…] we use […] our matrix [of risk, which] incorporates the bow-tie concept. [That is], you have there the hazard, the specific hazard and the defences implemented, then you have the unsafe event, the recovery defences and the consequence."* However, the common feature of these interviewees' accounts is that they both felt they needed an assessment tool to understand their organization's risk-exposure limit. Furthermore, using the method in isolation was of little use, as Charles-AB confirmed: *"[…] in comparison to the risk matrices, we have used the bow-tie with little effectiveness."*

The bow-tie method is useful as a means to construct a pictorial representation of the system's robustness, but it lacks the capacity to interpret the interactions that multiple causes may play in the final outcome, and oversimplifies the reality (BSI 2019). Nicholas-AL commented on its limitations in this regard: *"[…] people rely […] on the study of the barriers but forget about their interactions, about the context where the event has occurred, with the culture and everything else that contributes to the event. The context is essential; people […] oversimplify that analysis."*

The conclusions to draw from the interview statements are:

2.5 The bow-tie concept helps analysts to better understand and create a pictorial description of the scenario, and it can help them raise awareness of the mitigation and recovery controls that should be in place. Used as a stand-alone method, however, its capacity to evaluate a hazard or to tackle it with multiple interactions reduces; it performs better when embedded within another risk tool [F2.5].

5.2.6 FMEA / FMECA

Failure Mode and Effects Analysis (FMEA) and Failure Mode and Effects and Criticality Analysis (FMECA) are two methods that are used to identify how components, systems or processes might fail to accomplish their functions [SQ 2]. There are several types of FMEA/FMECA applications, which range from customized designs and off-the-shelf products oriented to particular components, systems and services, or specialized software, some dedicated solely for use in the healthcare sector (HFMEA[88]).

Louise-HS, who works within the healthcare sector, was unique among all the interviewees in her use of the method to evaluate risk. Generally, stakeholders demonstrated an unfamiliarity with the method. However, due to the pertinence of the conclusions drawn from the interviews, the following section is devoted to this tool.

Sabine-HS had recommended the interview with Louise-HS, because *“Healthcare HFMEA […] is a fascinating tool, but […] dedicated […] to a specific process.”* Louise-HS described how the process makes *“[…] it is easier [to define safety boundaries] […] when we use healthcare failure mode and effect analysis (HFMEA). […] In this evaluation model […], we identify the risk in all phases of the process. […] [The exercise] is done for all […] the details of that process or sub-process; and, therefore, I can say […] that, in certain areas […], if I exceed [by a certain amount] […] the risk […] is thereby unacceptable.”*

To capture the different risk perspectives, the team carrying out the application of HFMEA encompasses several professional valences. According to Louise-HS: *“We [have] an extended team with […] multiple valences. […] Each [person] holds his [own] notion of risk; we use the same risk assessment grid, […] the same matrix. […] As a risk manager, I might*

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[88] Healthcare Failure Mode and Effect Analysis (HFMEA) is classified as a FMECA tool (BSI 2018a)

think this is very high risk, but whoever is on the ground and operates with that process, […] might have a notion that the risk is lower. Therefore, the value we attribute […] is not an average, it is what we have discussed at the time."

A single analyst could implement the method, but Louise-HS pointed out the advantages of using the "overlapping approach", as discussed at 5.2.3 in the "Risk Matrix" section. According to her: *"If we are working in a team, there is a possibility that we will discuss the subject. […] When it is an individual, it is [solitary] analysis and, […] for me, this is one of the disadvantages. [Yet], it turns out to be the most objective we have."*

Using the HFMEA approach, Louise-HS classified every single failure mode according to its criticality. Among the several methods available, Louise-HS chose the "risk priority number",[89] whereby according to her: *"[With] this methodology we arrive at [a] risk priority number […] that has resulted from the severity of the incident and by probability and detection."* The capacity to attribute a number to each failure mode has the advantage of placing the potential occurrences in order of priority.

The risk priority number represents the criticality of the event. The main conceptual difference between this and the risk matrices derives from its third tabular element that is used to evaluate the detectability of the incident from the practitioners' point of view. To Louise-HS: *"The risk matrix is always the same. Then […], in terms of […] risk management, we frequently use a third table, [a] failure mode-and-effect analysis, which is the probability of detecting a failure. […] I can have two situations in which the final risk score is equal. […] If a fault occurs […] this is a dire situation, so this scale of detection is a third scale that also gives me a numerical value. The [lower] the numerical value the greater the probability of detecting that fault."*

Louise-HS provided several examples to demonstrate the increase in the detectability of a safety event. *"Instead [of the doctor] writing in full, I will have […] a field where it is already written extensively using a 'right, left' process, [whereby] […] [the doctor] just clicks […] and is positively identified. […] I am reducing […] the risk because the probability [of] failure […] is reduced, […] I can say that the score decreases by 'x' number of points. If I […] implement a second measure, so that someone can detect whether or not*

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[89] The most common methods are: mode criticality index, risk priority number, and level of risk.

this has happened, I am further reducing the risk; [for example,] […] I might include the information relating to the intervention in the consent form, allowing the patient to verify it."

Louise-HS did recognize the method's deficiencies, however: *"It may be somewhat subjective in the light of my perception […] of that incident or situation. From my point of view, this is the downside. Yet, it has the advantage of quantifying things that are very difficult to measure."* HFMEA is not used extensively in the healthcare sector. However, it does hold the advantage of converting an abstract reality into something measurable, thus allowing comparisons to be drawn.

In the literature, FMEA is evaluated as a tool that is useful to identify single-point failure modes and to identify redundancy. It is also seen as a reliable method for highlighting the key mechanisms that need monitoring. However, in complex systems like the aviation or healthcare industries, where failures may be the result of a combination of effects from various sources with several contributory factors, in these types of contexts, it is speculated that FMEA may not be an adequate tool to identify and assess safety hazards, which is why it is seldom employed (BSI 2019). Nevertheless, the lesson taken from the example presented by Louise-HS is invaluable: The FMEA is imposed to make up for the limitations of the risk prioritization feature of the risk matrix, which leaves analysts poorly guided on which risks to tackle as a priority. In Louise-HS's case specifically, she felt it was necessary to convert the risk assessment from a colour-based evaluation – namely, from a purely qualitative approach – into a semi-quantitative analysis, where a quantifiable output allowed a comparison between values to be established, and ultimately, made the development of a safety boundary possible.

The detectability feature included in the FMEA means that analysts can assess how likely it would be for the system, or someone operating the system, to stop an event from happening. The higher the detectability rate, the lower the risk. Detectability is seen as a protection feature – a mitigation measure or a barrier, even, that is incorporated into the system.

Similar to the SIRA component of the ARMS method, discriminating between the various detection settings presents a challenge in FMEA. No one can be certain that the detection feature (or barrier) will work as envisaged, or that the data will translate to a quantifiable figure. Its high degree of variability and subjectivity will make FMEA difficult to put into practice, but accepting its limitations and incorporating it into the system alongside the other protective measures would seem appropriate.

From Louise-HS’s account, it is possible to summarize that:

2.6 Despite its drawbacks and potential for inaccuracies, using the HFMEA approach it is possible to convert a purely qualitative method into a semi-quantitative outcome. Beyond the traditional characteristics of severity and probability or frequency of risk, it would seem appropriate to incorporate a third variable to strengthen the protections already incorporated into the system, although the analyst may be unable to quantify precisely the impact of those mitigation measures [F2.6].

5.2.7 Control Charts

Unlike the previous tools, the “control chart” is a method dedicated to gauging and presenting the operational data obtained from monitoring the system [SQ 2]. The objective is to analyse any trend or deviation that could forecast a departure from the organization’s objectives. To use an analogy, it could be seen as the safety system that provides a “medical check-up” to test performance.

The majority of the personnel working in the interviewees’ organizations used safety performance indicators (SPIs) – similar to those presented in Appendix H. These incorporate a large range of graphics and tables to demonstrate the continuous improvement of the organization’s safety-management system. Following the method described in the last two editions of *ICAO Doc. 9859* manual (ICAO 2013b, 2018b), organizations use an adapted type of “control chart” to present their results (BSI 7870–2:2013 2013), and hence the current section heading “Control Charts”.

Data presentation suffers from many weaknesses, ranging from an incorrect understanding of the limitations associated with the method to the incapacity of the system to incorporate both of the risk characteristics of frequency and severity. Yolanda-AS acknowledged that interpretation at management level was deficient, stating: *“[Regarding SPI], I think that at this stage everything is accepted, it depends on what is presented.”* Jack-AS, a safety manager from a regional airline, offered an even more caustic view, one which highlighted managers’ difficulty at interpreting the data: *“[Managers] do not understand what safety performance indicators represent.”*

Safety performance indicators, specifically the control charts, illustrate the frequency of occurrences. This is what prompted Gary-AS to mention how: *“[The control charts] are not* *used [to] monitor the risk because that does not give us the risk […] it gives us the evolution of specific indicators […] and trends, and then we check whether or not the measures we have implemented are appropriate."* He then went on to explain the usefulness of them: *"When [the control chart] goes outside [the limits] we will want to analyse the specific situation, we will try to understand if there is particular cause that could have led to the deviation or exceedance. Then, if this factor is identified, […] we will try to understand why the current barriers did not work."*

As Gap 3, below, will address 5.3.2 (Longitudinal Monitoring), system analysis is not continuous. As Bentes-AA pointed out: *"Trend evaluation is carried out monthly. […] The objective is to understand if we are breaking alert levels, and then to act. We are using the same method [to monitor risk], which is based on the […] standard deviations advocated by the ICAO."* There is a consensus among stakeholders concerning the level of alert: Bentes-AA explained how whenever a certain threshold is exceeded it prompts him to act, *"[We have] to analyse and realize […] what is going on, because when it exceeds the alert level, it has to be discussed in SAG. […] That is, when it exceeds three standard deviations […], or when it exceeds two times the two standards or even three times […] a [standard] deviation."* This sort of procedure is common throughout the industry. Jeremiah-AS, for example, explained how he operated a similar rule to trigger an internal discussion, if: *"A standard deviation, if exceeded three consecutive times in the period under review, typically one month, leads me to have to give visibility to this subject in SAG. […] [The same applies] if the deviation [achieves] two standard deviations in two months or three standard deviations in a single month."*

Apart from the rule used to trigger an analysis of the hazard, it seems obvious that analysts are measuring the functionality of their safety-management systems based on a frequency approach. Yolanda-AA provided a pertinent example: *"The objective is to try to reduce the number of unstabilized approaches [and] increase adherence to SOPs. […] The period [will be] […] of 12 months, i.e., every time we measure, we analyse the last 12 months, it's like a moving average."* Paul-HL offered another perspective of a monitored process from the healthcare industry perspective: *"The [programme to] 'stop infection' uses […] control charts […]. We use the 'control charts' to measure over time […]. And that is what will give us […], the notion of whether we are on the right track, if we are improving – in this specific case, whether we are reducing the incidence of infection."*

The ultimate objective of control charts or other types of graphics is to identify deviations. Risk monitoring, using the frequency feature alone, does not provide the analyst with an adequate sense of the organization's risk exposure. Measuring the risk using a control chart is similar to assuming that all events hold an identical level of risk. Nicholas-AL acknowledged this drawback: *"[…] SPIs, like the ones presented by the* ICAO Doc. 9859 *manual, are not effective because they are limited to counting the number of events while ignoring their severity. The indicator represents a sum of events and does not discriminate [between] those that are more important in safety terms."* As already stated, this method of presenting results may be misleading, since an increase in the number of events does not necessarily represent a higher risk exposure for the organization. Evidence to suggest that there is a general inability to present the level of risk, leads to speculation that operational staff lack a robust method to support safety investment decision-making. Therefore, apart from the investments required by legislation, the gap might create an investment barrier within the organization. Gap 3 at 5.3 (Safety Protection) [SQ 3], will scrutinize this finding.

From analysis of the tool used to present the safety results, it can be inferred that:

2.7 The ultimate aim of control charts is to present the performance of the safety system. However, the measurements of control charts, based on the number of occurrences, largely ignores the organization's level of risk exposure. As to the gap that limits understanding of the risk faced by the organization, the speculation is that this constitutes a barrier to investment in protection by the relevant decision-makers [F2.7].

5.2.8 Other Tools

Use of several other risk tools were discussed during the interviews, namely fault tree analysis and risk tables – both of which are used commonly within the healthcare industry – along with ingeniously weighted score tools. As these tools' use was either residual and/or only briefly discussed it has not been possible to appraise them, which is why analysis of these tools does not form part of the Gap 2's "Risk Tool" analysis.

5.2.9 Recapping on Gap 2

The discussion throughout Gap 2 has centred around the capacity of the risk tools to tackle the analysis and evaluation phases of the risk assessment (BSI 2018b). The conclusions draw from the data obtained from the 26 interviews with operational staff about their practice and daily challenges.

The discussion about the characteristics of the risk tools exposed how the standardization phenomenon imposed on the aviation industry hinders its ability to innovate and how, consequently, this limits the capacity of the industry to implement effectively the evaluation phase of the risk assessment, since risk appetite is not reflected in the risk tools. There is consensus that risk tools should be adaptable and fit the environment where they are used, they should be enabled to give consent to human evaluation, and should allow a comparison between the risk exposure and the defined safety objectives. Furthermore, a risk tool should be able to react proactively, receive real-time data continuously, and be able to prioritize hazards.

There was no consensus among stakeholders over which approach – quantitative, qualitative or semi-quantitative – would best serve the risk assessment purpose.

Stakeholders' organizations use risk matrices universally and some use a combination of tools. Although highly popular with users, most practitioners are conscious of the main drawbacks posed by the risk assessment, specifically: integrity, variability, and incapacity to prioritize different safety risks. The ARMS method constitutes a response to managing the high volume of data generated by safety-management systems. It did become clear that the method presented a challenge when implemented as devised. However, the reasoning behind ARMS – that risk analysis should be based on risk exposure, and how the outcome of similar events might differ – proved quite relevant. According to the ARMS approach, risk exposure is understood by taking account of similar and concurrent events. The risk matrix and ARMS are tools dedicated to measuring the risk posed by each hazard, the former being purely qualitative whereas the latter is a semi-quantitative tool.

The bow-tie method was the third tool discussed. Indeed, although this is not a risk tool as such, but rather a reasoning method used during the analysis phase, it nonetheless helps the analyst to develop a pictorial understanding of the potential pathways for the undesirable event, and to identify where the system may need mitigation and recovery measures. However, the bow-tie method has minimal capacity to evaluate a hazard, and it restricts the analysis to single interactions. Nevertheless, the reasoning that supports the bow-tie method is relevant, and thus would add value if embedded within a risk tool.

The HFMEA method, observed from a single interviewee practising within the healthcare industry, is dedicated to identifying single-point failure modes and to flagging up the need for redundancy, as well as to highlight key mechanisms within a process that might need further monitoring. Although only one interviewee used it in practice, the study of HFMEA was helpful, demonstrating the usefulness of converting a qualitative approach into a semi-quantitative one, and bearing comparison with the same approach attempted, unsuccessfully, using ARMS.

Finally, control charts were discussed. This tool, which is used to analyse the performance of the safety system, was not exempt from criticism. From the analysis, it was perceptible that their output does not convey a clear picture of risk and that this creates a barrier for future investment in improvement of the SMS.

Discussion about other methods was incidental, which is why analysis of these tools does not form part of Gap 2's "Risk Tool" analysis.

5.3 Gap 3 – Safety Protection

Safety protection is closely associated with the two preceding gaps – safety boundaries and risk tools – involving the definition of the limits within an organization and the way in which organizations measure them. To achieve a balance between production and protection [SQ 3] – since hazards do not affect organizations in the same way – in this section, the discussion is oriented towards understanding how organizations protect themselves against hazards, as they present themselves within the working environment. In this regard, Jeremiah-AS stressed the differences in the risk exposure faced by individual organizations: *"In the industry […] a wide range of players […] can contribute to identifying hazards, but not to identify risks. That is, hazards are a common element to operators; what is a hazard to [an organization] will undoubtedly be […] a hazard to me. However, the risks that arise from a hazard, [i.e.] the risks I expose my organization to, are different from other organizations."*

This discussion with the interviewees has its inception in the persistent dilemma presented by James Reason (1997; 2016), about investment in production versus protection. The debate begins with an organization's investment decisions [RQ 3.1] in a broad sense, in an attempt to understand how each organization handles its own specific risks, and then opens out to include complementary areas, which the interviewees saw as vitally important to achieve a balanced protective level.

Behind the safety-protection gap there is a broad concept that ought to be seen as a management tool really, because it is used to allocate the available resources where they are most needed. Should someone want to improve the performance of a particular operational area, it will require dedication in terms of time and assigning new resources or deviating available resources from elsewhere. As demonstrated by Lu et al. (2016), each protective safety element has a cost-efficiency aspect associated with it, with performance dependent on how well each element is utilized, so correct, robust management, therefore, is of the utmost importance. Louise-HS provided an example of an awareness campaign for staff that shifted resources to a different focus: *"This year the indicator [...] [was raised to] 85%, [but it] did not have any impact on resources, because this had to do with people's behaviour; [...] specifically [with] awareness of the implementation of the measures."*

The discussion below will focus on four subject areas that emerged from the interviews: safety investments, longitudinal monitoring, fuzzy frequency and service providers, all of which, ultimately, if correctly managed, would form a "safety-protection network" to improve the protection of organizations [SQ 3.1, SQ 3.2].

5.3.1 Safety Investments

The interviewees associated safety investments with several features. These included: recruitment of more staff, overtime, investment in new equipment, implementation of new software features and the like. The associations offered by the interviewees, who are representatives from organizations in the airline and healthcare industries working in the area of safety management, could reflect generally a policy of understaffing, which as Louise-HS confessed: *"I have associated [...] with more people!"* With the exception of two organizations, where the safety departments were staffed by more than 20 professionals and a third one with eight, the others had no more than two or three dedicated elements. Safety investments can also relate to acquiring new capacities. However, seen as a constituent element of the safety-protection network, this ought to be understood as an area where managers flexibly focus their attention to highlight a specific subject or safety risk.

The aforementioned concept implies that there is the need to understand where investment is required. Sections 5.3.2 to 5.3.4 explore how the interviewees' organizations made investment decisions.

According to the majority of the interviewees' accounts, it was clear that in most organizations the decision to allocate resources was an ad hoc exercise, supported by a rationale based on a risk-approach perspective, and lacking a robust process.

Executive directors tend to see the allocation of resources as a burden, but not only in financial terms; from a management perspective, resource allocation is a time-consuming activity that must necessarily reflect an understanding of where the resources are most needed. Larry-AB, a former board member, recognized the difficulties he encountered when considering safety investments: *"There were times when I felt that there might be a paradox […], the fact that there was not an incident for a long time tends to create less concern about some things that […] should not be minor concerns."* George-AB, another board member, raised concerns about the lack of a structured process to manage safety investments: *"A method of allocating resources is not documented."* The same executive director pointed out how resource allocation was based on industry standards: *"Resources are also assigned based on industry metrics. […] Regarding human resources we have not acted much, because according to the organization's understanding we have an adequate number of people for what we do."* Yet, later on in the interview, seemingly without realizing, he admitted how inadequate risk-management had led to a high degree of occurrences: *"The resources remained around the same at the time […]. The risk in that year was extremely high […] due to existent contributory factors […]. There were many phase-ins*[90] *and at the same time, […] there was a big outflow of staff. Then a lot of work was postponed, obviously within the limits allowed by the manuals, but pushing margins to the limits; and more occurrences began to happen."* Paul-HL described a new protective programme implemented in his organization, particularly how investment was not part of the equation: *"In the program 'stop hospital infection' they hadn't considered the investment."* John-AB's approach to resource allocation was proactive, involving gathering feedback in the field: *"I think for me, first and foremost, it is about interviewing, [and] talking with the people who are actually doing the job."*

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[90] A phase-in signifies the entrance of a new aircraft to the airline's inventory.

A different perspective of the reality of taking the unstructured approach when making decisions about investments in safety, emerges from the operational staff accounts. India-AS corroborated the status quo, stating how: *“To my knowledge, there is no formal procedure, the situations are considered on a case-by-case basis and [investments decided upon] according to their criticality.”* Gordon-AA’s airline implemented a similar procedure: *“Investments [are] determined on a case-by-case basis, without relating them to a level of safety.”* In the same vein, Bentes-AA corroborated the existence of a gap, mentioning that: *“I do not know how this is done. […] If it is considered, it does not reach us. […] At least to my knowledge […], there is no definition of resources; there is none. It is a significant gap that exists!”* Dimitri-AS[91] explained how in his airline: *“There is no relationship between investment and SPI”* although he admits, *“that some kind of relationship ought to exist.”* Gary-AS’s airline made no association between SPI and investment, either, but his scepticism centred on the relationship between investment and performance*: “We […] do not correlate [between] resources and performance. I do not believe there is a direct correlation.”* Nevertheless, seemingly without realizing it, his reasoning supported the existence of such a relationship: *“Unstabilized approaches […] at XXXX*[92] *[…] were around 23% or 24%. […] We identified a pattern there, […] and we intervened. […] Nowadays, XXXX is around 9% to 10%. In other words, reverted to [our] average. […] Then, the time will come [where] to lower by 1% we incur a high cost, or we have to invest a great effort.”* Gary-AS’s initial denial could be seen as the consequence of the incapacity of the risk tools used – risk matrix and ARMS – to perform a formal comparison as a matter of course, because by the end of the interview, without any persuasion from the interviewer, he came to support the relationship. This provides strong evidence of the existence of a gap within the airline industry, which Gary-AS affirmed by stating: *“I think it makes perfect sense to associate [safety objectives with investment]. […] Now the difficulty lies in arranging a parallelism that will correlate one thing with the other.”*

Without a structured model to guide decisions about investment, organizations are compelled to comply with regulatory impositions. India-AS recalled how the decision to impose a safety feature was made in her organization: *“We had […] an occurrence related to two open engine nacelles*[93] *[…]. We handed the plane over and had left the covers open, […] the locks were open. […] Airbus produced a solution that would solve […] the problem. […] The*

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[91] Dimitri-AS did not give his permission to record the interview.
[92] XXXX represents the ICAO code for the airfield mentioned by Gary-AS.
[93] The nacelle is a housing quite separate from the fuselage, holing engines, fuel, or equipment on an aircraft.

modification […] would be an Airworthiness Directive[94] *[within] two years, […] so it would become a mandatory directive. The Chief Technical Officer [decided] […] to phase it in as the planes arrive at the hangar."* Jeremiah-AS explained how his organization supported an investment: *"The rational […] was not to reach that safety [objective] in concrete terms or to decrease the exposure to a specific indicator. Typically, the investment was supported by [the argument] of the necessity due to regulatory purposes. It was the 'x' law, article 'y' that requested a specific feature, and therefore the [organizational] risk was non-compliancy with this [obligation]. It is always a compelling argument."* Sabine-HS stated how she made use of external examples: *"I have submitted only a written proposal to identify what happened in other places, in other countries, and therefore [recommended] that the centre should get these syringes."*

From Gap 2 – Risk Tools – it was not possible to perceive definitively whether the interviewees felt that the qualitative or quantitative approach, or even a mixture of the two methodologies (semi-quantitative), would adequately support risk management in aviation. The consensus seemed to that choice of approach was an issue that the best practice guidance could help decide. In this regard, Yolanda-AA focused on her attempt at "selling" the benefits of a robust system: *"[…] Executive directors see safety as a cost and not as an investment because we cannot demonstrate the benefit in concrete terms."* While addressing the frequency of events as a relevant factor, Kostas-AS recognized that the support of data was important – *"[To] justify the investment […], we have to present support for it"*; and wanted to stress that: *"[…] data is fundamental to creating […] complete visibility of where the problem lies. […] To develop […] the justification for the investment."* Other interviewees supported investment decisions with statistics based on SPIs. Nevertheless, as seen in Gap 1 on the development of safety boundaries, SPIs, based on a frequency approach, do not sufficiently convey a risk perspective. Furthermore, although according to the accounts of executive directors one might speculate that their preference is for quantitative data, this alone is not enough either, which explains the root cause of the interviewees' difficulties in this regard. Jeremiah-AS's organization had seen its investment attempts falter due [apparently] to failing to demonstrate the level of risk it was exposed to. In his own words: *"The statistics were presented [in the SRB] identifying a specific performance and the factors […] that had been present which prevented the goal from being achieved. […] [However,]*

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[94] An Airworthiness Directive, issued by a regulator (e.g. EASA or FAA), is a legally binding regulation to correct an unsafe product, part or appliance.

the [cycle] was not closed. The investment envisaged to mitigate the contributing factors, most of the time, was not implemented."

Another example, this time from the healthcare industry, describes how full implementation of a proven solution stalled because of an incapacity to demonstrate the risk-exposure level the unit was facing at the executive level. Here, Sabine-HS is speaking about an identification solution for patients: *"We have mechanisms on the market that allow the reduction [of errors of identification] by almost 100% […]; this is through the introduction of an electronic bracelet, with a barcode reading, where I can […] trace the identification of the patient, the therapeutic product, from prescription to administration. […] And the product exists in the market, and the only thing that blocks the implementation [are] monetary issues, and this makes me sad."* An inability to demonstrate the level of risk exposure the organization is facing is a situation Nicholas-AL acknowledged. He brings a critical realism perspective to bear, which argues that all contributory factors (or perspectives) must be included to support the view of risk exposure, and that its evolution must be perceptible to managers: *"[I]t is neither possible nor desirable to define or to develop […] an algorithm to calculate safety investments. However, considering that risk should be analysed through different perspectives […], risks should be represented on a diagram or an axis, not by a single point, but by a rectangle with a kind of an arrow showing the tendency of that hazard."*

George-AB made clear his support for the identification-of-contributory-factors (or perspectives) approach when acknowledging the reason behind his organization's difficult period: *"There were several contributory factors […] that caused the depletion of resources for maintenance in that year."* He then consubstantiated his claims by identifying the implemented investments: *"It was decided […] that we were reaching unbearable levels, […] there was a significant impact on the operation. Then a reinforcement plan was made at the level of the equipment we have in storage, […] at the level of spares [and] rotatable [parts]."*

In summary, it is perceptible from the accounts of the interviewees that a purely mathematical approach, based on quantitative data, will not convey the desired risk-approach perspective and, therefore, will be unable to overcome the difficulties of raising awareness of the risk exposure among the higher echelons of an organization. To be able to give a predictive perspective, investment decisions must be supported by a qualitative methodology [SQ 2, RQ 2.2], and tools [RQ 2.1] comprising the identified risk factors or perspectives must be incorporated, such as they are able to convey a clear picture of the risks, and allow comparison with the defined safety boundaries [SQ 1].

From the analysis of the interviews, it can be asserted that:

3.1 The research suggests that organizations lack a structured process to allocate available resources or make decisions about new investments. Decisions are currently handled in an ad hoc way or are pushed through by regulatory imposition. The decision-making process lacks the robust framework of a rationale based on a risk-approach perspective. Given the nature of safety risks, a qualitative methodology, and tools that are capable of revealing different risk factors (or perspectives), should support investment decisions. These should be able to convey a comparison with the defined level of risk – the risk appetite of the organization – and in this way, promote predictive analysis [F3.1].

5.3.2 Longitudinal Monitoring

Monitoring risk over time is relevant to understanding and assessing the degree to which mitigation measures have been effective in reducing the risk exposure faced by organizations. In Paul-HL's words: *"The longitudinal monitoring[95] [phase is central] to understanding if the interventions promote a reduction and avoidance of the events."* The concept is well-established in the different risk standards publications, and their recommendations are to monitor them continuously throughout their lifetime (BSI 2018b; ICAO 2018b).

Several of the interviewees used the expression "longitudinal monitoring" to reflect what they observed in practice, whereby mainstream safety risks are not monitored continuously, but rather in a longitudinal fashion.

The previous statement by Paul-HL did not suggest that monitoring is absent over significant periods, it merely suggested that the majority of safety risks remain unmonitored over a long period of time. There are exceptions, however, as the four accounts below demonstrate. Monitoring was associated with incident analysis according to Lary-AB: *"[It was] the number of incidents reported in successive periods and what was behind each incident type or each incident group. […] The analysis was carried out event-by-event, checking […] the reason behind it, and then […] deliberating on each occurrence."* Louise-HS's hospital continuously monitored infection: *"We track the [infection] indicator every day. […] We*

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[95] This phase is also known as "monitoring and review" in the BSI (2018b) standard or "safety assurance component" in the ICAO (2018b) SMS framework (see Appendix M).

have an algorithm that monitors the index. […] This algorithm will seek information at various points in the patient process and build […] the indicator."

Airlines use data derived from Flight Data Monitoring (FDM) to observe their operation. Typically, data dissemination occurs every month, whereby operational managers in SAG meetings discuss the results presented. Kostas-AS provided a very precise example of the process: *"Our metrics are […] updated monthly and […] distributed internally by stakeholders."* Gary-AS gave a similar explanation: *"FDM monitoring is carried out […] monthly. […] SPIs […] are presented […] at the SAGs."*

Autonomous collection and processing of FDM data is commonplace in the airline industry. However, for specific hazards – where data is obtained from several sources – namely reports, investigations (including FDM), and others, these take much more time to be processed and disseminated.

Gary-AS said that his monitoring process extended into a larger interregnum whenever risks are associated with new operations: *"Every three months – there is no defined interval – […] we make a specific report, for example, [about] airports that we have recently started to operate."* Santini-AS proposed that a hazard monitored by EASA – "loss of control in-flight" – exposes the organization to the same problems as longitudinal monitoring: *"I have an SPI for this event. [The current state] is not so good. […] It is calculated for the last quarter. […] Then I will only revisit it within three months."* However, Santini-AS revealed other examples relating to this issue during the interview, one of which related specifically to CFIT (which comes under the EASA surveillance): *"[…] We have to reduce it. [It was analysed] six months ago. […] We have not updated it, because we are waiting to see the statistics. […]."*

The same applied analogously to Gordon-AA's airline: the interviewee clearly recognized the longitudinal monitoring phenomenon, but at the time of the interview the risk associated with "flap overspeed"[96] was under control. However, after perusing the bar graphs it was clear that there were several periods where the number of acceptable events had exceeded the warnings and acceptable levels.[97] Gordon-AA's explanation for this deviation or exceedance of the limits was associated, for him, with the prolonged periods between data analyses: *"The FDM*

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[96] Aircraft wings are equipped with flaps. These surfaces, used during take-off and landing phases, are located in the trailing edge of the wings and are used to augment the lift capability of the wing. As they are exposed to airflow, manufactures limit their operating speed to avoid damaging the driving mechanism.

[97] The conclusions come from Gordon-AA's statement; nevertheless, it needs stressing that the data was supported only by a frequency component.

is assembled and analysed every month, whereas the SPI is done on a 90-day basis. This time lapse could allow the existence of deviations that have taken too long to be captured." The result is the absence of safety-risk variation during the "monitoring and review" phase, as Martin-AB's statement seemed to demonstrate: *"In general [the level of risk] has remained within what we have defined."*

This scenario is not exclusive to airlines, however. The healthcare sector, beyond a few indicators such as the one described earlier (see section 5.1.4), takes a similar approach. Louise-HS's hospital updated the indexes four times a year: *"We have indicators posted on paper by [all] the services. [...] It depends on the type, but for the majority [...] it is quarterly."* For Sabine-HS – who works for an organization that has decentralized risk management – analysis of the indicators might extend for a whole year, largely prompted by the prospect of publishing the company's annual report. Her account was self-explanatory: *"In the office, we cannot evaluate [the risks] more often, so we have to make this evaluation every year. [...] If [the threat] is assessed as high, the interlocutors have to evaluate the [effectiveness] of the measures every six months. [...] but what happens is that many do not accomplish their tasks."*

India-AS's organization has had an SMS implemented for over five years which means that the system could be classified as a mature one. Their hazards are scrutinized using 11 different categories (see Figure 5.16) to identify a range of risks. This interviewee's organization has a decentralized system, so she affirmed, *"We ask the owner to monitor the risk."* It was not possible to identify any evolution in response to the different risks consulted, although the interviewer raised several questions[98] during the interview to try to understand the monitoring procedure. Unfortunately, the interviewee continually circumvented the questions.

Several explanations might explain the absence of regular risk-exposure updates, Santini-AS's provided one example: *"Although it seems otherwise, processes are more straightforward to implement than monitoring. [...] Because from the moment you execute [them], you get the idea that you have solved the problem."* Another seemingly plausible explanation related to the incapacity of the risk tools to receive data continuously, which obliged the analyst to peruse

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[98] An example of a question to get a better understanding of the mitigation process was *"After implementing the mitigation measures, in this specific example, you have classified the risk as 'minimal' (D5). At the end of the project, did you find that the risks were under-, over-, or well-assessed?"*

the safety database to update his former evaluation. George-AB had identified this drawback previously while describing the safety-risk life cycle (see section 5.2.1): *“When we analyse a risk, we take a snapshot, and then we […] agree on an amount of time, for instance, six months to re-analyse it.”* Sabine-HS supported the continuous flow of data, drawing attention to how *“Many things happen every day, […] the ideal was […] to be able to do constant monitoring.”*

From the analysis of how safety risks are monitored over time, it can be inferred that:

3.2 The majority of safety risks do not attract continuous monitoring. This has the potential to create a breach in the safety-management system. The speculation is that the time period observed between evaluations allows deviations to occur, which exacerbate the organization’s risk exposure [F3.2].

5.3.3 Fuzzy Frequency

The previous paragraphs have discussed the tools that determine the observance of safety boundaries and how frequently they are used. As these tools used during the risk assessment protect an organization from exposure to risk, they hold the potential to develop into an uncertainty-exposure stance among stakeholders. The speculation is that there is a gap in relation to a lack of understanding of the risk faced by organizations, which has the potential to constitute a barrier between organizational protection and decision-makers.

Whether using purely frequency or risk-based figures, predicting exactly the level of risk exposure in aviation is like trying to guess which direction a table tennis ball will take in rough waters. However, Nicholas-AL’s analogy shone some light on the use of frequency: *“It is difficult to simplify safety […] so that it can be measured by certain parameters; it is a very complex issue, […] like a living organism.”*

For example, in the healthcare industry, by looking at a representative population sample, one could predict the probability that such and such an individual will suffer from a specific disease, although the information may be of limited relevance. However, a risk analyst would not be able to identify what the next health issue a specific individual should be concerned with is likely to be, even though a disease or organ malfunction will commonly present with several associated symptoms, which can be used by a medical doctor to identify the (system) failure. Independently of the probability or the frequency, therefore, the symptoms are the clues that a risk analyst should be looking for to determine which ailment (or accident) ought to concern the patient (organization). These medical analogies, likewise, can be translated into airline safety risks whereby, having identified a certain “symptom”, a reinforced protective barrier comes into play, whether this is by reallocation or through the acquisition of new investments.

In order to develop a risk-exposure scenario that is workable, Yolanda-AA suggested that: *“A tool [has to] […] attribute different weights to different events.”* In the earlier example presented by Sabine-HS, if a risk-based approach is not used the output from a risk tool would convey a fuzzy scenario, such as in the case of the risk of falls: *“In six hospitals, I have 503 records of patient falls. Of course, not everyone has damage associated […]; usually 70–80% [of falls] cause no injury to the patient.”* Jeremiah-AS also stressed the need to understand the characteristics of the data: *“15% [of unstabilized approaches] only constitute a level of comfort if they are […] marginal deviations. I can have 15% of exceedances, [which are] considered highly deviant.”* Although the data referred to in the previous statements would contain more information, a risk analyst, in order to identifying the degree of injuries and deviations, would need far more detail to be able to construct a scenario. The following accounts indicate why this is so.

Ultimately, the risk analyst’s objective is to identify and mitigate the root causes of the event. Therefore, making use of bow-tie reasoning, for instance, an analyst would be asking what the contributing factors for the occurrences were. George-AB described his organization’s SPI structure: *“These indicators were created because early in the implementation of SMS […] we realized that these occurrences happen very frequently, and could become precursors. […] They are the small things of everyday life, which alone do not deserve much attention, but if they are associated with other contributory factors they can give rise to [an accident].”* Although frequency-based, Dimitri-AS supported the previous account: *“Safety Performance indicators are considered quite intuitive. They are […] supported by a frequency of events. The events that contribute to the SPI are further broken down with the purpose of identifying their root cause. Namely where they had their inception.”* Identifying the contributory factors of risk is not a straightforward process: it requires perseverance, an understanding of the business, and knowledge of the subtleties of flying an aircraft. This is what Jeremiah-AS advised*: “The biggest challenge is the acquisition of relevant and valid information […] that allows analysts to perceive that there are factors, which, under certain adverse circumstances (or in a combination of specific factors), can contribute to an unsafe [event] or an accident […].”*

While the use of fuzzy frequencies in isolation conveys irrelevant information, the use of a combination of tools, which could include risk-based frequencies, aggregating contributory factors and evaluation by an integrative risk tool, could go towards conveying to the analyst a risk-exposure perspective. Recalling the previous analogy, analysts cannot know the exact track a table tennis ball will take in rough waters, but they will certainly be able to build a clearer perspective of the potential scenario when armed with elements of the detail. Nicholas-AL's account supported this approach: *"[A risk-based approach is] not just counting the number of times things happened. [...] It is [...], actually, [about understanding] what kind of event could have happened, how close to the accident [...] we came, and [how] those gaps played a role."* It is worthwhile considering the reality faced by each organization individually: a comment by Jeremiah-AS stressed the difficulties of using generalization to gain insight into a particular operator, *"Each operator [...] has its [own] operational reality; it is not possible to generalize. [...] There is a common ground: I can [...] say that an unstabilized approach may have a relatively small core of factors that are common to all operators, but it will not be possible to say that only these factors are present, and that when those are under control then the problem will be solved."*

Coming close to an undesirable event, a serious incident, even an accident, is akin to being seen to be reaching the defined limits or objectives approved by management. Occasions when near misses occur raise deep concern, as Louise-HS stressed: *"I am even more concerned by cases where near-miss occurrences are known to exist. However, as long as the patient suffered no consequences [...] the tendency is for [this] information to be hidden."*

As seen in Gap 1, establishing safety boundaries is not straightforward. Nicholas-AL summarized the challenges and confirmed some of the statements he had made earlier on the subject: *"Presenting a single risk might not attract the attention [of management]. However, if [threats] are displayed in an aggregated form to give a risk picture, this would attract their attention, which is what they are trained for, to understand aggregate data."*

Although the previous accounts suggest that a tool to support the development of a risk-exposure scenario is required, the anticipation remains to be able to forecast situations that occur without any symptoms, such as this near miss reported by India-AS: *"Open engine doors was the event that happened. Objectively [...], the event generated a delay. However, something went wrong which crossed our safety net without us noticing. [...]; we saw that this event could have escalated to an accident."*

Such events, known as “black swans”; are, typically, extremely difficult to detect, as they reveal few or no contributory factors, and frequently have devastating outcomes. However, these types of accidents are beyond the objectives of the present research.

The ability to maintain continuous monitoring of the organization’s risk exposure is an invaluable feature of the safety risk-management process, as noted above. However, as the accounts from interviewees made clear, continuous monitoring alone does not assure robust protection. From the accounts of interviewees, it can be perceived that:

3.3 In order to develop a risk-exposure scenario as discussed in the ARMS section at 5.2.4, SPIs should be supported by other frequencies that take a risk-based approach, integrate the root causes of the undesirable events and are capable of being presented in an integrated fashion [F3.3].

5.3.4 Service Providers

Aviation is an interdependent industry. The specificity of civil aviation compels every single airline to depend on a plethora of specialist partners. This is a position that Jeremiah-AS corroborated by stating: *“Nowadays, due to necessity, companies [...] are increasingly contracting out services.”* Further, reflecting the seasonal nature of the aeronautical industry, Kostas-AS also admitted to recurring to third parties: *“We accept the fact that there will be times in our operation when we will have to outsource charters to make a flight [...] [available to our] customers.”* The activity is recurrent to the point that some airlines have customized their offer to include a charter segment, such as the example provided by Santini-AS: *“Currently, it is no longer flying as a tourism company [...] the operation has changed [from an] ACMI to performing flights for third parties [operators]. [...] It made us start thinking about the standards of the companies we were outsourcing flying to.”*

Beyond internal risks, the reliance on third parties also means that an organization is confronted with multiple external sources, originating from suppliers that have the potential to affect the airline’s risk exposure. Surprisingly, SMS has an egocentric vision, in that it fails to recognize the interdependency that exists among stakeholders, as George-AB acknowledged: *“SMS is working more and more by silos. There are SMS from the operator, from air traffic management, from CAMO, and we are glad to have an SMS with a risk-management model in there! But how do they talk to each other? [...] How do these tools dialogue with each other?”* George-AB elaborated further on the perceived gap: *“I think* *there is an essential theme. […] [H]ow are interfaces managed […] between the various players, between a customer and a supplier, between a supplier who then independently turns to a second-level supplier?"*

To minimize risk exposure, a contract is established. This is subject to evaluation before proceeding and then subjected to an audit or a survey, as Santini-AS acknowledged: *"Our customers frequently audit us. We try our best always to be within the […] standard they require for us."* George-AB's company dealt with more than 2,000 suppliers, and he commented on his survey-based analysis of providers: *"We have several ways – let's say indirect ones – to control the risk [introduced by providers]. One of them is the desktop audit. […] We send a survey, which is used to classify the provider's risk level automatically. […] Then the analyst evaluates the main hazards that exist with that supplier, proposes mitigation measures, and then […] the supplier […] is approved or not."* Nevertheless, frequently, the execution of the continuous monitoring does not occur or, alternatively, reactive measures, such as event notifications, will substitute for it. As India-AS suggested: *"In the contract we place specific conditions and certain indicators […] concerning the activities that are related to the work developed. […] For example, […] that the provider is obliged to report to us any occurrence pertaining to our aeroplane."* Kostas-AS also confirmed a gap in this area: *"It is an area that needs to be further strengthened. […] At this moment, we accept this gap. […] [H]owever, […] before choosing a service provider, we do an audit to try to select the best [partners]."* Kostas-AS specified the nature of the gap as he saw it: *"We exchange reports when it's pertinent […], but we do not have access to [the provider's] data. We do not have access to their hazard log."*

Organizations also outsource the audits, whereby companies use industry-recognized standards, such as the IATA Operational Safety Audit (IOSA) standard, developed by the IATA. In this regard, Jeremiah-AS, a safety expert who contributes to several aviation forums, asserted that: *"The understanding that exists within the industry […] is that companies should only […] establish code-share, ACMI or any [other] kind of agreements, regular or non-regular, with companies that are IOSA certified."*

The IOSA standard is a comprehensive norm that covers a wide range of aviation scopes.[99] However, certification is not assurance of a high safety standard, but rather only a guarantee

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[99] The IOSA standard has eight scopes that cover the whole range of operational areas undertaken by a commercial airline. These are specifically: The Organization and Management System (ORG); Flight operations (FLT); Operational Control and Flight Dispatch (DSP); Aircraft Engineering and Maintenance (MNT); Cabin

that auditees have implemented both specific standards and recommended practices. This is why Dimitri-AS supported the use of an additional procedure: *"Before establishing a contract, we perform a pre-audit, and require the IOSA certification."*

Continuous supervision requires considerable strengths of the resources made available, as Jeremiah-AS pointed out: *"The ability to monitor, and guarantee that these services have a level [and] a standard [...] compatible with [what] you require them to have, runs into the ability [...] to monitor that quality."* Nonetheless, as noted previously, this practice reveals airlines' incapacity to establish a continuous monitoring process. The drawback Kostas-AS recognized earlier as a gap, Gary-AS – who confessed that he had been unable to establish a robust monitoring programme – also called out: *"We are not aware of the safety performance of other companies. We had [an accident with a partner] […], and it was not a comfortable situation, because we had no control. Moreover, […] from a contractual point of view, the accident demonstrated the existence of several weaknesses."*

From the discussion on this subject, it can be asserted that:

3.4 The continuous monitoring of service providers is essential to controlling an organization's risk exposure; and, therefore, it is an instrumental factor in achieving a robust safety protection. However, the interviewees cast doubt over whether stakeholders' approaches dealt adequately with the safety risks that originated externally, which as an active breach, has a direct impact on Gap 3 – Safety Protection [F3.4].

5.3.5 Recapping on Gap 3

As Appendix E.6 illustrates, "safety protection" was a subject that accounted for around 20% of stakeholders' concerns. This is reason enough to speculate that this area deserves the focused attention of both legislators and regulators to address the four components identified in the gap.

Gap 3 has addressed measures to enhance safety protection in light of the interviewees' perceptions, which highlighted breaches that have the potential to affect the organizations' risk exposure. Organizations fail to institute a structured process to allocate or relocate their available resources. Compounding this weakness is the fact that organizations do not monitor their risk exposure continuously. Moreover, in the majority of the situations observed, the

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Operations (CAB); Ground Handling Operations (GRH); Cargo Operations (CGO); and Security Management (SEC).

evaluated risks used a set of variables that conveyed a distorted risk exposure: the data did not encompass a risk-based approach, failed to integrate the contributory factors, and did not carry out the analysis in an integrated manner. Finally, organizations did not apply a robust method to account for the risk exposure that originated externally.

5.4 Gap 4 – Safety Culture

To understand the influence exerted by "safety culture", the research questionnaire included two questions[100] related to the subject. The relevant statements amounted to approximately 10%, as Appendix E.6 illustrates. The result reflects the stance observed during the interviews, which saw the majority (to avoid mentioning the whole sample) of interviewees recognize that the safety culture embedded within the organization had a significant impact on its risk exposure [SQ 4].

The recently published ICAO (2018b) risk-management manual dedicated a whole chapter to organizational safety culture. According to the view of the ICAO, the safety values enshrined in the behaviour of both management and operational staff will directly affect implementation of the organizations' safety programmes. ICAO (2018b, p. 3-1) argued that "safety culture has a direct impact in safety performance." Thus, as safety culture is seen as the single most influential factor in the management of safety, therefore, it should be considered throughout the risk-assessment process: risk identification, risk analysis and risk evaluation (BSI 2018b).

5.4.1 Sustainable Factor

Safety professionals acknowledge the importance of safety culture, for example, Barros-AS asserted that: *"We are looking at the cultural issue with great concern."* To support this stance, the same interviewee added: *"Currently we have a very immature flight crew. So, we have to be a little more restrictive [...]."* Louise-HS, a senior safety professional, shared a similar opinion: *"[Professionals] are heavily influenced by the safety culture, [...] and [this] is certainly reflected in the implementation [...] of the measures on the ground."* She admitted that: *"There are specific areas where the safety culture is more deeply rooted [...]. There are specific professional groups that [...] have a more robust safety culture because*

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[100] To understand how culture influences the definition of risk, assessment and mitigation, the research questionnaire (presented in Appendix E.1) included two questions: *"How do you take into account [your] company safety culture when defining the safety boundaries?"* and *"Do the risk tools incorporate (or in some way attenuate) the influence exerted by [your] organization's culture?"*

they work in areas of higher risk and so this […] is somehow accounted for in an informal way." Jeremiah-AS also recognized the importance of a safety culture, but he acknowledged his incapacity to account for it: *"Safety culture in risk analysis?"* [A long silence], *"I am not aware of how we can use […] it as a calculation factor or contributor to the final risk […] I think you should consider. [However], when you find a culture […] where people in their activity do not have a […] risk assessment and [have taken an] avoidance stance, you have a series of [unacceptable] behaviours."* Peter-AS corroborated with a similar sort of attitude: *"The [culture] is a factor, [but] I do not consider it in risk analysis."* Santini-AS even more pragmatically declared: *"I have no indicators, no knowledge and no tools to [consider the safety culture]."*

From the previous accounts, the inference is that culture is enshrined in the analyst's reasoning; however, risk analysts do not consider the influence of culture in a structured way. Yolanda-AA's statement, which is self-explanatory, supported this claim: *"The fact that […] you know that the culture influences the way people work has an impact on the way […] you assess the hazards. Therefore, you might not do it consciously. […] You do bear this in mind; [although] we might not do it in a systematic way."*

Although not taken into consideration during the risk analysis phase, stakeholders did recognize safety culture as a key factor in achieving a strong safety performance. For Paul-HL, *"Culture is a variable"*, and *"fundamental […] in terms of sustainability of practices."* Sabine-HS understood safety culture as the backbone of the safety system: *"[Culture] has a direct connection […] because when the safety culture is poor […] nothing happens."* Nicholas-AL's perspective was in line with the previous view: *"Under the ERC process, when the safety analyst is faced with the second question – effectiveness of [the] remaining barriers*[101] *– safety culture plays a key role. The barriers will not be effective if the organization has an eroded safety culture."* However, once again, the ARMS methodology fails to consider safety culture objectively.

The previous statements suggest that:

4.1 Stakeholders consider safety culture as a contributing factor in the organization's safety performance, and agree that it influences the whole safety system. Ultimately, it has either a positive or a negative impact on overall safety-system performance. In terms of risk

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[101] The question this perspective relates to was: *"What was the effectiveness of the remaining barriers between this event and the most credible accident scenario?"*

exposure, the safety culture appears to function as an inversely proportional variable – that is, a strong safety culture reduces an organization's risk exposure whereas a careless one increases its risk exposure [F4.1].

5.4.2 A Sociological Approach

Safety culture does not evenly distribute itself at the same level throughout an organization. Although the interviewees did not elaborate in any depth on this perspective, several accounts deserve highlighting because they drew analysts' attention to one important characteristic of safety culture.

George-AB emphasized the different behaviours that exist within his organization. For him: *"[There are] many subcultures in here. […] If we go to an area […] of maintenance – for instance, engines, […] – the technicians are acculturated in a certain way, because they come from professional schools. […] Within the technician team, there is an intrinsic risk culture. Now if we go to people who are not technicians, people who are involved in material management or planners, technicians at the administrative level, I often think people take unnecessary risks or are not fully aware of the risks they are exposed to."* George-AB saw maintenance as an activity where there is an under-reported level of risk: *"One of the significant problems for maintenance, not only here, but common to other congeners, is the small amount of data. […] People solve the problem but do not report it."* Moreover, George-AB found significant differences in the level of reporting within certain departments of his organization: *"There are areas where plenty of events are reported; there are other areas where nothing is reported."*

Barros-AS, emphasizing the generational differences of pilots, had identified how: *"[…] there's a culture shock for the older ones who are go-minded and the younger ones who are a bit more stringent."* Jeremiah-AS experienced a similar reality in his organization: *"There is a cultural […] component of the company that has decades [of experience], [where] its commanders find […] that in the box of standards or in the written documents there is a margin of interpretation. […] So, there are people who have a risk assessment stance that I would classify as less conservative and, therefore, do things they should not do."*

Safety culture is distributed unevenly across different groups of professionals in an organization. Sabine-HS underlined the differences in risk classification between the people practising on the front line and the back-office staff: *"[In HER+ software] we see who made* *the evaluations. […] Then, in each risk, the programme presents the average of the group. […] If the outcome was a high [risk], this means that there were people who always classified it in the extreme. […] These people are […] those who are there in the service [on the front line]. […] They feel the risk more keenly, […] even when it never occurred."*

From the above discussion it can be inferred that:

4.2 "Safety culture" does not spread homogenously throughout an organization. However, among different groups of professionals, classes or groups within the same organization, similar patterns of behaviour can be identified [F4.2].

5.4.3 Embedding Safety Culture in Risk Management

From the previous paragraphs, it is notable that culture is a remarkably difficult concept to handle as part of risk management. However, undoubtedly, it influences the way people behave and act upon the risks they face when going about their daily activities. One of the approaches conveyed by a question[102] for Gap 2 – Risk Tools – asked interviewees to reflect on the importance of safety culture and describe how it was recognized within their organization [RQ 4.2].

An interview with a member of a reputable organization – where there are sound reasons for the workforce's pride in the safety-management system implemented there – produced a surprising response. The sense of pride that staff working for the organization displayed, however, seemed to contrast strikingly with the safety manager's quite defensive attitude. When asked about how safety culture was realized within the organization, Peter-AS's reaction was notable, he was perceptibly uncomfortable when answering the question, and reacted by merely offering the observation: *"That's a good question; it's not a factor. It has not been considered a factor!"* The objective was not to embarrass the interviewee, but his reply merely supports the claim that: "safety culture is not easily handled by practitioners".

Other interviewees treated the question as a natural outcome of the discussion. Jack-AS's evaluation was that his organization had made some sound improvements, but he admitted that there was no model to account for what a good safety culture ought to look like, saying that: *"In practical terms, I do not know how [...] one can [incorporate such safety culture],*

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[102] The question being: *"You have your traits, you have your national culture, and at the organizational level you are influenced by pilot culture, cabin crew culture, and the maintenance team's culture, and the like. How do you integrate culture into your risk analysis?"*

but it would be ideal to do so." In a similar vein, India-AS acknowledged that her risk assessments were devoid of a "safety culture" component: *"We do not have a tool that considers [safety culture], because our [...] statistics [...] are still very poor."* Neither Dimitri-AS or Gordon-AA gave permission to record their interviews, but both admitted to *"[the] influence exerted by [safety] culture; however, their department has no means to incorporate it into the assessments."*

Gary-AS measured the safety culture among crewmembers using indirect methods. The absence of directives resulted in a latent doubt: *"We [...] measure ['safety culture'], but we do not know if the measurement is realistic and effective. [...] One of the indicators we have is at the reporting level. We also have a ratio between occurrences identified in FDM that require [mandatory] reporting and then we confront this figure with the report received."* The same interviewee also recognized that safety culture did not feature in the risk assessment process: *"My tools do not [consider safety culture]. [...] When you're doing a risk assessment, you might consider [generally the organizational] culture. However, [at the level] of the tool, I haven't yet figured out how to do it [but eventually] will use some of these factors."* While quite remarkable, Gary-AS's account aligns with the statement made in the first paragraph of this section: safety culture is seen as a sustainable factor, thus while a positive safety culture reduces the organization's risk exposure, a poor one increases it. Although not part of Nicholas-AL's remit, his stance on this issue was similar to Gary-AS's: *"I think [safety culture] needs to be taken into account indirectly [...], at some point during the risk assessment somebody is going to ask can I or can I not trust that our people will detect this [or that, such and such a] problem?"*

Similar behaviours are prevalent throughout the industry, and while Barros-AS was conscious of the importance of changing certain aspects of it, he admitted he had not yet been able to make safety culture fully accountable: *"We do not [integrate safety culture into risk analysis] [...], but we are trying to reach that level."* The same applied to Sabine-HS in the healthcare industry: *"The safety culture assessment is based [on a] national questionnaire. [...] The results incorporate [...] dimensions that are fragile, and therefore we consider those in the day-to-day. However, there is no [reflection] in our assessments."*

From the discussion about the integration of safety culture in the risk assessment, it can be concluded that:

4.3 Stakeholders are conscious of the important role played by “safety culture” in the risk-management process. However, despite their efforts, they have struggled to find a way forward to incorporate the concept, directly or indirectly, within the risk-assessment activities of their organizations [F4.3].

5.4.4 Recapping on Gap 4

The interviewees see safety culture as a key factor that influences their organization’s safety performance, and they are also aware that it can inversely affect overall risk exposure; to put it another way, they know that while a strong safety culture reduces the organization’s risk exposure, a careless one will increase it. From the interviewees’ accounts, a perception emerged of a safety culture non-homogenously distributed throughout the organization, although similar patterns of behaviour among different groups of professionals could be identified. Even so, safety culture received no systematic consideration during the risk-management process. The potential impact on the organization’s safety performance is not reflected, in either the definition of safety boundaries [RQ 4.1] nor in the ability of the risk tools to incorporate the influence exerted by the safety culture [RQ 4.2]. These two drawbacks support the existence of Gap 4.

5.5 Emergent Subjects

Beyond the concerns that data sharing among stakeholders elicited – a subject addressed earlier under section 5.3.4 (Service Providers) – other issues emerged during the research process, which, although not directly associated with the subject of risk management, have the potential to contribute to the enhancement of commercial aviation safety. The issues are addressed synthetically in the hope that they might stimulate other scholars and practitioners to undertake further research into this area.

5.5.1 Potential conflict of interests

This subject arose after performing the sixth interview. When speaking about a past experience, Lary-AB affirmed that there was an incompatibility: *“[...] in the last year [...] the auditor [was reporting to] me. I’m sorry, but this does not make any sense, I do not have any problems with accountability, the auditors can see whatever they want to see. However,* *do not place them [in the position] of reporting to the people/person they are supposed to be evaluating.*"

This account raises the issue of independency and this can be seen to be mirrored in the way airlines structure their management organization. According to European Commission Regulation (2012), subject to the existence of enough resources, one single person may act as Compliance and Safety Manager,[103] which may raise the issue of vested interests. To do a benchmark with the banking industry, specifically with the "Three Lines of Defence" model (3LoD), where "checks-and-balances" are assured by three independent lines of responsibility and accountability, it is speculated that the merging of the two relevant functions of the 2nd and 3rd LoDs in a single person might reduce the transparency of the system.

Making a comparison between the 3LoD and the Commercial Aviation Management (CAM) system (European Commission Regulation 2012; Chartered Institute of Internal Auditors 2013; Arndorfer & Minto 2015), respectively, the following correlation was obtained:

- The 1st LoD – owns and manages the risk, represented by operational line managers.
- The 2nd LoD – oversees risk, embodied in the Safety Department.
- The 3rd LoD – provides independent assurance, personified in the Compliance Department.

To address the subject, an additional question was added to the research interview questions.[104] The subject was raised whenever an organization had opted to merge the two functions of the 2nd and 3rd LoDs into a single function. There was no unanimity among the interviewees, but it was possible to perceive how impactful and uncomfortable the subject was for them.

As the researcher perceived it, the main reason for this driver was for the purposes of cost-efficiency, and the reasoning behind this driver is so enshrined in leadership that managers

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[103] The European Commission Regulation (2012) norm AMC1 ORO.GEN.200(a)(6) [Management System] (c)(5), states that: "In the case the same person acts as compliance monitoring manager and as safety manager, the accountable manager, with regards to his/her direct accountability for safety, should ensure that sufficient resources are allocated to both functions, taking into account the size of the operator and the nature and complexity of its activities."

[104] The question, which still lay within the realms of safety protection, was: *"If you acknowledge the implementation of 'The Three Lines of Defence' model, benchmarked from the banking industry, would you consider [it] a helpful management strategy?"*

answered without realizing how conflictual the situation might be. The accounts below refer to the managers who bundled both functions together.

George-AB acknowledged initially the European law, stating: "*It may be the same person [...], but there must be an awareness that they are independent functions that must attract independent resources."* However, having then explained how the concerns raised by the question were not connected with the efficiency of the teams in his organization, but how instead they were associated with the independence of a director who is responsible for both disciplines, namely the person capable of informing the board in a transparent way, the interviewee then rephrased the answer he had given previously to state that: *"Well, I understand! There is a problem with Safety. There is a risk that is poorly controlled, for example, and if it were independent, the [...] compliance department could join the board meeting to say: 'those personnel are not safe, [...] they are not complying with what is in the manual.' Yes, there really can be a loss of independence, and issues could exist that would not be addressed."*

Kostas-AS provides another good example of the issue, saying that: *"Safety and compliance [...] come together in our organization. Because we are part of the same department, [safety] is currently not audited [internally]."* However, after the interviewer had elaborated on the subject, explaining the issue of the presence of a single representative of the two areas for the board, the interviewee answered as follows: *"Oh, right. In that case, you are quite right. [...] I do not go to the board [...] to say that I have a problem. [...] That is the reason why we are not audited internally."* The example provided by Charles-AB is even more elucidative of the internal struggle the manager could face. The interviewee began by saying*: "I believe there is [conflict of interest], but within [...] our department there are different areas, [...] safety management [and Quality Control] all report [to me]."* He then continued, and ended up saying how: "*I think managers are free to take action; therefore, I believe there is no conflict of interest."*

Other accounts to show the defenders of the two poles could have been included in the transcriptions, but it suffices to give one more account to summarize the main stance provided by the interviewees. Gordon-AA's pronouncement, for example, affirms how the "Three Lines of Defence" model has been very elucidative, *"[...] this is all about what safety is, building barriers to prevent hazards to see the light of the day."*

Nevertheless, it is understood that the European rule must apply to a large spectrum of operators and that the subject had not yet been discussed among the regulators to acknowledge the current situation and adjust the terms. From the previous accounts, however, it seems that there is space to speculate that the gap is creating obstacles to better implementation of the SMS, at least in larger organizations, and the issues deserve to be scrutinized by the regulator and to become the subject of further research in the future.

5.5.2 Executive Management Safety Training / Competency

Training airline personnel is a highly regulated technical-function subject area, specifically for airline pilots, members of the cabin crew, flight dispatchers, operational ground staff and the like (EASA 2015, 2020b; IATA 2019). At the other pole, the "training and competency" required for management positions is left to the discretion of the airline and ultimately to the national regulator. In this regard, the European law (EASA 2020a, pp. 243, 258) states that:

> *"*The operator shall establish, implement and maintain a management system that includes: […] maintaining personnel [that are] trained and competent to perform their tasks; […]. All personnel should receive safety training as appropriate for their safety responsibilities.*"* (underscore added by the author)

The norm is generic in nature and it is difficult to see how it could be otherwise, since it covers a vast range of subjects and circumstances. Being a requirement that sets the tone, it is supplemented by specific legislation that addresses each function separately. However, the same does not happen with the management function, that which directly holds responsibility for directing how safety and risk management are implemented within the organization.

The problem has its inception in the management schools, where students have to be alerted to the relevance of safety issues (Zohar 2000). This is the reason why Kim et al. (2019) warn that, regardless of how well an SMS is designed, it is people who guarantee its successful application. Top executives are the members of the organization who develop and/or approve the airline's policies. It is they who have the authority to allocate resources, surpassing the benefits of SMS, if they do not consider these critical aspects of effective SMS implementation as a priority.

In a worldwide study covering the 100 top airlines in terms of Revenue Passenger Kilometres (RPK), Wilson and Lohmann (2019) found support for the hypothesis that the finance background of CEOs (17%) drives their selection process due to financial complexity and the narrow profit margins of airlines. Nevertheless, operations-originated CEOs are the most common functional background, representing 24% of the sample. Other origins could be found, such as sales and marketing (16%), entrepreneurs (10%), and other professionals of no prevailing background dominance (20%).

With such a diversity of origins, it is important to understand how efficiently these managers exert their safety function, and how adequate safety training tailored specifically to meet these managers' needs – who after all play a vital role in the implementation of the SMS – can be effectively administered. As the interviewees echoed some of these same concerns their insights should definitely not be overlooked, as finding F1.1a exposed.

The subject of training was not initially included in the research questions, but emerged only later within the subject of safety protection (Gap 3). Therefore, after the fourth interview, two questions directly related to training were added.[105] The main stance shared by the interviewees related to the vagueness of training requirements for managers. Santini-AS affirmed: *"[The requirement] is too succinct. [...] Quite concise. It is short and vague",* which was a view supported by Peter-AS, who stated: *"The legislation should be more specific and not leave the training programme so vague."*

The imprecise nature of guidance in this area creates an impression that the subject is not that important. This oversight, in turn, leaves room for people to neglect conscientiously paying regard to it and to undermine its importance. A lackadaisical approach such as this can be observed from Lary-AB's account, stating: *"It was a formal requirement […] but if this was not attended to [...], no one was upset about it."* John-AB, addressing the universality of SMS training, recognized its importance by stating that: *"the safety manager has to have […] more training, [including] the COO. I think that all [airline] management has to have [more training]."* However, perceptible from this interviewee's words, was that safety-management training was not a practice implemented within his airline. When asked whether he felt comfortable

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[105] The first question: *"The Safety-Risk Management in particular (and the SMS in general) is rather a technical subject that requires specific knowledge to guarantee that each stakeholder is able to fulfil his or her specific safety responsibilities. Therefore, if I brought into the discussion the subject of training, framed as a safety investment, what would you have to say about this matter?"* And the second: *"As a member of the Board of Directors (or as member responsible for safety), what kind of academic training (related to the risk management and SMS) have you attended? Do you consider recurrent training? How often?"*

performing his safety responsibilities, he recognized indirectly how he was lacking vital knowledge to fulfil his safety obligations, confessing: *"Did you see Eleanor? […] She was walking out! My safety manual is open there, but I have been through training. [She is] giving me supplemental instruction […], helping me to understand exactly [what] I've got [to know]."*

Inquiring of a manager whether she or he is capable of discharging his or her safety responsibilities is always an embarrassing question, particularly when a manager is not fulfilling the basic safety obligations. Kostas-AS's answer provides an example of the difficulties that the question poses and the ingenious answer that in this case was obtained: *"Every year, all our employees have to do [SMS] training. […] The accountable manager must also do so, [but] he does not sit in a classroom. [...] We provide the SMS training during the safety review board meeting."* The SRB is a high-level meeting where the strategic safety objectives are decided, which seems an inappropriate place and opportunity to administer safety training.

From the interviews, the general consensus remains that the daily management of SMS is in jeopardy due to the absence of a structured training programme for management positions. Yolanda-AA's statement supported this stance: *"Executive Committee Members have [thousands] of other concerns beyond safety issues, they have no idea what their role is and instead are waiting for us to tell them what they have to do."* The stance was also supported Jeremiah-AS's statement: *"The fact of being deficient leads to some essential stakeholders failing to understand the technicality of the subject and how they are contributors to this system. Therefore, training is as vital as all other operational activities."* Sabine-HS also recognized that a gap existed, stating: "*I think that the Council's members should have further in-depth knowledge to help in managing the institution's risks."* Charles-AB saw this too, and concluded: *"It is essential to put in place compulsory training for these key positions."*

Training of personnel in management was a gap recognized by the majority of the interviewees, which the research has confirmed [F1.1a]. Leaving the training (and the minimum standard competency) open and vague for management personnel leaves open the possibility to speculate that the legislator is allowing the presence of an ensuing drift and creating a natural barrier between senior management and operational staff. The former group will not be able to understand safety risks, whereas the concerns posed by the latter will be neither perceived nor accepted. The gap could be compounded if the previous emergent subject is present, that is, a distinct conjoining of both a lack of knowledge (and competency) and the presence of vested interests. Therefore, it seems that the subject deserves to be the object of further research and requires looking at closely by the European legislator.

5.5.3 Challenges for Airlines

This section summarizes the concerns raised during the final phase of the interviews – closing questions – that did not find an appropriate space within the previous gaps and concerns. Nonetheless, the concerns are felt to somehow contribute to the robustness of the SMS and could also motivate future researchers to delve further into the topic.

Three subjects in this respect were found:

Safety-risk management is still seen as the exclusive responsibility of safety professionals in the commercial airline industry. This could lead safety managers to decentralize risk management within their organization were they to find the opportunity to restructure the system. This view was shared by George-AB, who said that he would decentralize risk management into satellite areas; it was one shared by Gary-AS also, who claimed that operational managers resign their responsibility of actively managing safety risk, and this was a view that Jeremiah-AS also took. Nicholas-AL went a step further, however, arguing that the challenge is associated with the involvement of senior management within the safety framework. Without their leadership and support, this interviewee felt, SMS could not be hoped to function in its plenitude.

Lack of training was another challenge that, similar to the “executive safety training” gap, was a concern of the majority of safety professionals interviewed. Analogous to the understaffing policies observed during the interviews, lack of training seems to have become so normalized that executive managers are not even that sensitive to the problem anymore.

Finally, the last challenge to be addressed frequently among the interviewees’ concerns related to the capacity to analyse data in a faster, more efficient fashion, to be able to offer a more predictive power than is currently possible. Sabine-HS claimed there was the need to equip her office with analytic tools to process data faster, while Dimitri-AS said he would invest in “information technology” systems capable of interpreting “big data”. This is also the reason why Nicholas-AL anticipated the problems the SMS had in capturing the “safety reality” while using a slow drifting system.

5.5.4 Recapping on the Emergent Issues

Throughout the current section, two main subjects were identified: potential conflict of interests and executive managers' safety training and competency.

Commercial aviation is a fast-changing environment, and executive managers must be able to master, scrutinize and judge the data that is presented to them. However, the research identified a lack of SMS knowledge at the executive level, which has the potential to hinder their capacity to manage the risk management of the airline effectively. Thus, the training issue has the potential to be compounded by the design of the organizational structure, since it has the potential to harbour vested interests, which, ultimately, might impede information reaching the executive management. Those two issues potentially widen the gap that exists between management and operational staff.

Training is not a problem exclusive to executive managers; it cross-cuts the whole organization. Similar to the problem of understaffing, [lack of] training has the potential to echo in the higher echelons and, if the situation persists indefinitely, it can silently undermine the organization's ability to manage its risks. Two other challenges are on the horizon for airlines: The first relates to the decentralization of the SMS, which has made managers accountable for their organization's risks. The second is associated with the capability of airlines to manage high volumes of data quickly and predictively. An expectation of current thesis is to promote discussion of these issues with the findings it has put forward.

For ease of reference, a summary of the subjects discussed above, intertwined with the analysis of Gaps 1–4, have been summarized below in section 5.6.

5.6 Safety-Risk Findings from the Research

Table 5.2, below, summarizes the findings from the research interviews; each of the findings is set against the identified gaps to illustrate its association. The emergent subjects are also identified in the table at the end.

Findings from the Research		
GAP	Finding	Description
#1 **SAFETY BOUNDARIES**	1.1 Bridging the gap	Executive directors are concerned with the subject of safety. However, from their accounts, it is perceptible that they are neither familiar with the SMS framework nor with the risk exposure of their organization [F1.1a]. Safety figures differ significantly from the financial jargon, the latter being the language executive directors are trained to understand. Consequently, executive directors neither contribute to nor establish guidelines to help develop safety boundaries [F1.1b]. Moreover, the approach of executive directors' evaluations of the impact a particular strategic decision might have on the risk exposure of the organization is unstructured. Finally, the framework established by the ICAO sets the two hierarchical levels apart by promoting meetings (SRB) only on an occasional basis – normally at six-month intervals – as demonstrated in practice [F1.1c].
	1.2 Development of safety boundaries	Operational staff define safety boundaries [SQ 1 & RQ 1.1] based on frequency. While this lends itself to a proactive perspective, it nonetheless hinders the objective of gauging the risk exposure faced by the organization, which could mean that it impedes the framework's ability to manage the safety risk [F1.2a]. Risk exposure is a complex subject, whereby construing it from one simple indicator is inadequate. In fact, it requires a set of data – such as the contributing factors mentioned by Gary-AS, George-AB, Nicholas-AL and Louise-HS – in order to reproduce, albeit deficiently, the reality faced by practitioners [F1.2b]. The current research suggests that the way safety risk is currently analysed constitutes a gap, which exists as a consequence of the way the safety boundaries are construed.
	1.3 Blurred boundaries	Operational staff must develop a means to evaluate barriers and to correlate effectiveness with the level of exposed risk. Hence, the risk tool needs on one hand to be able to measure the level of risk exposure and, on the other, somehow incorporate the data provided from the level of protection implemented in the field [F1.3].

	1.4 Safety assessment	Assessing safety risks supported by a frequency approach has the potential to develop into an uncertainty-exposure stance among stakeholders. Therefore, the tools used to assess safety risk must be analysis-based using a risk-based approach – namely, it must incorporate both variables associated with risk: frequency and severity [F1.4].
	1.5 Safety promotion	The management of safety promotion is not structured. The approach leaves operational staff unable to perceive how far the organization is from its safety boundary or limit. Ultimately, this could act to impede staff as they work to convey the appropriate safety message throughout the organization [F1.5].
#2 **RISK TOOLS**	2.1 Characteristics of the risk tool	The standardization imposed on the aviation industry has its advantages. However, standardization hinders the ability to innovate and to adapt the risk tools to reflect individual airline's risk appetite; it also highlights the incapacity of stakeholders to effectively implement the evaluation phase of the risk management. The conclusions to draw from the interviews are that it is essential for risk tools to be adaptable to the environment of their use; that they have the ability to consent to human evaluation; and that they enable comparison between the established safety boundaries and the actual risk exposure. In other words, the risk tools should incorporate each individual organization's risk appetite [F2.1a]. Further relevant features to emerge during the interviews are: the ability of risk tools to react proactively; their capability to anticipate future scenarios; and their ability to improve the system's capacity to receive data in real-time, thus avoiding longitudinal monitoring to assess the evolution of risk exposure [F2.1b]. Finally, in order to orient the available investment resources in organizations, risk tools should be able to prioritize, as appropriate, the analysed risks [F2.1c].
	2.2 Type of Approach: Qualitative *vs* Quantitative	Among operational staff, there is division as to whether the quantitative approach would be more appropriate than the qualitative approach, and even a suggestion that a combination of the two methodologies would provide a more accurate picture. To understand which methodology would reduce the subjectivity of

RISK TOOLS		the risk assessment most effectively in practice is, therefore, relevant [F2.2].
	2.3 Risk matrix	Risk matrices are the primary tool used in risk management among stakeholders. Nevertheless, using other tools alongside risk matrices would complement their strengths. Matrices suffer from three main drawbacks: the first of these weaknesses is integrity – the reports from matrices draw attention to their incapacity to integrate within the tool the three fundamental risk-management activities of the risk analysis, the evaluation stage, and subsequently the outcome resulting from implementation of the mitigation measures [F2.3a]. The second drawback relates to the variability associated with the risk-analysis outcome, which is dependent on the stance taken by the analyst [F2.3b]. Finally, there is the incapacity to prioritize safety risks in an efficient form – risk matrices depend on the colour palette to discriminate between safety risks, and the reduced number of available colours of the palette turns the task of prioritization into a challenging game [F2.3c]. Recognizing the variability produced by the tool, stakeholders have introduced the "overlapping" method in an attempt to reduce the level of human subjectivity.
	2.4 ARMS	The first stage of ARMS – Event Review Classification (ERC) – proves to be efficient as an approach to manage a high volume of data. It still presents challenges, however, in relation to implementation, consistency of the potential outcome appraisals, and reliability of each safety barrier, and its results still seem incapable of conveying the actual exposure to risk the organization faces. The first stage creates a false sense of standardization, this is because it is dedicated to reviewing a specific event; while the risk evaluation, if required, is postponed until the second phase – the Safety Issue Risk Assessment (SIRA). At this stage, carrying out the risk analysis involves a set of cascading questions that can prove even more challenging to answer than the first-stage questions. The cause of the difficulty relates to organizations' lack of access to sufficiently robust data to support the decision-making process. This means, in turn, that the analysts tend to abandon the second stage of this method, relying instead on frequency-of-event

		data upon which they can speculate, but which, in fact, merely represents a re-occurrence. Although users' initial expectations have faded over time, the method's underlying reasoning is relevant: the risk analysis must consider the risk exposition – similar occurrences might generate a different set of risk exposures – and it is essential to incorporate similar events to convey a realistic risk-exposure scenario [F2.4].
	2.5 Bow-tie concept	The bow-tie concept helps analysts to better understand and create a pictorial description of the scenario, and it can help them raise awareness of the mitigation and recovery controls that should be in place. Used as a stand-alone method, however, its capacity to evaluate a hazard or to tackle it with multiple interactions reduces; therefore, it performs better when embedded within another risk tool [F2.5].
	2.6 FMEA/FMECA	Despite its drawbacks and potential for inaccuracies, using the HFMEA approach it is possible to convert a purely qualitative method into a semi-quantitative outcome. Beyond the traditional characteristics of severity and probability or frequency of risk, it would seem appropriate to incorporate a third variable to strengthen the protections already incorporated into the system, although the analyst may be unable to quantify precisely the impact of those mitigation measures [F2.6].
	2.7 Control charts	The ultimate aim of control charts is to present the performance of the safety system. However, the measurements of control charts, based on the number of occurrences, largely ignores the organization's level of risk exposure. As to the gap that limits understanding of the risks faced by the organization, the speculation is that this constitutes a barrier to investment in protection by the relevant decision-makers [F2.7].
#3 **S** **A** **F** **E**	3.1 Safety investments	The research suggests that organizations lack a structured process to allocate available resources or make decisions about new investments. Decisions are currently handled in an ad hoc way or are pushed through by regulatory imposition. The decision-making process lacks the robust framework of a rationale based on a risk-approach perspective. Given the nature of safety risks, a qualitative

TY PROTECTION		methodology, and tools that are capable of revealing different risk factors (or perspectives), should support investment decisions. These should be able to convey a comparison with the defined level of risk – the risk appetite of the organization – and in this way, promote predictive analysis [F3.1].
	3.2 Longitudinal monitoring	The majority of safety risks do not attract continuous monitoring. This has the potential to create a breach in the safety-management system. The speculation is that the time period observed between evaluations allows deviations to occur, which exacerbate the organization's risk exposure [F3.2].
	3.3 Fuzzy frequency	In order to develop a risk-exposure scenario as discussed in the ARMS section at 5.2.4, SPIs should be supported by other frequencies that take a risk-based approach, integrate the root causes of the undesirable events and are capable of being presented in an integrated fashion [F3.3].
	3.4 Service providers	The continuous monitoring of service providers is essential to controlling an organization's risk exposure; and, therefore, it is an instrumental factor in achieving a robust safety protection. However, the interviewees cast doubt over whether stakeholders' approaches dealt adequately with the safety risks that originated externally, which as an active breach, has a direct impact on Gap 3 – Safety Protection [F3.4].
#4 SAFETY CULTUR	4.1 Sustainable factor	Stakeholders consider safety culture as a contributing factor in the organization's safety performance, and agree that it influences the whole safety system. Ultimately, it has either a positive or a negative impact on overall safety-system performance. In terms of risk exposure, the safety culture appears to function as an inversely proportional variable – that is, a strong safety culture reduces an organization's risk exposure whereas a careless one increases its risk exposure [F4.1].
	4.2 A sociological approach	"Safety culture" does not spread homogenously throughout an organization. However, among different groups of professionals, classes, or groups within the same organization, similar patterns of behaviour can be identified [F4.2].

E	4.3 Embedding Safety Culture in Risk Management	Stakeholders are conscious of the important role played by "safety culture" in the risk-management process. However, despite their efforts, they have struggled to find a way forward to incorporate the concept, directly or indirectly, within the risk-assessment activities of their organizations [F4.3].
---	Emergent subjects	Commercial aviation is a fast-changing environment, and executive managers must be able to master, scrutinize and judge the data that is presented to them. However, the research identified a lack of SMS knowledge at the executive level, which has the potential to hinder their capacity to manage the risk management of the airline effectively. Thus, the training issue has the potential to be compounded by the design of the organizational structure, since it has the potential to harbour vested interests, which, ultimately, might impede information reaching the executive management. Those two issues potentially widen the gap that exists between management and operational staff. Training is not a problem exclusive to executive managers; it cross-cuts the whole organization. Similar to the problem of understaffing, [lack of] training has the potential to echo in the higher echelons and, if the situation persists indefinitely, can silently undermine the organization's ability to manage their risks. Two other challenges are on the horizon for airlines: The first relates to the decentralization of the SMS, which has made managers accountable for their organization's risks. The second is associated with the capability of airlines to manage high volumes of data quickly and predictively. An expectation of the current thesis is to promote discussion of these issues with the findings it has put forward.

Table 5.2 – Safety-risk findings from the research

Chapter 6 now introduces the "Oyster Model", incorporating the research findings and the insights obtained from the CLR.

6 An innovative Safety Risk Model: Bridging the Gap between Management and Operational Staff

6.1 Introduction

The “Oyster Model” aims to close the gap between management and operational staff to strengthen the organization’s safety system [F1.1c]. The structure of the model has its inception in the conceptual framework titled “The continuous safety-risk management cycle”. Using the insights from the critical literature review and the findings from the research, the following paragraphs address the four gaps, making use of the concept conveyed by BSI (2018b). The objective is to provide decision-makers with a risk model that enables them to define (and track) the level of risk exposure they are willing to accept.

The ultimate objective of the “Oyster Model” is to give organizations a risk model capable of defining and reinforcing the organization’s own safety boundaries and thereby harness the benefits provided by the continuous monitoring and informed resource allocation that is integral to the model’s design.

The intention of the seven stages of the model, as illustrated in Figure 6.18 below, is to address each gap identified in the CLR, with the aim of constructing a substantial barrier to defend the organization against future incidents and accidents. Based on the mitigation and recovery measures implemented in the field, the model allows organizations to understand how close to an undesirable event they are; or, from another perspective, to gauge the safety margin against the possibility of an incident or accident occurring.

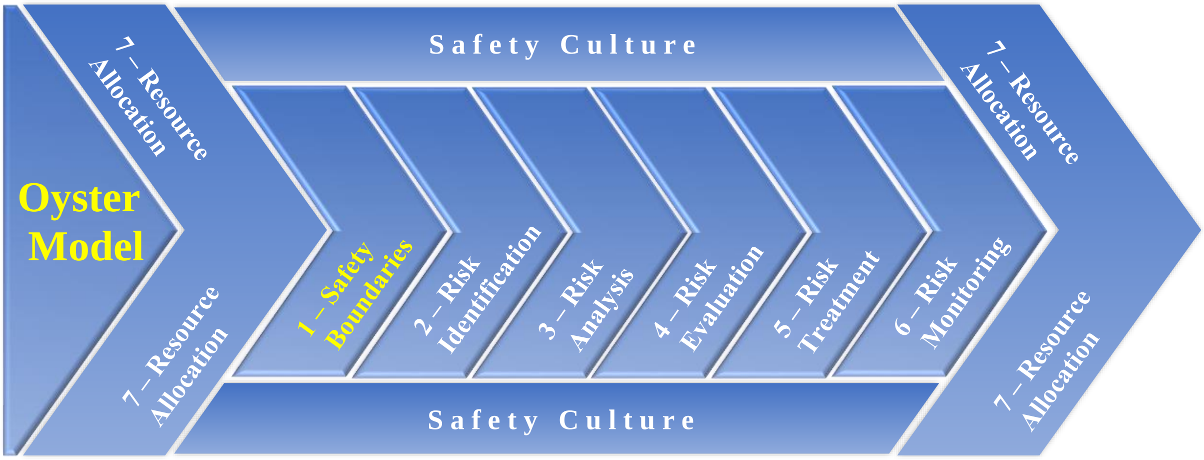

Figure 6.18 – “Oyster Model” (developed by the author). Source: Adapted from Risk Management Guidelines BSI 310000:2018 (BSI 2018b)

According to the “Oyster Model’s” integral design features, each organization is seen as an “oyster”; in essence, it is protected by an armoured structure to secure the inside against the harsh environment outside, but promotes a structure that is not a closed assembly. Thus, this structure reacts whenever it is stimulated, in order to defend itself against threats from outside. This is why it is coined the “Oyster Model”, to incorporate the stance conveyed by the analogy.

The “Oyster Model” is supported by two risk tools: The “risk-exposure” map and the “Stack” map. The tools that support the “Oyster Model” will allow decision-makers to make informed and systematic decisions about acceptable risk-exposure levels and, as a result, allocation of resources. From the operational staff perspective, the supporting tools will enable them to analyse, evaluate and monitor risk exposure more effectively, reliably, and in real time. Moreover, it will provide a proactive perspective that is capable of identifying potential drifting in risk exposure.

Chapter 6 has been reserved specifically to explain the development of the two risk tools that support the “Oyster Model” and to understand how they tackle the four gaps identified in the Conceptual Framework (safety boundaries, risk tools, safety protection and safety culture). Chapter 7 has been reserved to provide a detailed explanation of the implementation of the model within an organization and to identify the potential challenges the organization will need to overcome in order to maximize the full benefits of the model. Figure 7.31 in chapter 7 provides details about the integration of the risk tools within the “Oyster Model”.

6.2 Scope and Limitations

The “Oyster Model” follows the concept laid down by BSI (2018b), but the scope of influence laid down by this concept is restricted by its own definition of risk level (“risk criteria” in BSI terms): safety boundaries, risk analysis, evaluation, monitoring and resource allocation. The risk identification and treatment phases have not been altered in the model’s design. The model’s objective is to provide a proactive step in the risk-management process, and, at the same time, specifically endeavour to reduce the gap that exists between management and operational staff.

The analysis will not consider risks that have already materialized. The recent concept of “risk and loss” (“riss”) presented by Nisula (2018), where both components are added together to obtain the total severity, will not be incorporated into the “Oyster Model” either.

6.3 Safety Boundary Development

Airlines (and similarly healthcare units) face a myriad of risks in their daily activities. Handling these hazards systematically, to protect the organization against any threat that could jeopardize its objectives, is essential. Any risk tool selected must be capable of incorporating the organization’s main phases of risk management, be able to rank and prioritize risks and, at the same time, identify the risks that go beyond the organization’s safety boundaries (Duijm 2015; Baybutt 2015).

Currently, the safety boundaries devised by management are framed within the safety policy of the organization, this comprises a set of objectives and high-level statements addressing safety priorities and identifying the most significant safety risks (ICAO 2018b). These generic objectives, termed by Sackmann (1991) as “axiomatic knowledge” – the visible component of the organization’s safety boundary – have a low impact outside the hierarchy of top management, thus proving difficult for employees collectively to fully understand [F1.5]. Therefore, the tool should reflect both the organization’s safety boundaries and act as a risk-communicating device (Flage & Røed 2012; Levine 2012; Ball & Watt 2013).

The “risk-exposure” map, which emerged from the research has its genesis in traditional risk matrix models [F2.3]. Significant contributions also come from the ARMS methodology [F2.4], bow-tie [F2.5] and the FMEA methods [F2.6]. To overcome the drawbacks and gaps identified in the CLR and those that emerged from the research, a semi-quantitative approach, as defined by the British Standard Institution (BSI 2010, p. 13), was adopted [F2.2].

Academia has demonstrated several of the drawbacks associated with matrices, as section 2.5.1 (Risk Matrices) identified. The most limiting among those identified are: subjectivity, consistency, resolution power and risk aggregation.

The "quantitative community" accepts qualitative approaches based on an output comparison using either method. However, it is relevant to note that no single method is capable of quantifying precisely the risk-exposure level produced by every single hazard, since neither method reflects the reality perfectly (Healy & Perry 2000; Bisman 2010; Nisula 2018). Therefore, a false condition underlines the whole exercise from the start. At most, any risk model is only capable of achieving a residual part of the reality. In this regard, a statement by Nisula (2018, p. 163) reinforces the limitations: "any model used for risk assessment would be highly simplistic compared to the extreme complexity of the real world".

Figure 6.19, below, based on linear scales, minimizes the identified gaps, although "range compression" (Levine 2012) is present in the tool. Identical "dynamic ranges", thus the distance between the lower-left vertex from cell "1A" to the upper-right vertex of cell "2B", represents a 16% difference of risk exposure between the two points, whereas the same difference in cells "4D" and "5E" represents a 63% difference.[106] The iso-risk contour – obtained from the product of "severity" by "frequency" – results in a hyperbola, which agglutinates lower and higher risks in the lower and upper corners, respectively. These characteristics represent a reality of a sort, whereby events of lesser consequence and severity account for a reduced level of risk in opposition to the extreme pole of the tool. Linearity is achievable with logarithmic scales, but at the expense of reduced resolution. Differences between risks are only perceptible where several orders of magnitude are observed (Levine 2012). Risk matrices of this type could be useful to regulators who are faced with a vast quantity of data, as demonstrated by Nisula (2018). However, at the organizational level, because of the limited range of information available, this type of matrix is of reduced utility.

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[106] Using the analogy provided the Rasmussen's risk-management framework, the higher the percentage the lower the "buffer zone" is, that is, the distance between boundary of unsafe performance and aggregate risk index.

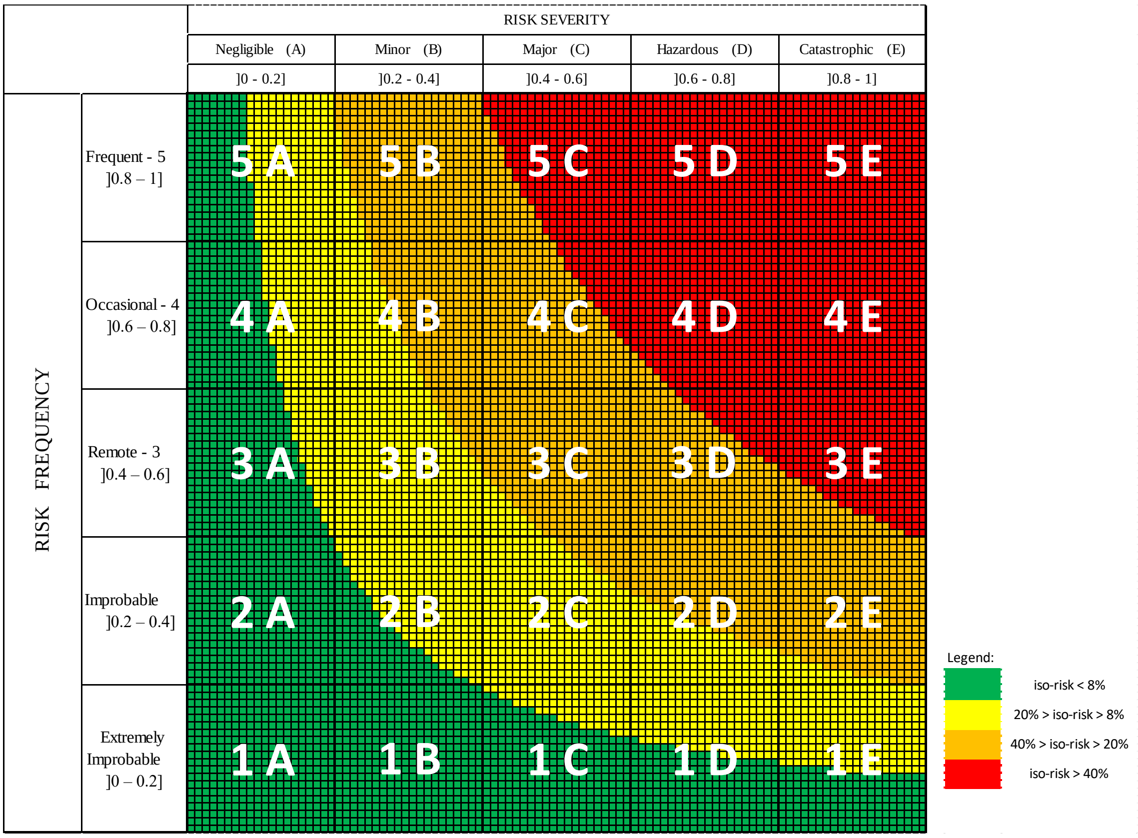

Figure 6.19 – Risk matrix with iso-risk contours

The number of iso-risk contours depends on the number of approved risk-levels an organization decides to include. Commonly in practice, each colour is associated with a management level, often in relation to whichever of these levels of management is accountable for that particular risk level. Each management level can either accept it, or, if exceeded, raise the decision relating to its accepted risk level to an upper echelon. During the interviews, it was commonplace to see matrices with four and five different levels, whereby the lower level was associated with the safety department and the higher level was seen in relation to the CEO or accountable manager. Figure 6.20, below, exemplifies a tool with a five-colour code and different exposure levels as illustrated by the legend. Nevertheless, for the purposes of clarity, the explanation of the risk tool will refer to Figure 6.19, which has four levels.

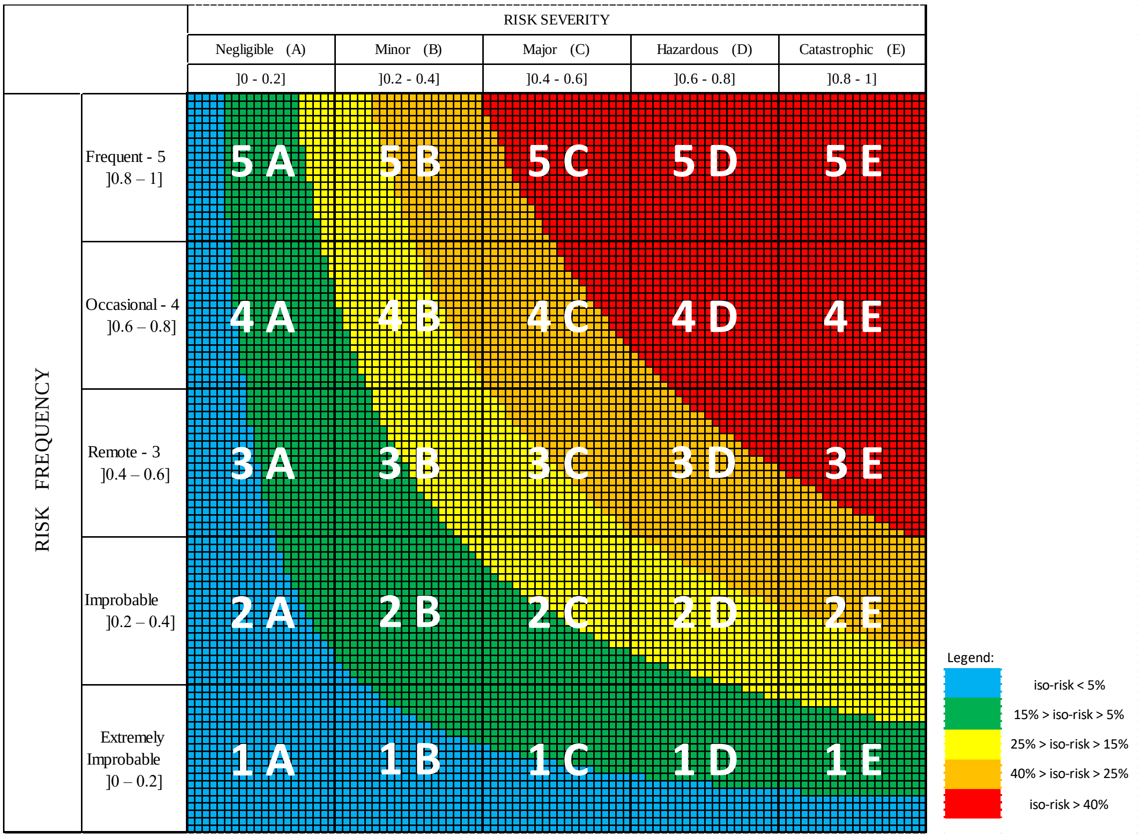

Figure 6.20 – Risk matrix with five iso-risk contours

In this intermediate phase of the safety boundary presentation, the tool might appear to be a simple risk matrix; ultimately one that resembles that presented by ICAO (2018b). It maintains the ordinal scales and follows the semi-quantitative approach, whereby the outcome results from the product of two variables: severity and frequency.

Taking insight from the interviews, the occurrence axis captures the variable “frequency” instead of the “likelihood” or “probability” [F1.2a & 1.4]. Organizations support their analysis using frequency-of-occurrence data from a predetermined number of events. However, this is not generalized practice, since there are organizations using the industry’s aggregate data, as Figure 5.16, “Risk matrix incorporating multiple risk perspectives”, illustrates. Nevertheless, using frequency-of-occurrence data was a generally recurrent practice among the interviewees. In the example given in Appendix H, ratios were used to compare the number of events that occurred over 1,000 generated flights. In both instances there was no consideration of the specific severity within each occurrence, which suggests that there was a compromise in the potential risk-exposure analysis [F1.4 & 2.7].

As clarified in the CLR (section 2.5.5), the risk-severity analysis generates a great deal of ambiguity among analysts, particularly in the aviation domain, where a plethora of risks may have contributed to the undesirable outcome. Thus, further analysis of the whole set of interview narratives of the research may clarify the best approach to follow. Using the severity descriptors taken from the ICAO matrix (2018b), Table 6.3 (below) presents the number of times each descriptor was found in the aggregate data generated from the 26 interviews.[107]

Severity Descriptor	Number of times observed
Negligible	0
Minor	1
Major	3
Hazardous	0
Catastrophic	2

Table 6.3 – ICAO severity descriptor analysis

In fact, the interviewees seldom used the terms proposed by ICAO (2018b) to refer to a risk-severity level. Therefore, to avoid a potential bias towards any specific taxonomy, scrutiny of other terms that are found in different risk matrices and were observed during the interviews are compiled in Table 6.4, below (please note that the previous descriptors were not considered).

Severity Descriptor	Number of times observed
Insignificant	0
Low	9
Moderate	0
High	9
Extreme	1

Table 6.4 – Expanded severity descriptor analysis

Table 6.4 denotes a tendency to aggregate risks into a restricted number of definitions using the extremes poles, whether high or low risk. This dichotomy suggests that safety personnel are more concerned with the sort of risk that might jeopardize their operation and less concerned about undefined, seemingly unimportant or minor sorts of risks. Taking the last observation into account, which indicates a tendency towards the two extremes, a third analysis was conducted to understand the level of responsiveness to the well-established concepts defined by the industry: incident, serious incident and accident. Table 6.5, below, presents the results.

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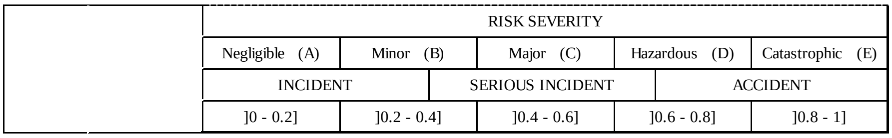
[107] Note that of the 26 interviews, five interviewees were unrelated to the aeronautical industry, thus the philosophy of the ICAO did not have an influence on their work.

Severity Descriptor	Number of times observed
Incident	38
Serious incident	1
Accident	28

Table 6.5 – Commonly used severity descriptors

This paragraph scrutinizes the results obtained, even though they are quite self-explanatory. Stakeholders use the terminology proposed by ICAO (2020), as depicted in Appendix J. Yet, if stakeholders use this type of taxonomy, it would be pertinent to this inquiry to ask why the tools use a different structure even though this creates so many interpreting and evaluating challenges, as Budescu et al. (2012) have demonstrated. The analysis suggests that there is a mismatch between the published concepts and the working language. Therefore, the severity axis should attempt to incorporate the three concepts that encompass the potential outcome of an undesirable event: incident, serious incident and accident. There is no predetermined rule about how to establish the ranges for each concept. Considering a linear scale, Figure 6.21, below, represents a division comprising 33% for each category. Therefore, during the risk analysis phase, operational staff ought to concentrate on what the potential outcome could be should the risk materialize. This well-established taxonomy, already used within the aeronautical premise, should reduce the variability associated with this stage of the risk-analysis [F2.3b].



	RISK SEVERITY				
	Negligible (A)	Minor (B)	Major (C)	Hazardous (D)	Catastrophic (E)
	INCIDENT		SERIOUS INCIDENT		ACCIDENT
	]0 - 0.2]	]0.2 - 0.4]	]0.4 - 0.6]	]0.6 - 0.8]	]0.8 - 1]

Figure 6.21 – Risk severity scale employing commonly used descriptors

With the introduction of linear-ratio risk scales for severity and frequency, the former will have three classifications for severity. In contrast, five levels for the number of occurrences will constitute the latter. The severity scale reflects working practices limited to three levels. However, in relation to frequency, it is feasible to introduce more than five levels, depending upon the organization’s preference. The presence of alphanumerical figures results from the intersection of severity and frequency, the purpose of which is to create heightened awareness as the level of risk exposure – that is, the criticality of risk exposure.

Figure 6.22, below, presents a “risk-exposure” map, comprising 100 units for each linear scale. Both scales range from 0,01 to 1. As a result of the product “frequency × severity”, the lower-left vertex from cell “1I” accounts for 0,01%, whereas the upper-right vertex from cell “5A” accounts for 100%. As a generic risk tool, for explanation purposes, throughout Chapter 6, the frequency scale will retain the values used to generate the “risk-exposure” map – 0,01 to 1. However, as explained in Chapter 7, the frequency scale will be customized for each organization’s reality and be replaced by the production level.

The example used in Chapter 7, depicted in Figure 7.36 considers a production level of 10,000 flights per year, along with each threat that concurs for the hazard under analysis, which presents an approximate number of 30 events per year. A frequency scale ranging from 1/10,000–100/10,000 would be suitable in this specific case, whereby each unit represents one event. However, for a hazard with a higher exposure level, using the same production level, the scale can easily be adapted for a range of 10/10,000–1,000/10,000, where each unit represents 10 events.

Concerning the severity scale, from Figure 6.23 onwards, risk maps will incorporate the measures implemented in the field. In the severity scale, each threat is plotted according to the severity of the event (incident, serious incident or accident), and aligned with the remaining mitigation/recovery measures that proved effective.

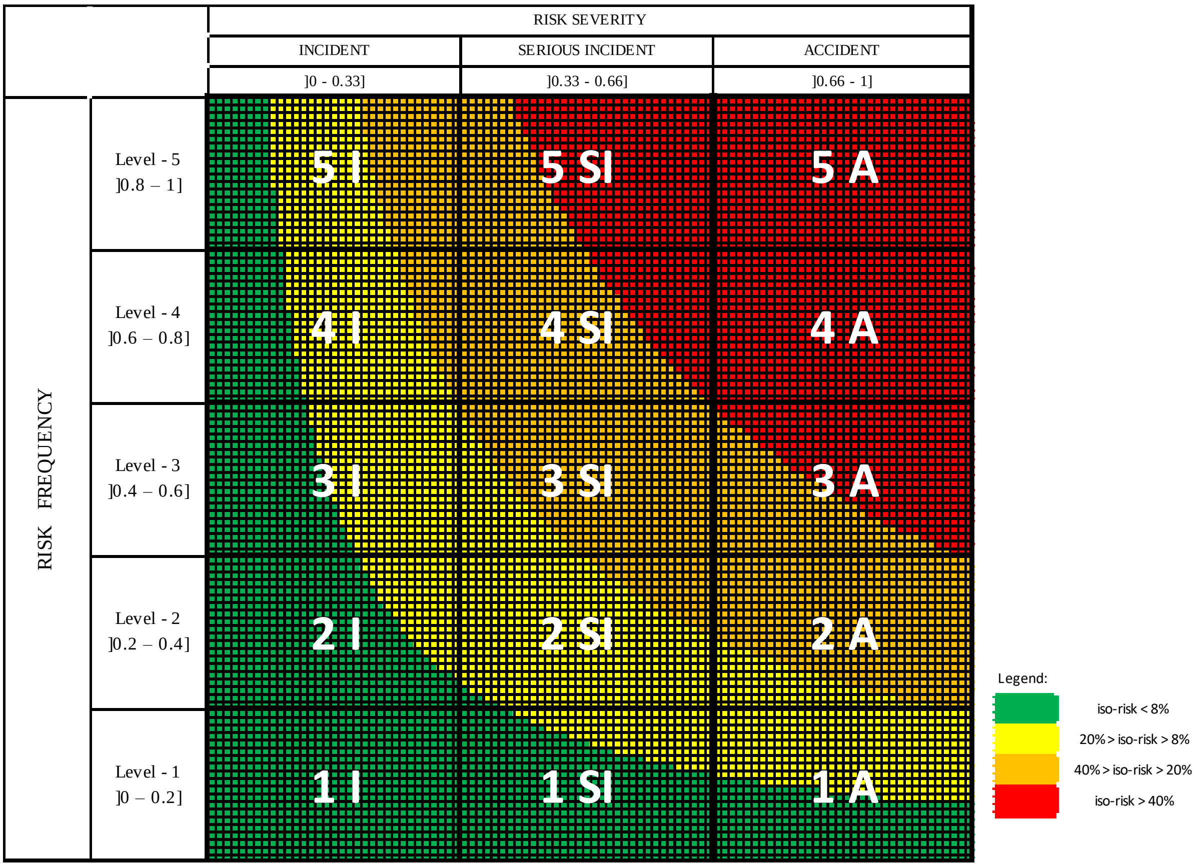


Figure 6.22 – Risk tool with iso-risk contours (frequency × severity)

From an analysis perspective, this version of the proposed tool does not incorporate the protection level of mitigation and recovery measures currently implemented in the field [F1.3]. Using the standpoint brought by the ARMS (2011) methodology [F2.4], an analyst should be able to understand how close the event was from an undesirable event – that is, from an accident. In the current tool, the objective is pushed forward to incorporate incidents and serious incidents, as these have a significant impact on an organization and represent the antechamber of an accident. Furthermore, from a continuous improvement standpoint – that is, to understand the resilience of the safety system – the analyst would need to verify the performance of the barriers already implemented in the field. This analysis would allow the organization to evaluate the robustness of its system and to plot each event correctly on the "risk-exposure" map.

With the purpose of a mitigation measure being to reduce the likelihood of an unsafe event occurring, a recovery measure in contrast is seen as the last resort to prevent the materialization of a threat (Hopkin 2012; ICAO 2018b). Thus, every single protection measure implemented in the field potentially contributes to a reduction in the number of occurrences. This means, therefore, that whenever a near miss occurs, some of the mitigation and recovery measures have failed, others may not have been utilized, and one or more may have proved effective. The higher the number of barriers implemented, the lower the number of occurrences will be. Thus, using the reasoning brought from the “bow-tie” method [F2.5], it would be sensible to incorporate the mitigation and recovery measures into the “frequency scale” (Townend 2019).

The purpose of the risk-analysis and monitoring phases of the “Oyster Model” is to understand and evaluate the resilience of the system while at the same time revealing the level of risk-exposure an organization is facing. Although it is plausible to have the mitigation and recovery measures included in the occurrence scale – as they do reduce the frequency of the threat – they will not influence those occurrences that have already materialized. As it is relevant at this point to understand how far one (or the system) was from an undesirable event, the analyst therefore should address two topical questions: First, what would the most probable outcome (incident, serious incident or accident) have been had the mitigation or recovery measures not detected or stopped the occurrence? Second, how many protective measures remained active between the event and the undesired outcome? This second topical question is associated with the “space-of-possibilities” concept adapted from Rasmussen (1997, p. 190), to understand how thin (or thick) the buffer zone is that exists between the event and the occurrence. Hence, with those two topical questions answered, one should be able to plot the position of each event correctly on the “risk-exposure” map, which represents the very reason why the mitigation and recovery measures should be given a position on the severity scale. Figure 6.23, below, presents the new tool that will account for the measures implemented in the field. Here, the extra row in the severity scale – “(Remaining) Mitigation & Recover measures” – is included in order to measure the events that have actually materialized. The example below considers a total of 10 implemented measures. Carrying out a comparison with the frequency scale, each severity category would thereby divide the number of units by the implemented quantity of mitigation and recovery measures.

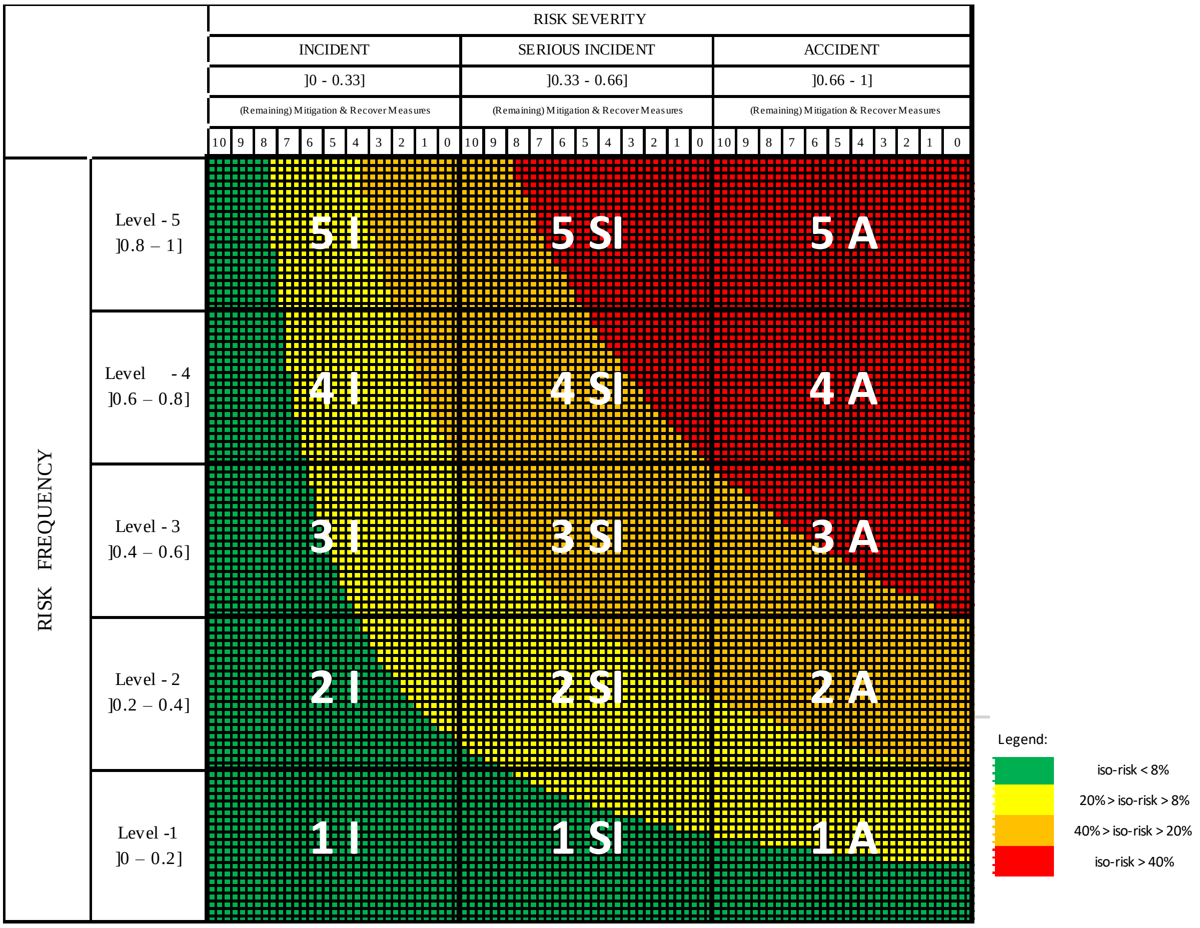


Figure 6.23 – A continuum “risk-exposure” map

Employing the “Exposure-risk” tool during the initial analysis – in both the evaluation phase and in the subsequent stage of risk monitoring – should enable the analyst to overcome the integral[108] weakness presented by the risk matrix [F2.3a]. The number of remaining barriers between an occurrence and the undesirable outcome will act as the criterion upon which to evaluate the system’s resilience. It is for this reason that the title incorporates (in brackets) the word “remaining”, in order to remind the user of the ensuing phase. Nevertheless, in Figure 7.33 in Chapter 7, the two inner rows of the severity scale have been removed.

Depending on the number of barriers an operator wishes to include in the system, several options can be envisaged. Figure 6.23 presents one option that includes 11 entries for each type of event. The first column of each category, labelled “0”, represents a complete absence of measures. Every single measure otherwise accounts for three units, except for the “zero” measures for accidents that incorporate four units due to design restrictions. The difficulties

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[108] Integrity represents the ability of a tool to incorporate the analysis, evaluation and monitoring phases of the risk-management process. For further details refer to section 5.2.3.

presented by a static number of available units (100) will be easily overcome by dedicated software designed to deal with the task, as discussed in section 7.8. Appendix K presents a tool with eight entries.

Practice has demonstrated that introduction of a diversity of overlapping and mutually supporting barriers are resistant to single failures (Reason 1997). This suggests that were every single barrier to work as per its design, this would mitigate the threat tenfold (or to an even lesser degree) in probabilistic terms, and therefore, it would be improbable that the threat would manifest at all. However, in complex technologies such as commercial aviation, barriers have not removed the threat of accidents; instead, they have changed the characteristics of the threat. From the perspective of James Reason (1997, p. 8):

> "Their greatest danger comes from rare, but often disastrous, organizational accidents involving causal contributions from many different people distributed widely both throughout the system and over time."

Therefore, on the basis of the "'Swiss Cheese model [of] accident causation", operational staff should never forget to be afraid of adverse outcomes, and safety analysts ought to continually delve into the reasons for active failures and latent conditions[109] within their organization (Reason 1997, 2016; Rasmussen 1997).

Reason's (1997) "Swiss Cheese" model has encroached on the reasoning of operational staff; and, with the support of the tool, analysts will be able to integrate the whole range of risk-analysis processes with the risk tool [F2.3a].

Opposed to the ARMS methodology – where evaluation of the remaining safety mitigation measures contributes to understanding their resilience – the current model only specifies them, while the robustness of the safety system hinges on the presence of additional measures to inhibit the materialization of the undesired event [F2.4]. Beyond Reason's (1997) claims that safety mitigation and recovery barriers perform poorly in complex technologies – in which active failures and latent conditions play a role – other

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[109] Active failures are "unsafe acts of two distinct types: errors and violations. Errors arise from informational problems and fall into three categories: skill-based slips and lapses, rule-based mistakes and knowledge-based mistakes. Violations arise from motivational factors and fall into four types: routine (or corner-cutting) violations, thrill-seeking or optimizing violations, necessary violations and exceptional violations" (Reason 2016, p. 14); "Latent conditions are to technological organizations what resident pathogens are to the human body. Like pathogens, latent conditions – such as poor design, gaps in supervision, undetected manufacturing defects or maintenance failures, unworkable procedures, clumsy automation, shortfalls in training, less than adequate tools and equipment – may be present for many years before they combine with local circumstances and active failures to penetrate the system's many layers of defences" (Reason 1997, p. 10).

factors interact to have a bearing on the success of the measures implemented. The performance of operational staff, specifically human fallibility (David 2014) and the "practical drift" widely documented in the literature (NASA 1986, 2003; Rasmussen 1997; Snook 2000), is suggested to interfere with the performance of the barriers. Therefore, it does not seem appropriate to evaluate them when they have not been directly involved in the event. There will be circumstances and interactions that will be a challenge to evaluate objectively. Consequently, it seems more reasonable to identify the safety system's distance from the materialization of the hazard. That distance will represent the remaining safety margin (or "buffer zone", using the Rasmussen's (1997) jargon) between the occurrence and the undesirable event. Nevertheless, practical information could and should be obtainable from the measures that directly intervened in the occurrence.

The risk tool presented in Figure 6.24, below, is presented in its raw form. Risks vary in both their nature and level of intrinsic hazard. Thus, the "risk-exposure" map needs to be customized or fine-tuned to reflect the safety boundaries of the organization and to be able to measure a specific safety-risk exposure [F2.1a], namely, be able to make the comparison between the established boundaries and the actual risk exposure. There are risks that appear in the front line and are tolerable up to a certain threshold, whereas there are others that are much less acceptable. Even for a specific risk, it is not possible to generalize a limit for all airlines. The operation of each company has specific characteristics, subtleties and variables that are not possible to replicate in their entirety. For example, the "fatigue" hazard takes into consideration many variables: Fatigue might be a consequence of the type of operation, the operating environment, the type of aircraft, the journey period, and the like. Therefore, each airline must identify its own threshold. In this specific case, to fine-tune the aggregated measure with the addition of a sick-leave ratio to the equation, for example, would represent an excellent indirect threshold indicator.

Due to its potential for a catastrophic outcome, the EGPWS and GPWS event, depicted in Appendix H, is a relevant example of a non-tolerable risk in operation or, at least, it would only be tolerable under specific conditions. The (E)GPWS safety feature includes several basic modes and presents the pilot with two types of alert messages – an advisory aural and a visual "caution" and "warning". The former relates to less critical events, whereas the latter appears whenever a collision with the ground is imminent. A delay in establishing a landing configuration generates an aural and visual caution “Too low gear”, “Too low flaps” or even “Too low terrain” – associated with unsafe terrain clearance when not in landing configuration – Mode 4. Those events are certainly less problematic than a warning “Pull Up” and “Terrain” – related to an excessive terrain closure rate – Mode 2 (Airbus 2019).

The organization’s executive team should work in close coordination with the safety department to distinguish the acceptable from the unacceptable, that is, to devise the safety boundary for the threat. In other words, the executive is responsible for making the decision about the level of safety-risk exposure (risk appetite) the organization is willing to accept. This decision must consider the hazard level of the safety risks, the historical performance of the organization and the number and reliability of mitigation and recovery measures implemented in the field. Translation of the exposure level into a ratio provides the information in a language easily understood by management staff and, in turn, the “risk-exposure” map tool converts this same information into colour coding [F1.1b].

The purpose of the analysis is to understand the level of risk exposure faced by the organization. Thus, the analysis should consider what the most probable outcome would have been had the operational staff failed to detect the event or had the mitigation or recovery measure, implemented by the system, failed to stop the event from happening. In the (E)GPWS example, considering the ICAO’s definitions transcribed in Appendix J, the outcome would be an accident.

The calibration considers the most critical outcome: an accident as per the (E)GPWS example. Figures 6.22 and 6.23, above, demonstrate the calibration when it has not been customized for any specific hazard. However, as Figure 6.24 below illustrates, using the same calibration as per the (E)GPWS case and thereby imagining a total of six implemented barriers in the field (tinted column), and using the accident severity category with a ratio of 10,000 flights, the four iso-risk bands (green band < 8%, 8% < yellow band < 20%, 20% < orange band < 40%, and red band > 40%) would represent the following risk exposure:

- Number of events < $10*10^{-4}$ events (green band, or other ratio, depending on the number of flights).
- $10*10^{-4}$ < Number of events < $25*10^{-4}$ events (yellow band).

- $25*10^{-4}$ < Number of events < $50*10^{-4}$ events (orange band).
- Number of events > $50*10^{-4}$ events (red band).

While no period was given in the (E)GPWS case, it seems reasonable to consider an observation window over the last 12 months of activity. Furthermore, depending on the airline operation the above scenario might prove inadequate, but it might equally prove more effective were it to be implemented in specific (problematic) destinations.

The above exercise requires that the executive team hold a minimum level of understanding and knowledge of risk concepts. Without this minimum-level standard, the executive team would be unable to discuss these subjects or understand the implications of their commercial decisions, or make effective decisions about the investments they need to allocate to the protective component of their organization. It is essential that the subject "safety training and competency" is enshrined within the daily activities of the board [F1.1a, b & c]. Section 5.5.2 addresses the subject of "executive management safety training / competency" in more detail.

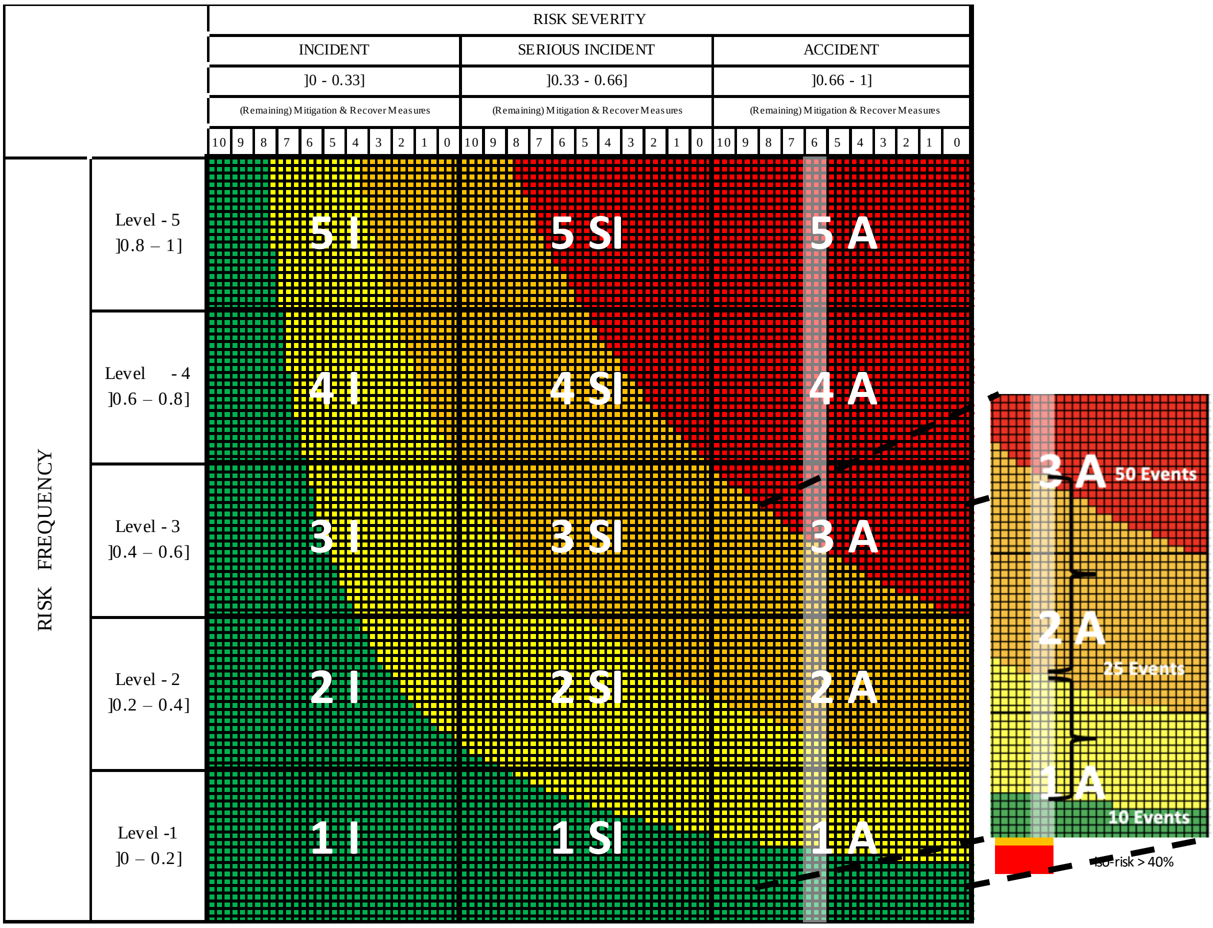

Figure 6.24 – A continuum "risk-exposure" map

6.4 Safety Risk Analysis and Evaluation

Section 6.3 presented the new risk tool that support the "Oyster Model", it addressed how a safety boundary should be developed, and how the executive board could (and should) participate in its development [RQ 1.1]. Three variables were considered when developing the "risk-exposure" map: the hazard level of the safety risk (incident, serious incident or accident), the historical performance of the organization, and the number and reliability of mitigation and recovery measures implemented in the field.

This section does not go into any in-depth detail regarding the activities that compose the analysis phase of a risk because this is not its purpose, but nonetheless these are: uncertainties, sources, scenarios, evaluation of control measures and the like (BSI 2018b). To proceed with the explanation of the "risk-exposure" map, the current section undertakes analysis of the hazard "runway excursion",[110] using data covering operations over 24 months, which was made available by one of the interviewees.

The organization had not collected and processed the data accurately according to the characteristics of the "Oyster Model", so no identification of the barriers that failed had been done and nor had the events been classified according to the severity scale: incidents, serious incidents and accidents. Instead, implementation of a conversion adapted it to the model's needs. Another difference related to the fact that the runway-excursion hazard was not analysed in an aggregated mode. However, with due consideration of the research findings, the whole set of threats are judged in a consolidated fashion [F1.2b]. Due to the sensitivity of the information contained in the dataset, and to maintain the ethical stance that underlies the current research, anonymity and confidentiality (Fisher 2010; Diener & Crandall 1978) were guaranteed to the contributing organization.

Among the tasks that compose the risk-analysis phase, the development of a scenario is one of the most critical stages during identification of contributory factors or risk precursors. In the specific case of the runway excursion, several causes are easily identifiable. Thus, during the take-off phase of a flight, strong crosswinds, a rejected take-off manoeuvre or an incorrect

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[110] A runway excursion occurs during the take-off or landing phase of a flight whenever an aircraft departs or approaches the runway in use (Skybrary 2019). Runway excursion is a hazard listed by the European Plan for Aviation Safety (EPAS). In the report for the period 2018–2022, EASA cites that this hazard was responsible for 13% of the total fatal accidents in commercial air transport in the previous decade, making it a major concern among European stakeholders (EASA 2017).

performance calculation, to name only some scenarios that could adversely affect the aircraft, could lead to a runway-excursion event. The landing phase of the flight should undergo the same exercise. In the end, the airline will be able to identify a set of threats it deems worthwhile taking control over. To understand the threats posed by any hazard, the recommendation is that the same exercise – scenario analysis – be applied to every single situation. For simplicity, in this specific case, seven threats were eligible to demonstrate the outcome from the scenario analysis. Appendix L contains the data used for this presentation.

At this point, it is relevant to revisit the severity concept to take a view of how the interviewees understood the concept. Their understandings of the severity concept (incident, serious incident and accident) were extracted from the set of narratives as a whole. Analysis of Table 6.5 posed an intriguing question as to why, across all the interviews, the interviewees used the term “serious incident” only once. A similar question might be raised as to why a discrepancy exists between the two extremes. Perusing the definitions for each concept in Appendix J might well shed some light on the differences contained in Table 6.5. The two main categories of events are the accidents and the incidents, the latter being any event before an accident occurs, which affected or had the potential to impact upon the safety of the operation. Indeed, incidents would account for more events than accidents, for the simple reason that they have a broader scope.

Moreover, serious incidents are composed of events where a high probability of an accident was present. Therefore, when an analyst performs the risk-analysis phase of risk management, the most probable outcome forecasted would be an accident or an incident. Serious incidents are accidents that were avoided due to the barriers implemented in the field (ICAO 2020). In light of the previous reasoning, therefore, it is understandable that an analyst would far more likely be concerned with accidents and incidents than serious incidents, the former two having a higher prevalence over the latter. The results are in line with the definition of a hazard used by ICAO (2018b, p. vii), where the consequences of events are restricted to incidents or accidents.

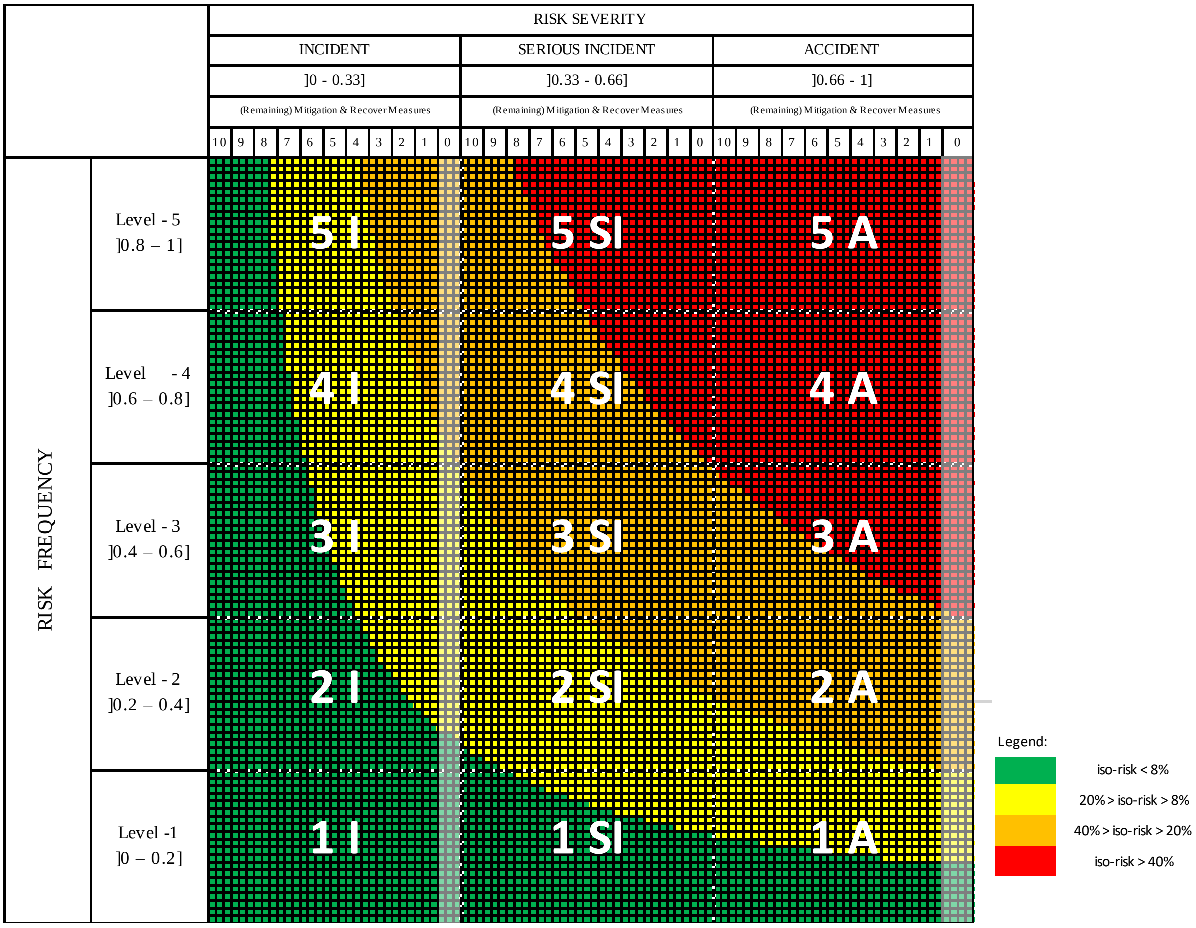

Figure 6.25 – A continuum “risk-exposure” map with vertical columns

Given the results of the previous analysis, the tool will initially study two entries: one for events that have the potential to provoke incidents and the other associated with accidents. Two vertical tinted columns, under the “zero (remaining) mitigation & recovery measures”, which represent the absence of protective measures, denote these entries. Figure 6.25 represents these changes. The “risk-exposure” map maintains the dashed lines and alphanumerical codes to preserve the analyst’s awareness of the real risk faced by the organization.

Tables L.19 and L.20 (see Appendix L) provide the details of the data between 2018 and 2019. In the beginning an organization might not have this initial data available, particularly the data provided in Table L.18. Nevertheless, initially, data might derive from previous experience or expert judgement. While this could be viewed as coarse information, fine-tuning will occur during the monitoring period.

Figure 6.26, below, presents 2018 data in relation to the “runway-excursion” hazard, plotted onto the “risk-exposure” map. In this specific case, the whole set of threats were capable of generating an accident – which is reason enough to ensure input of the right entries from the accident side. After exporting the data from the exposure map that relates to the CLR (see section 2.5.5), several types of information were obtained:

- Exposure cloud: This area encapsulates the whole set of threats, the limits of which are represented by the light-blue line, but also falling within the green and yellow areas of exposure.
- Risk criticality: The exposure cloud occupies four squares, specifically: 1I, 2I, 1SI and 1A.
- Aggregate threat information: The current example of the runway-excursion threat, accounting for an aggregated risk exposure of 4%,[111] is represented by the black iso-risk line. The circle "T" represents the exact position of the "total aggregate risk exposure" in the iso-risk, which accounts for an average of 14/10,000 events. The movement of the circle "T" will identify the hazard's evolution tendency. The calculations are set out in Table L.22 (see Appendix L).
- Specific threat information: After applying the defensive measures that exist currently, it is possible to perceive the existence of two threats in the yellow band. Both of them require an objective acceptance, whereas the rest of the threats remain in the green (acceptable) band. Threat 5 relates to a potentially serious incident, while threat 6 has a higher criticality due to its position in the accident area. Threat 4 rests in the green band, but a small increase in risk exposure has the potential to change its level.

The analysis exercise explained above was presented for a hazard where the risk scenario showed the existence of seven threats. The previous reasoning could apply to hazards composed of a single threat. In this case, a single white circle would take form in the map.

In this case, where a hazard is composed of several threats, the evaluation phase was undertaken in a specific and aggregated fashion. The exposure policy defined at the beginning of the process, reflected in the four colour bands of the tool, allows a direct comparison between the risk appetite and the current reality, turning the evaluation phase into a straightforward process [F2.1a].

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[111] As mentioned earlier, using the analogy provided by Rasmussen's risk-management framework, the higher the percentage the lower the 'buffer zone', that is, the distance between the boundary of unsafe performance and the aggregate risk index.

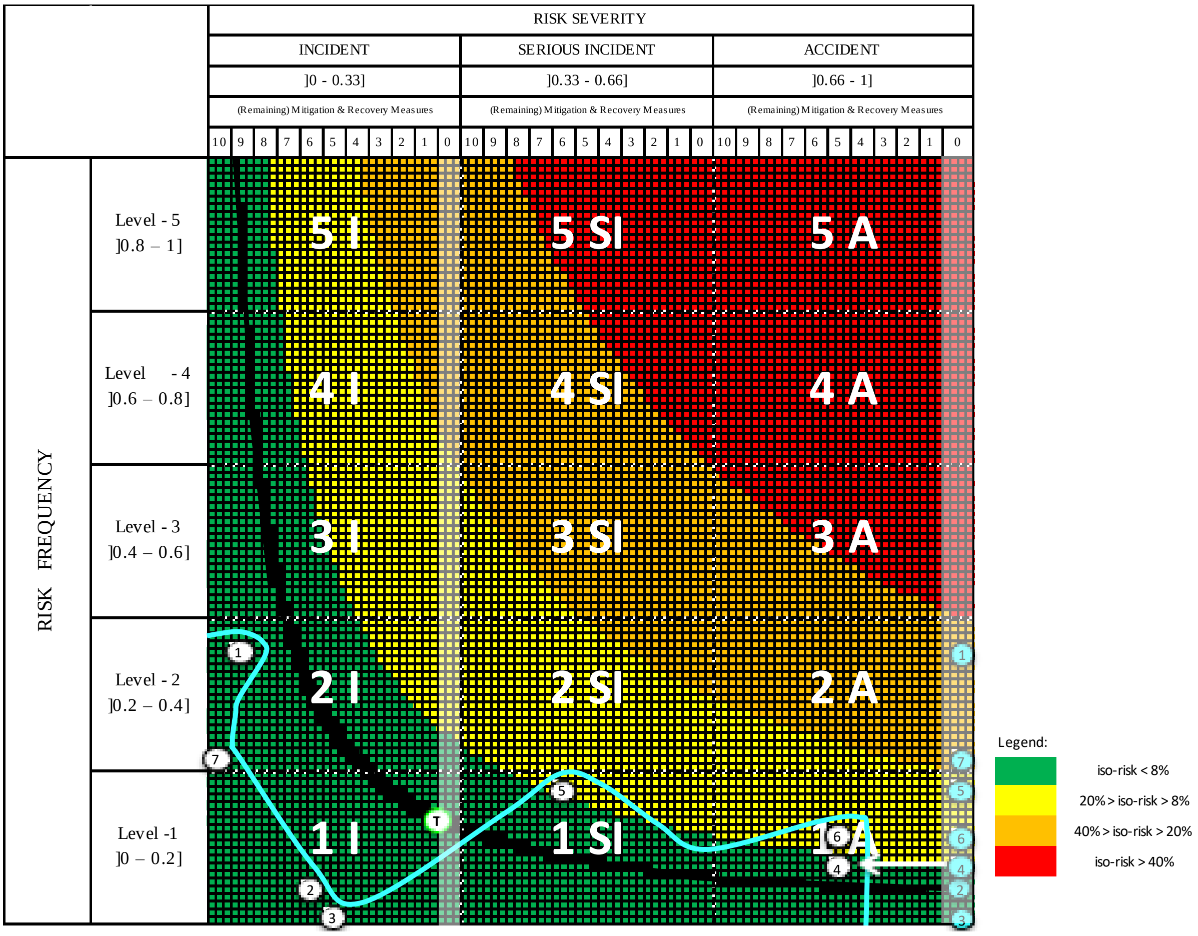

Figure 6.26 – “Risk-exposure” map containing the runway-excursion threat, 2018

In this section, the runway-excursion hazard has been used as an example to describe how hazards should be analysed and evaluated. The risk analysis involves the following actions:[112]

1. Identify the threats that contribute to the hazard.
2. Evaluate the potential outcome of each threat (incident or accident).
3. Place each threat in the zero “(Remaining) Mitigation & Recovery Measures” (tinted columns adjacent to zero measures – Blue circles).
4. Identify the number of protective measures associated with each threat and the forecasted outcome (incident, serious incident or accident).
5. Evaluate the exposure ratio of each threat, i.e. the number of events in the period under analysis or, in the absence of a specific value, the forecasted exposure ratio.

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[112] Steps 3 and 4 were detailed uniquely for explanatory purposes. An analyst or software dedicated to the task would omit the first step and plot directly the white circles to draw the risk-exposure cloud.

6. Using the guidance from the previous section, plot each threat in the "risk-exposure" map, and develop the risk-exposure cloud by drawing a line that encapsulates the whole set of threats.
7. Plot the iso-risk line equivalent to the "total aggregate risk exposure" and plot the "T" circle.

The evaluation phase compares the risk policy or risk appetite with the organization's current exposure. For the purposes of the presentation, there was a choice of four different perspectives: the exposure cloud, the risk criticality, the aggregate and specific threat information.

Section 6.5, utilizing the runway-excursion data from 2019, will now present how hazards could be monitored continuously throughout their existence.

6.5 Safety Risk Monitoring and Resource Allocation

6.5.1 Monitoring phase

One significant deficiency identified during the interviews related to the monitoring phase. Here, it was observed that safety risks were monitored sparsely [F3.2] and that the tool currently in use (the risk matrix) was incapable of receiving information in a continuous form [F2.1b].

Risk management is an iterative process. However, in a complex system such as commercial aviation, no one is capable of ensuring whether the measures implemented have a direct impact on risk exposure because multiple changes, interactions and agents might interfere with the outcome. Nevertheless, although the information might be degraded, an analyst still needs to receive feedback about the actions and measures implemented. This is why, ideally, safety risk should be monitored continuously, and risk exposure should be constantly assessed in parallel. Thus, every event that is processed should be reflected on the "risk-exposure" map. Figure 6.27, below, reflects the evolution of the runway-excursion hazard during a 12-month period of operation, after the start of the monitoring phase. For the purposes of demonstration, the previous data from 2018 (white circles and light-blue line) has been maintained in the "risk-exposure" map.

Figure 6.27 observes that:

- Exposure cloud: The area moved in a left-facing direction, reducing the amount of risk exposure. A white arrow represented the evolution of the risk cloud.
- Risk criticality: Throughout the period, the risk-exposure cloud did not occupy areas in the accident zone. This is evidence of the robustness of the measures implemented in the field.
- Aggregate threat information: There is a reduction in the overall exposure, which is represented by the movement of the circle "T*" in a left-facing direction.
- Specific threat information: There are no individual threats located either in the accident column or in the yellow band.

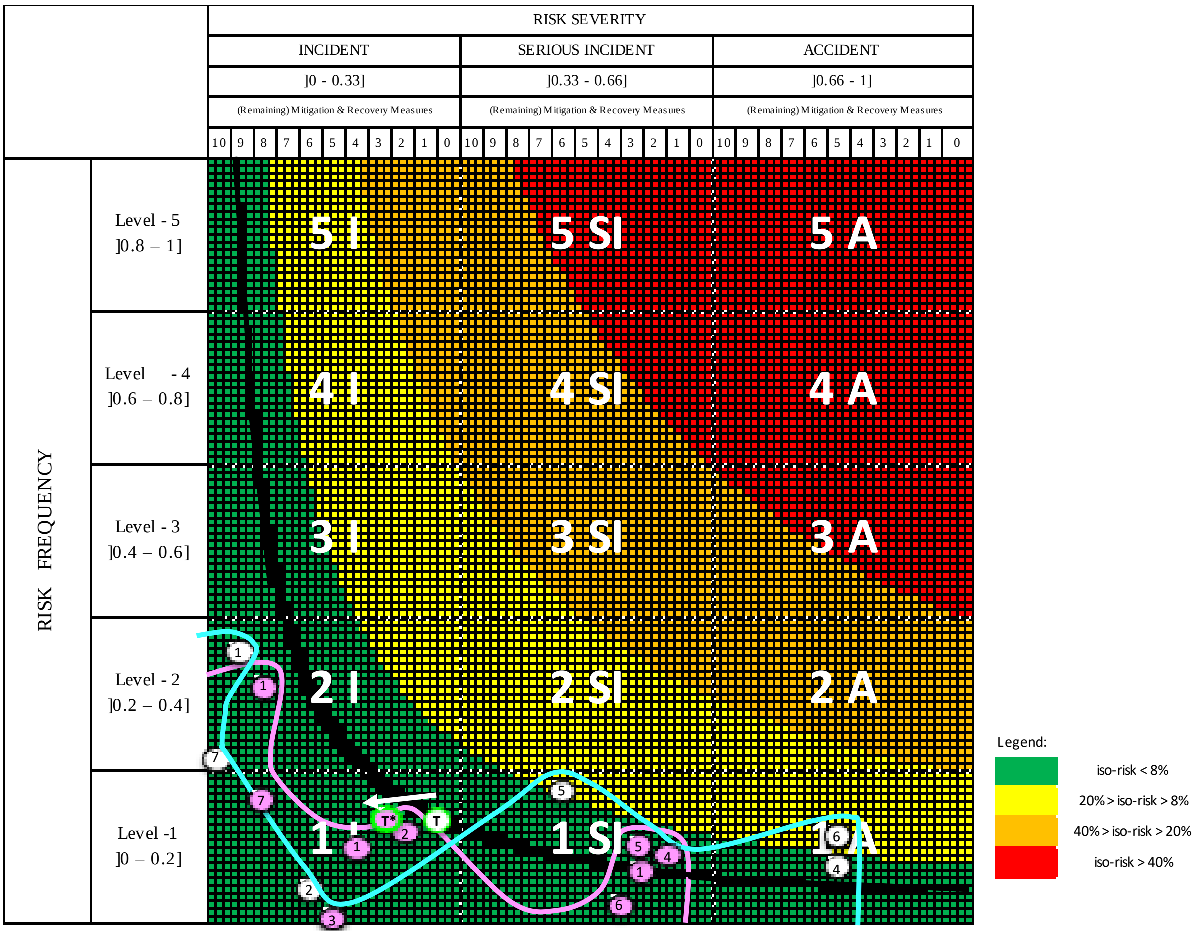

Figure 6.27 – "Risk-exposure" map containing the runway-excursion threat, 2018 and 2019

From the perspective of continuous improvement, the three major contributory threats call for immediate analysis. The resilience of the implemented barriers is a relevant point to consider. Using threat 4 as an example – incorrect performance calculation –, one can observe that in 2019 the organization was exposed to nine occurrences that produced serious incidents (see

Tables L.20 and L.21, Appendix L). These events did not result in an accident because of the actuation of two protective measures, e.g. pilot monitoring and the use of full power to continue the take-off manoeuvre. In this specific case, it is essential that the analyst understands why the remaining barriers (those that have accounted for less success) reveal themselves as ineffective in stopping the event from materializing. The “Oyster Model’s” ability to provide transparent identification of where significant weaknesses exist in the company’s safety system is one of the considerable advantages of the model.

From a broad perspective, an analyst will be able to assess the barriers implemented in the field, understand which are worth keeping and investing in, or identify those that have proven deficiencies and need replacement or readjustment.

The monitoring phase incorporates an individualized threat perspective when considering the robustness of the mitigation measures of each threat. The resource allocation section below sets out the collective stance from the monitoring phase when prioritizing the whole set of hazards/threats.

6.5.2 Resource Allocation

One of the weaknesses identified during the interviews was the prioritization of risks [F2.1c and F2.3c]. Within the “risk-exposure” map, a comparison between the threats of the runway-excursion example is a straightforward exercise, even with the existence of a significant difference in the frequency of the threats. However, when comparing different hazards, the discrepancy becomes more substantial, depending on the nature of the hazards being analysed. According to the interviewees’ accounts, unstabilized approaches undoubtedly have a higher exposure (or frequency) ratio than the aggregate runway excursion, and yet, speculatively, it will have a lower severity. On the other hand, considering the hazardous level of each threat, management would decide on each specific risk exposure, which would result in different “risk-exposure” maps. As these threats are not directly comparable, an analyst must recur to the safety policy established within the organization, which ideally would be standardized throughout the company. In the current example, the tool has four acceptable levels (iso-risks contours). Therefore, exporting threats to a “Stack” map, and placing threats according to their severity and relative vertical position in the iso-risk contour or band, is essential. Similar to the “risk-exposure” map, the lateral position of the “Stack” map identifies the three severity categories, while the vertical position of each threat identifies the relative risk frequency within the iso-risk contour.

Using the runway-excursion hazard example, based on data from 2018, Figure 6.27, above, depicts the relative weight of the seven threats. Using threat 1 as an example (white circle), one can see that it is positioned vertically in the first third of the green band, within the incident area, which is why it is to be placed in the same relative position on the "Stack" map. To perform a comparison of the whole range of threats contained in the hazard log, that is, the entire set of threats monitored by the organization, would involve importing them into the "Stack" map, such as that illustrated in Figure 6.28 below. Alternatively, a different approach can be envisaged: for instance, associating each threat with a figure identifying their relative weight in the respective iso-risk band. Another advantage of the "Stack" map is the visual perspective it conveys, identifying the whole set of threats by their relative weight and classified by the potential outcome.

Figure 6.28, below, incorporates only one hazard – runway excursion. Therefore, the example used for explanatory purposes does not offer any more information about prioritization than that obtained from the "risk-exposure" map. The example used in Chapter 7, however, to explain the implementation of the "Oyster Model", considers two hazards with specific safety boundaries, allowing a more complete understanding of the "Stack" map comparison feature.

Figure 6.28 – "Stack" map

Beyond the comparison obtained from the runway-excursion aggregate data (see Figures 6.26 and 6.27), the perspective offered by the “Stack” map enables the analyst to identify which threats are more significant and concerning, and thereby to manage safety investments from a more informed position [F3.1]. However, because the comparison between the established safety objectives and the actual risk exposure must make allowance for human judgment [F2.1a] as well, “Stack” map analysis will be essential, as reality is captured in a deficient form.

Both risk tools act as a cumulative source of risk information since they can receive and record data continuously [F2.1b]. Hence, the perspective conveyed by the “risk-exposure map” (whereby the organization is always able to identify the risk exposure the operation is subjected to and integrate the contributing factors [F3.3]) is expected to capacitate the development of a proactive perception. The suggestion is that, beyond the ability to project future scenarios, the “risk-exposure” map can be a useful communicating risk tool, too [F1.5], since it conveys a visual perception of the current situation: safety objectives versus current risk exposure, and its tendency. Note, however, that in the case of an aggregate hazard, the exposure evolution can be carried out at the threat level.

The risk tool’s design is such that, subject to minor changes, it will be able to receive data directly from the FDM. This feature will be explained in section 6.5.3, where an approach to breaking the communicative silos created by the actual ICAO (2018b) SMS framework is discussed, in line with George-AB assertion that: *“SMS is working more and more by silos.”*

6.5.3 Service providers

Another perspective brought by the “Oyster Model” lies in the possibility to import data from external sources to the organization [F3.4], turning the monitoring phase into a much more robust process. Therefore, if an operator contracts a service provider to accomplish any assignment on its behalf, for example, a wet-lease contract or a specialized function, the lessee should be entitled to request data to feed into its own system. The lessor should share the anonymized reports to feed into the “risk-exposure” map, or, if using the same method, provide access to already-processed data.

The solutions currently implemented in the industry do not impede the exchange of safety information. Nevertheless, as seen during the research, the data stakeholders currently use is based on a frequency approach, which does not lend itself to a risk perspective, and will be of no use to measure the risk exposure an operator is adding to its operation when contracting a third party [F1.4]. Certainly, there will be difficulties associated with the process, particularly with reporting standardization and taxonomy.

Collecting risk-based data to update the “risk-exposure” map, even automatically, undoubtedly slows down the process. However, depending on the characteristics of the threat, the tool’s design allows it to receive data directly from the FDM. While minor changes will be required to adapt the tool should the process be in use widely by third parties, then the exchange of data could be streamlined. Nevertheless, it is relevant to note that an inherent degradation is added to the “risk exposure” map. The cultural impact, defences and recovery measures implemented by external service providers will not be taken into consideration, as the organization has no possibility to intervene in those variables. It is, therefore, less precise data.

Using threat number 1 – “high energy over the threshold” from the “runway-excursion” hazard as an example –, modification of the tool would enable it to accommodate data from the FDM system. Instead of using the number of barriers that have remained intact in the system to avoid an undesirable event, the severity scale could transform this process by accounting for the level of deviation over the threshold that was observed, which will be reflected in the landing distance. In this specific case, the variable to be measured would be the kinetic energy – represented by the airspeed an aircraft indicates immediately before landing. The standard final approach speed is known as the reference landing speed (VREF).[113] The value depends on several factors, whereby aircraft weight, selected landing configuration and wind speed are relevant variables in the result. Consideration ought also to be given to the runway length.

A 20-knot deviation on a runway of less than 2,000-metres long presents an entirely different level of risk than a longer runway of, say, 4,000 metres. Another factor to consider is the condition of the runway surface, since this influences the braking capability of the aircraft. However, data from the FDM does not consider this as a factor, which is another limitation to consider. Thus, considering the measurable operational conditions from the FDM, the

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[113] The reference speed used for normal final approach is equal to 1.23 times the stall speed of configuration FULL (Airbus 2019).

severity scale could be modified to identify the difference between VREF and current speed. For this specific threat and depending on the characteristics of the operation, the scale should be adapted to reflect the operational environment. For a large aircraft like the Airbus 320 or 330, used respectively for medium- and long-haul flights, it is suggested that a scale of 50 Kt is adequate. In this specific case, for a scale of 100 units, each severity unit would represent 0.5 Kt. As noted, the results could be verified in specific airports where runway characteristics – length and surface conditions – might be of concern, instead of relying on aggregate data for the whole operation.

The calibration of the “risk-exposure” map follows the same method as explained above in Section 6.3. As an example, Figure 6.29, below, uses the maximum acceptable (green band) frequency of 12 events for a 20 Kt deviation from the VREF. The other two alert levels for the same deviation relate to 25 and 50 events for the orange and red iso-risks contours respectively, as the threat number 1 circle illustrates. As explained previously, it should be noted that the production level has not been addressed in the example. This will be discussed in Chapter 7.

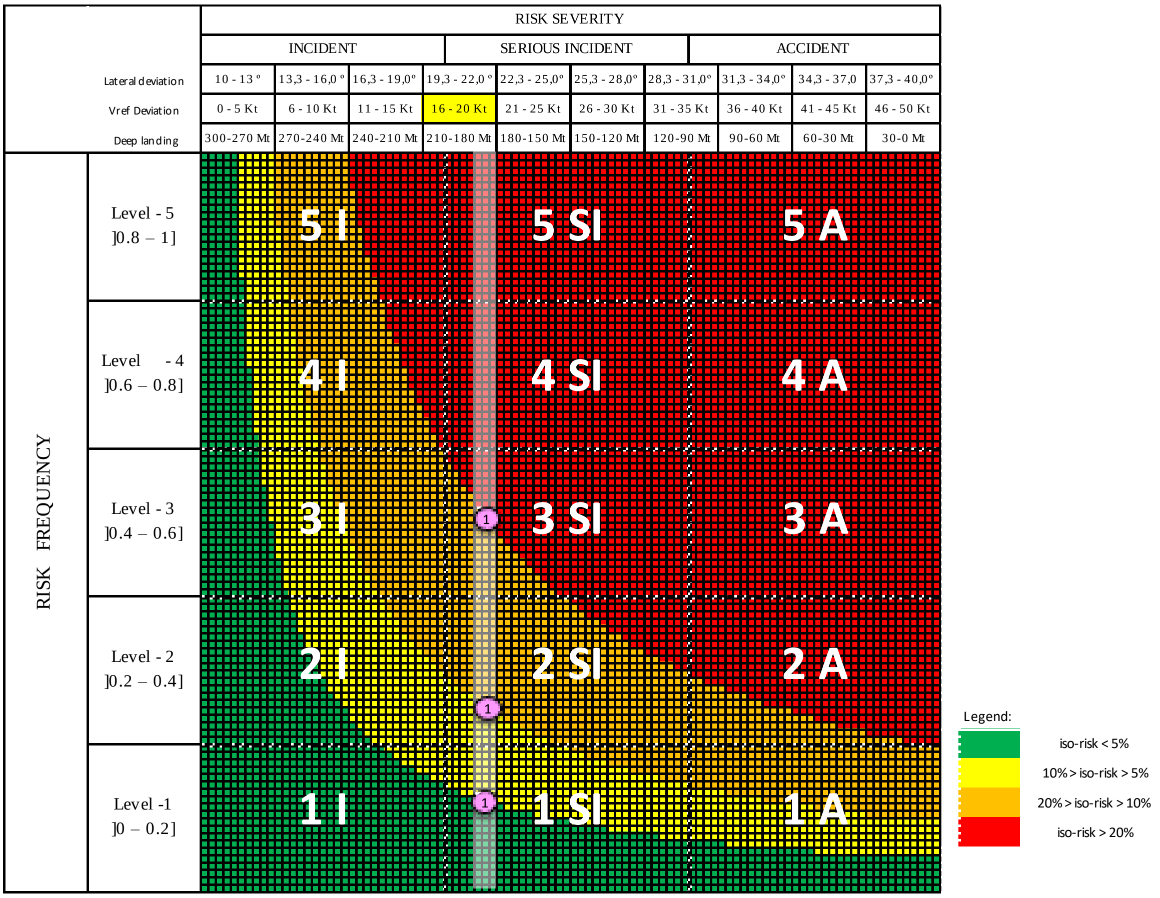

Figure 6.29 – “Risk-exposure” map adapted for service providers.

In order to develop a "risk-exposure" map, one could perform the same exercise for the remaining threats that also constitute the runway-excursion hazard. These include a "deep landing", assessing the touchdown point ahead of the normal touchdown position and the remaining available runway length; the "lateral deviation", where the variable to be measured would be the angle achieved between the aircraft and the runway axis; or the "high rudder deflection on ground" made during the take-off and landing phases (EOFDM 2020, p. 42). The decision about the characteristics of the severity scale should be discussed during the analysis phase of the risk-management process. Nevertheless, as exemplified by the "lateral deviation" threat, note that the severity scale does not have to start at zero. Moreover, to gain a comprehensive understanding of the impact produced by third-party hazards, data should be imposed in the organization's "risk-exposure" map, whereby the severity scales could be omitted.

6.6 Safety Culture

Based on both the critical literature review and evidence from the interviews, safety culture is a crucial factor that contributes to the safety performance of the whole system [F4.1]. Several examples have been presented to support the influence exerted by this relevant variable, such as the events identified in NASA's accident reports (NASA 1986, 2003). The recent occurrences in relation to the Boeing 737 Max, which led to two catastrophic accidents (Hradecky 2019a, 2019d) are other examples of how an organization's [safety] culture may influence the safety performance of the whole organization. In a recent article, Gelles (2019) quoted a former Boeing manager who affirmed:

> "Employees […] were overworked, exhausted and making mistakes […]. A cascade of damaged parts, missing tools and incomplete instructions was preventing planes from being built on time. Executives were pressuring workers to complete planes despite staff shortages and a chaotic factory floor."

The former manager added:

> "Workers were completing jobs out of sequence, leading to additional mistakes. And senior executives at Boeing exacerbated the problems, […] by berating employees about delays and urging them to work faster."

In the Boeing example, the suggestion is that the cumulative sequence of mistakes was a consequence of Boeing's cost-cutting policy (Beene & Suhartono 2020), which in turn reflected the “management pressure toward efficiency” and the “streamlining of the safety rules”, as depicted in “Rasmussen’s ‘space of risk exposure’” (see Figure 2.9).

Safety culture is a dominant conditioning factor, to the extent that there is a suggestion it has the capacity to impair the reasoning and decision-making capacity of managers, whereby they deny the evidence that actually confronts them. An article by Edgecliffe-Johnson, Hollinger and Stacey (2019) supported this “negation approach”, quoting Associate Director of the National Preparedness Leadership Initiative, Eric J. McNulty’s view of Boeing’s thinking as: “we’re Boeing: this can’t be happening to us”. The authors stress that Boeing “failed to question potential failings in its culture, its close relationship with its domestic regulator or its fast-changing market”. A statement from a congressional official, in acknowledgement of how the organization’s culture influenced the accidents, supports the argument of Edgecliffe-Johnson et al. (2019): “There is a cultural issue at Boeing. It is going to take a lot of things to turn this company around – a new leadership, and possibly a fresh perspective.”

The Transport Safety Board (TSB) of Canada, in an aggregate internal safety investigation into the air taxi industry,[114] covering a period of 17 years (2000–2017), concluded that it accounts for more fatalities than all the other Canadian transport sectors combined (FSF 2019). As contributory factors, the TSB identified a weak safety culture that considered unsafe practices as acceptable and then became the norm, and inadequate management of operational hazards. Unsafe practices, if not halted, tend to become “normalized”, leading to a continuous increase in risk exposure. The sociological approach identified in the research (see Section 5.4.2) plays an important role, as the previous examples demonstrate [F4.2]. When the whole workforce behaves negatively in a synchronized fashion, this leads everyone to accept that deviating from safety patterns is the standard, and the acceptable way of operating.

The objective of the proposed risk model is to capture the systematic migration of the safety system towards the edge of the unsafe performance boundary. There are two ways one might represent the migration: by the movement of the “risk-exposure” cloud or by enlargement of the whole area. Considering that the model is based on a cumulative risk-based sequence of events, the latter approach would probably more realistically represent the increase in risk

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[114] The air taxi industry includes aircraft that transport fewer than 10 passengers on missions, including search and rescue missions, delivering people, equipment and food to various sites, transporting workers to remote sites, transporting patients to hospitals, and the like.

exposure. A general expansion would represent a positive increase – in other words, it would express the result of the two deviating vectors. A sole movement in the right-hand or upward direction would represent, respectively, uniquely a severity or a frequency increase, which would not necessarily reflect the reality. In the Boeing example, the deviation was exacerbated to the extent that the former manager already quoted above was drawn to making an inconceivable statement: "[…] for the first time in my life, I'm sorry to say that I'm hesitant about putting my family on a Boeing airplane" (Gelles 2019). Figure 6.30, below, illustrates the speculation that a deficient safety culture has an inverse impact on the risk exposure of an organization, using the data from the previous runway-excursion example (2019) to represent an increase in risk exposure due to a weak safety culture.

The CLR identified several methods of measuring safety culture and the culture climate in general. Yet, no research has surfaced to show the development of the relationship between the two concepts and the risk exposure affecting the organization. The best link identified was in relation to the identification of weaknesses and strengths within organizational culture. Thus, Figure 6.30 accounts for three units of expansion, which in this specific case is equivalent to a failure of a protective measure. Indeed, it would be near-impossible to come up with a concrete and objective formula to determine what level accounts for safety culture. However, whether using the aforementioned methods or developing specific indexes (SPI), it is possible to determine whether culture is exerting a positive or negative influence on the organization's total risk exposure. With this data, it would be possible to learn whether the workforce's safety culture has the potential to influence the risk exposure positively or negatively, and consequently to convey an image that risk exposure is higher (or lower) than the risk cloud shown by the tool.

Figure 6.30, below, represents a deficient safety culture. For threats 1, 4, and 5, it is possible to perceive how a reduced number of barriers directly influences an organization's distance from a potential accident, and how a functioning safety culture has the potential to decrease that distance [F4.3].

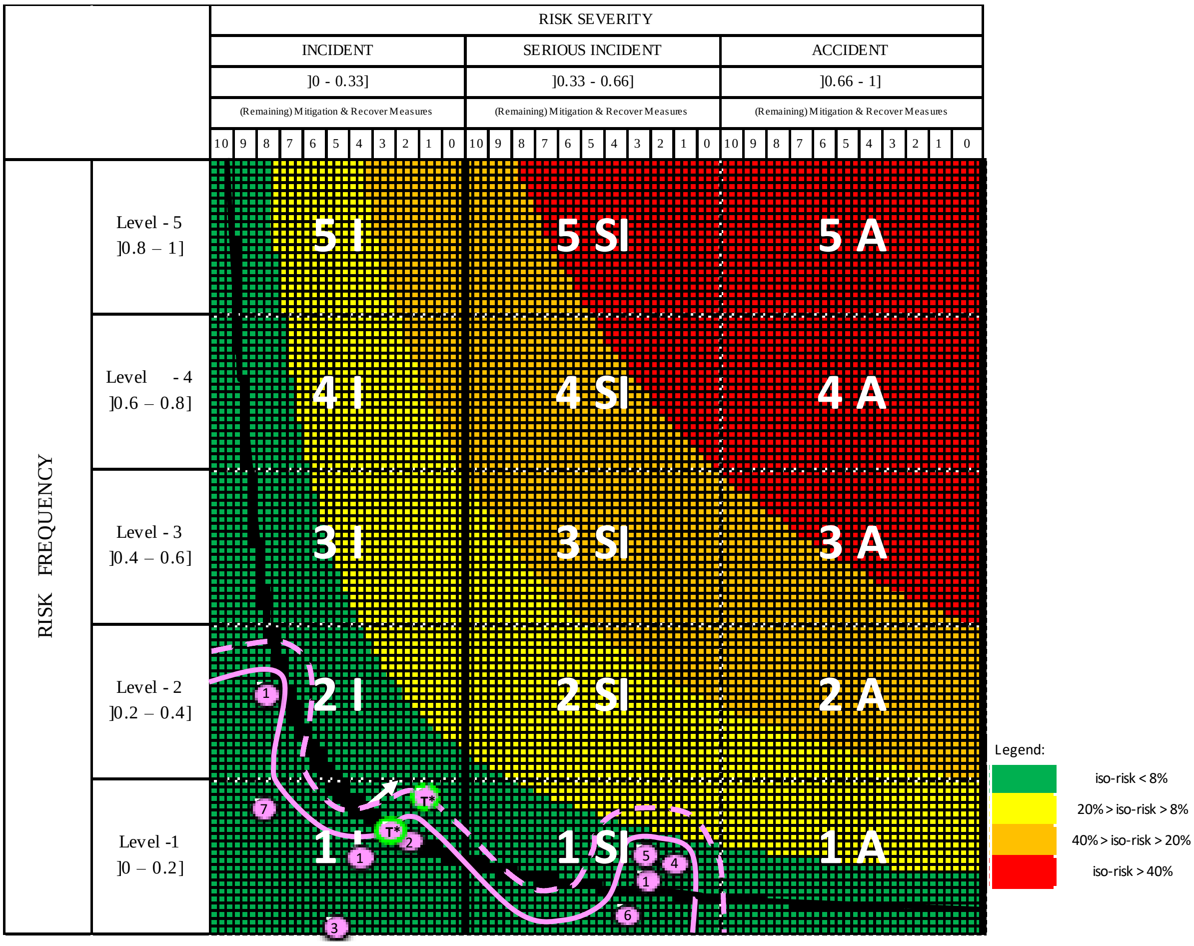

Figure 6.30 – “Risk-exposure” map containing the runway-excursion threat plus the cultural impact (2019)

This section concludes the presentation of the risk tools dedicated to supporting the “Oyster Model”. Implementation of the model incorporates seven stages: the development of the safety boundaries (or risk appetite) for each hazard, risk identification, the analysis of the hazard and its constituent threats, the evaluation, treatment, monitoring phase and resource allocation. The model also incorporates the potential impact that safety culture may have on the organization’s risk exposure. Chapter 7 now presents an example of implementation of the “Oyster Model” within an airline, which explores the nature of the changes such an organization will need to consider should it decide to implement the “Oyster Model”.

7 Implementation of the “Oyster Model”: An innovative Safety Risk Model Bridging the Gap between Management and Operational Staff

7.1 Introduction

The “Oyster Model”, supported by the current research, incorporates the stance conveyed by the conceptual framework illustrated in Chapter 3 (see Figure 3.14 “The continuous safety-risk management cycle”), and follows the risk-management guidelines established in the BSI (2018b) process. The approach is similar to the method adopted by the ICAO (2018b) SMS. Thus, it is not anticipated that implementing the model would be likely to cause any significant disruption in the way risk-management is conducted in airlines following the ICAO SMS framework. The “Oyster Model”, illustrated by Figure 6.18 in Chapter 6, is designed to fit within existing activities. However, it will require that changes are made to the conceptual stance that underlies the five phases – definition of safety boundaries, risk analysis, risk evaluation, risk monitoring and resource allocation – which, having been improved by the model, provide the ability to correlate the safety culture of the organization with its agreed upon risk-exposure tolerance. The remaining two phases – risk identification and risk treatment – belong to the set of activities that constitute the “Oyster Model”. However, as no adjustments have been introduced to the BSI (2018b) process, no further changes are anticipated in order to implement it.

The “Oyster Model” is supported by the “risk-exposure” map and the “Stack” map tools that were detailed in Chapter 6. The former of these risk tools supports the implementation of the inner stages[115] of the model – stages 1–6 – while the latter is dedicated to supporting the final stage – the resource allocation. The purpose of the resource-allocation stage is to identify the more significant and concerning threats and, thereby, to manage safety investments from a more informed position [F3.1]. Figure 7.31, below, associates the use of both risk tools – the “risk-exposure” map and the “Stack” map – visually with each phase of the “Oyster Model”.

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[115] The expressions “stage” and “phase” are used interchangeably throughout this chapter.

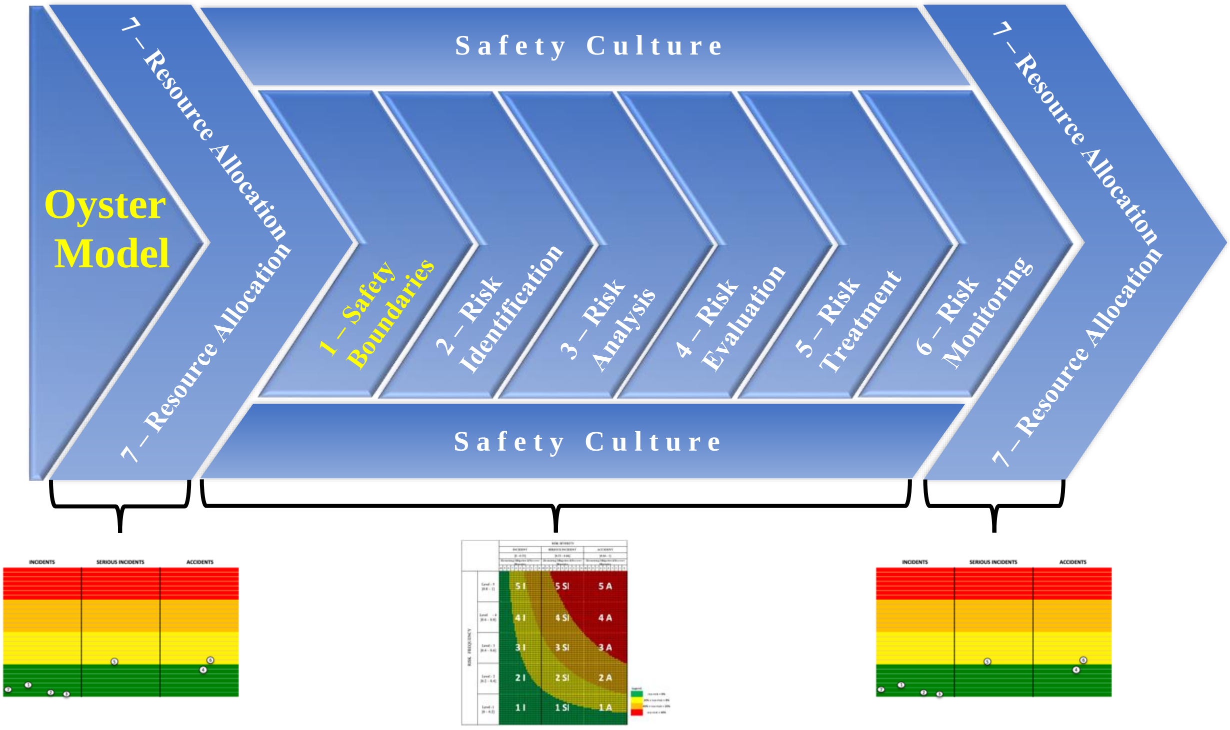

Figure 7.31 – “Oyster Model” and associated risk tools

Implementation of the “Oyster Model” begins with defining the safety boundaries. This initial stage allows the organization to define its risk appetite according to each hazard. The cycle begins and ends with the Resource Allocation stages. The repetition of phase 7 – Resource Allocation, in Figures 6.18 of Chapter 6 and 7.31, above, aims to convey the continuous stance of the model as depicted in the conceptual framework. The cycle runs on a loop, that is, it is continually revisiting and evaluating past decisions in light of the results obtained from the stages 1–6.

“Loss of Control In-Flight” (LOC-I) data will be used throughout Chapter 7 to explain each stage of the “Oyster Model”. Similar to the occurrence described in Chapter 6 (see section 6.4), the organization had neither collected nor classified the data according to the “Oyster Model’s” characteristics. Instead, data were adapted to the model’s requirements. Again, it should be noted that confidentiality and anonymity form the ethical basis that has guided the research throughout. Section 7.7 illustrates how risk priorities are decided upon and how resources are allocated within the premises of the “Oyster Model” at the Resource Allocation stage. Chapter 7, therefore, confronts the runway-excursion hazard, as discussed in Chapter 6, with the LOC-I data.

Following each stage of the “Oyster Model”, the subsequent paragraphs detail the tasks with which an organization must comply in order to implement the “Oyster Model” successfully.

7.2 Organization characteristics / Risk Exposure and Stack maps set-up (Stage 0)

As explained in section 6.3, before each hazard is analysed, the organization ought to calibrate its risk tools – the “risk-exposure” map and “stack” map. The objective of this preliminary task is to have a standard comparison listed for the risks in the risk register (see Appendix G). For that, the following decisions/data must be determined, defining the:

1. Number of iso-risk contours the organization wants to have in the “risk-exposure” map and “stack” map (See Figures 6.18, 6.19 & 6.26, on Chapter 6).
2. Number of frequency levels the “risk-exposure” map should have (see Figure 6.22, above).
3. Production level of the organization.

In the first step, the decision about the number of iso-risk contours may be associated with either a specific number of severity levels or a risk-level decision-making process, or involve consideration of both concepts. To maintain coherence with the examples used throughout Chapter 6, the four iso-risk levels have been maintained. The current standard reflects the observations made during the research – that is, risk matrices with four decision levels.[116] The number of iso-risk contours is the only decision required to develop the “Stack” map, as this tool has the sole function to compare the threats according to their criticality and relative position in each iso-risk band.

The second decision, which is associated with the frequency levels for the “risk-exposure” map, will help to discriminate between threats that stand in the same iso-risk position. Moreover, during phase 4 of the “Oyster Model” – risk evaluation –, the frequency levels will be used in the risk-critically analysis. Using the same rationale as that used for the number of iso-risks, a five-level standard will be maintained.

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[116] The four-decision levels standard, reflected in risk matrices with four colours, was observed in five organizations. The first level was the desired level of operation, the second was associated with a nominated person’s responsibility, the third to a Board member, while the last one was the sole responsibility of the accountable manager or the CEO.

The last input to be considered in the set-up phase relates to the production level of the organization. Although data for the current example – Loss of control in-flight – comes from a different organization than the one that agreed to kindly provide the data used in Chapter 6, both organizations have a similar production rate (10,000 flights per year), which is why this range for the frequency scale has been chosen.

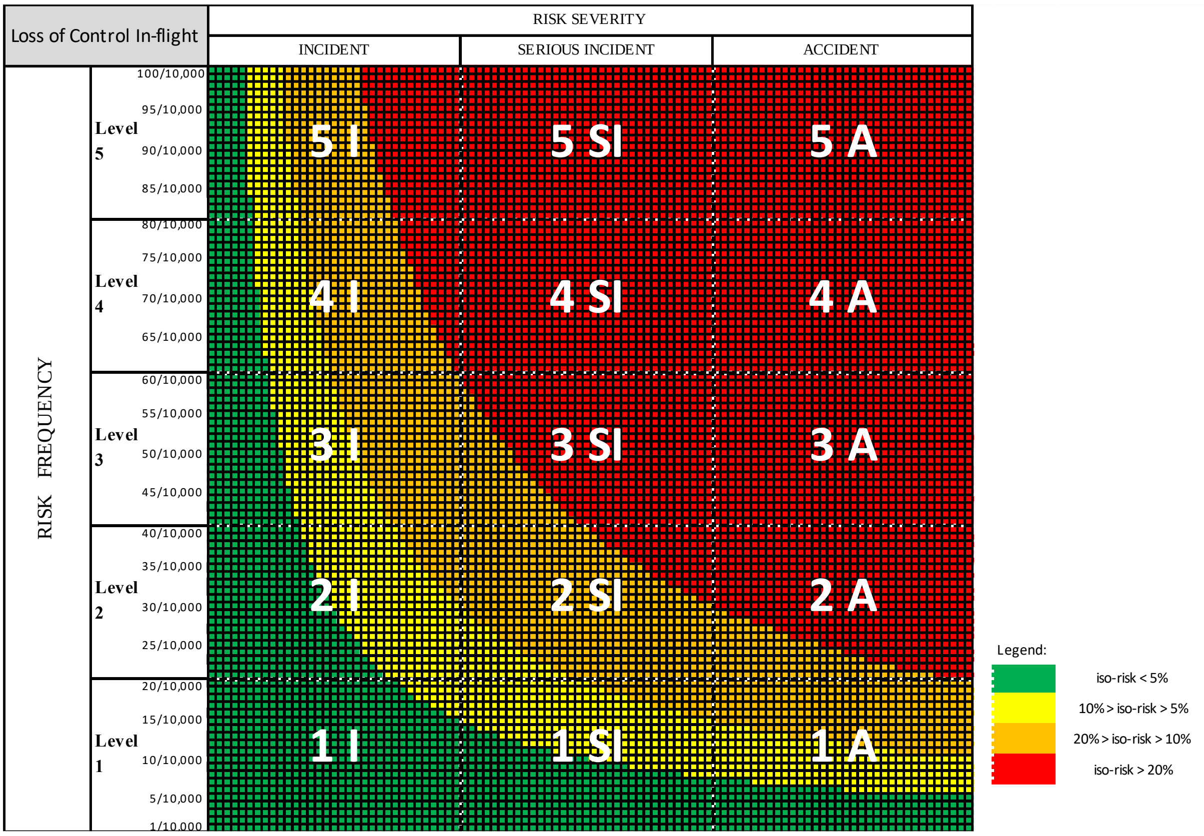

Figure 7.32 – The organization’s risk-exposure map set-up

At this stage, as depicted in Figure 7.32, the overarching set-up of the “risk-exposure” map is completed by the organization. The remaining decisions that are required in order to complete setting up the risk-exposure map are associated with the risk appetite and the hazard characteristics which are being analysed. The following two sections discuss the four remaining stages to conclude the “risk-exposure” map set-up:

- Stage 1 – Safety Boundaries – definition of the acceptable risk-exposure level.
- Stage 2 – Risk Identification – Identify the threats that concur with the undesirable event.
- Stage 3 – Risk Analysis – Study the characteristics of the threats identified previously.

- Stage 4 – Risk Evaluation – comparison of the risk analysis with the initial risk-exposure level already established.

7.3 Safety Boundaries set-up (Stage 1)

Defining safety boundaries is the first step (stage) of the “Oyster Model”. The acceptable risk-exposure level (risk appetite) takes into consideration many variables. It should reflect the organization’s values, objectives, available resources and the nature of the hazards that are likely to be encountered (BSI 2018b). Therefore, in this first stage, the organization should identify the exposure level for each iso-risk band, considering:

- The nature of the hazard.
- The historical performance (if available).
- The nature of uncertainties that can impact the outcome.
- The ability of threats to combine between themselves.
- Reliability of the exposure data – measurement ability and accuracy.
- The organization’s ability to protect itself.

At the current stage, the activities of the “Oyster Model” are not hermetically sealed. They work interactively with the three stages that follow: risk identification, analysis and evaluation, and thereby influence the safety-boundary definition. The number of aggregate threats that contribute to the hazard, the robustness of the protective measures, the potential outcome of each threat, and the impact generated by the safety culture, influence the exposure an organization is willing to accept, which is why these stages must be set-up and operated in a coordinated fashion. The defined risk exposure for the LOC-I will be a starting point. At the end of phase 4 – the risk evaluation –, with due consideration of the risk-exposure level, the safety boundaries may need to be honed. Thus, in the initial analysis, along with the available information and the seriousness of the hazard, the organization will consider the following risk-exposure level for the LOC-I hazard:

- Green band: Number of events < $5*10^{-4}$.
- Yellow band: $5*10^{-4}$ < Number of events < $10*10^{-4}$.
- Orange band: $10*10^{-4}$ < Number of events < $20*10^{-4}$.
- Red band: Number of events > $20*10^{-4}$.

At this initial development stage, in order to ascertain the current exposure level, one should think in terms of an extreme situation. Opposed to section 6.3, where the example considered a known quantity of mitigation and recovery barriers, as a first step in the sequential activities of the “Oyster Model”, the whole set of precursory threats should be considered to have zero mitigation and recovery measures implemented, and the probable outcome to materialize as an accident. The resultant exposure level would represent an acceptable rate of five events for the green iso-risk band, a maximum of 10 events for the yellow, and 20 events for the orange band. Beyond 20 events, the risk would not be acceptable, as Figure 7.33 below illustrates, using threat number 1 as an example.

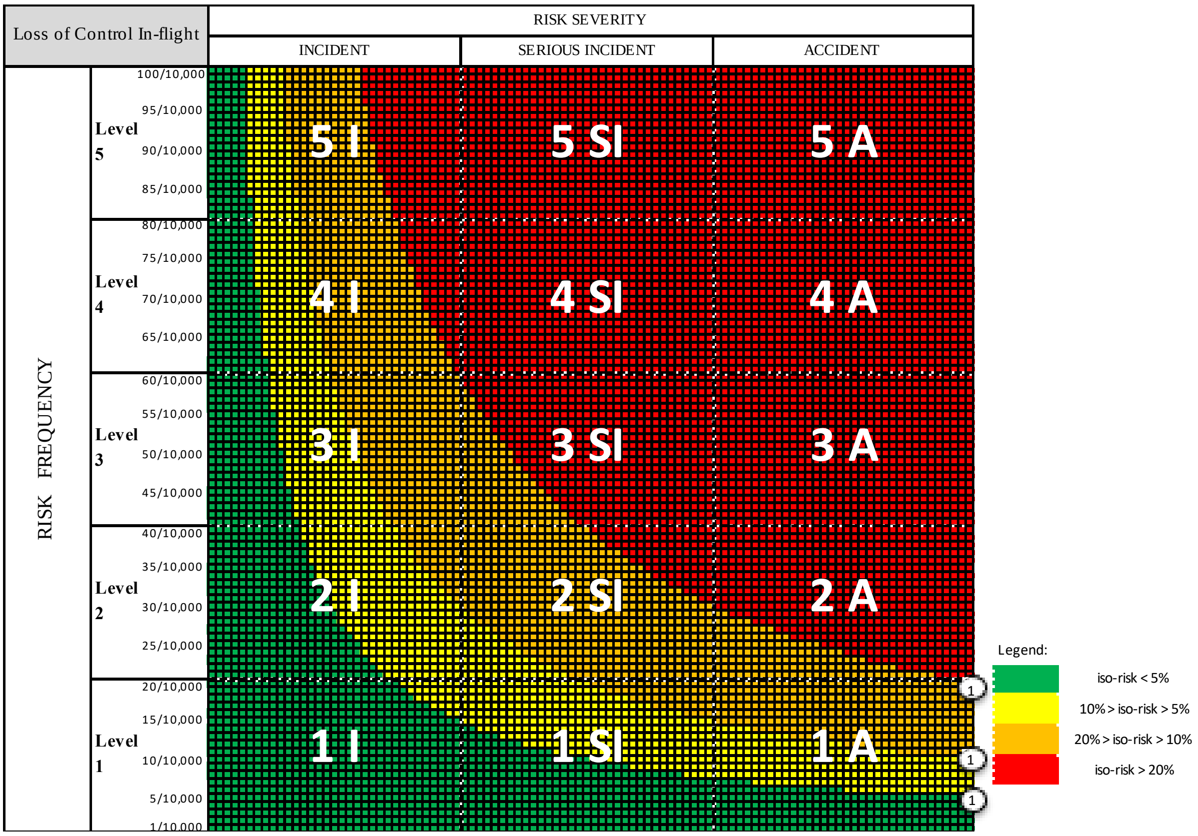

Figure 7.33 – The organization’s risk-exposure level

As mentioned, the following three stages are interdependent. For that reason, the BSI (2018b) considers them in an aggregated way, designing the set of activities as the “risk assessment” phase, which is why the section that follows is titled “Risk Assessment”, which includes those three phases.

7.4 Risk Assessment (Stages 2–4)

The implementation of these stages – risk identification, risk analysis and risk evaluation – implies the accomplishment of the following assignments:

1. Identify the threats that have the potential to activate the hazard (stage 2).
2. Identify the existent (or develop at a later stage – risk treatment (stage 5)) protective measures implemented in the field for each threat (stage 3).
3. Judge the potential outcome pre- and post-mitigation measures (accident or incident) should the threat materialize, and identify the number of occurrences that the organization has been exposed to (stage 3).
4. Incorporate the impact of the safety culture into the risk-exposure map (stage 3).
5. Evaluate the hazard, making a comparison between the safety-risk analysis and the established risk-exposure level (stage 4).

Risk identification (stage 2) follows the traditional methodology described in the BSI (2018b). Independently of the methods used, the objective of this stage is to identify, recognize and describe safety risks that might impact or thwart an organization’s objectives. The study of each threat implies developing a scenario and, consequently, identifying the associated protective measures implemented in the field. Table 7.6, below, summarizes the data obtained from this initial phase:

- Descriptors – The organization’s threats that have the potential to contribute to the risk-exposure level generated by LOC-I (stage 2).
- The protective measures associated with each threat (stage 3).

Threats	Descriptors[117]	Implemented Protective Measures[118]								Total
		#1	#2	#3	#4	#5	#6	#7	#8	
1	1 – LOC-01 – Fire, Smoke and Fumes	✓	✓	✓		✓			✓	5
2	2 – LOC-09 – Abnormal Operations	✓		✓	✓	✓	✓	✓		6
3	3 – LOC-14 – Inadequate Aircraft Attitude	✓		✓	✓	✓		✓		5
4	4 – LOC-19 – Windshear	✓		✓	✓	✓		✓		5
5	5 – LOC-23 & 26 – Loss of Thrust & Engine Failure	✓		✓	✓	✓			✓	5

Table 7.6 – LOC-I descriptors and associated protective measures implemented in the field

Table 7.6 identifies that the risk-exposure map will require a severity scale with six mitigation and/or recovery measures, as the “Abnormal Operations” threat accounts for six measures (see “Total” column).

In light of the information previously collected, analysts shall continue to deepen their risk study by reviewing risk sources, uncertainties, frequency, severity and the like. The ultimate objective is to understand the possible scenarios, perceive the potential outcome that each threat may generate, and ascertain the effectiveness of the implemented measures in the field. The risk-analysis phase includes identifying the number of occurrences the organization has been exposed to in the previous period. In the absence of such information, safety analysts should anticipate a credible number to represent the known reality. Table 7.7, below, summarizes the data retrieved from the organization in 2018.

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[117] Similar to the explanation offered in Appendix L, descriptors were extracted from EASA EOFDM (2020). In the current example, the scenario considers the development of means to:

- “Detect the presence of fire, smoke or fumes in the cabin, cargo compartment, [and] engines (…) (LOC-01).
- Identify operations at or beyond the edges of the operating envelope or not in compliance with the standard operating procedures (SOPs). This should cover all airframe and engine limitations (as specified in the aircraft flight manual (AFM), including but not limited to indicated airspeed/Mach versus altitude, vertical speed, G limits, flap speed limits, speed brake limits, tire speed limits, landing gear limits, temperature limits, manoeuvrability speeds, engine parameters, tailwind, crosswind, excessive rudder inputs) (LOC-09).
- Identify cases of excessive angles of pitch and roll. The identification should consider the range of values acceptable for each phase of flight (LOC-14).
- Identify situations of windshear (reactive and predictive) (LOC-19).
- Identify situations of unintended loss of thrust, or reduced engine performance, taking into consideration (but not only) the range of values acceptable for each phase of flight and fuel flow. The descriptor considers latent or active engine failure, including foreign object damage (FOD) and hardware degradation and failure (LOC-23 & 26).” EASA EOFDM (2020)

[118] Legend of Table 7.6: 1 – Specific training & checking; 2 – Aircraft installed extinguishers (recovery); 3 – Aircraft installed protective features; 4 – Instrument guidance; 5 – Pilot Monitoring; 6 – Safety awareness; 7 – Safety campaigns (Line Operations Safety Audit – LOSA); 8 – Preventive maintenance.

Threats	Descriptors	Events 2018	Initial Outcome	Mitigation/ Recover	Final Outcome
1	LOC-01 – Fire, Smoke and Fumes	6	Accident	5	Incident
2	LOC-09 – Abnormal Operations	5	Incident	6	Incident
3	LOC-14 – Inadequate Aircraft Attitude	2	Accident	5	Incident
4	LOC-19 – Windshear	24	Accident	5	Incident
5	LOC-23 & 26 – Loss of Thrust & Engine Failure	18	Incident	5	Incident

Table 7.7 – Loss of Control In-Flight: Dataset from 2018, occurrences per 10,000 flights

The data for the number of occurrences was retrieved from two sources: reporting and flight-data monitoring. EASA’s Guidance on how to implement their FDM programme identifies 32 descriptors that have the potential to contribute to LOC-I (EOFDM 2020). However, while operators cannot implement the whole range of indicators, on the other hand, the organization that provided the data considers these six indicators as the more relevant and accurate for the scenario being evaluated. Note that event number 5 incorporates two descriptors: Loss of thrust and engine failure.

Figure 7.34, below, illustrates the current risk exposure at this stage of the analysis, where the first three assignments identified in the beginning of the current section were accomplished. As part of the implementation phase, it is relevant to understand how the risk-exposure cloud was developed.

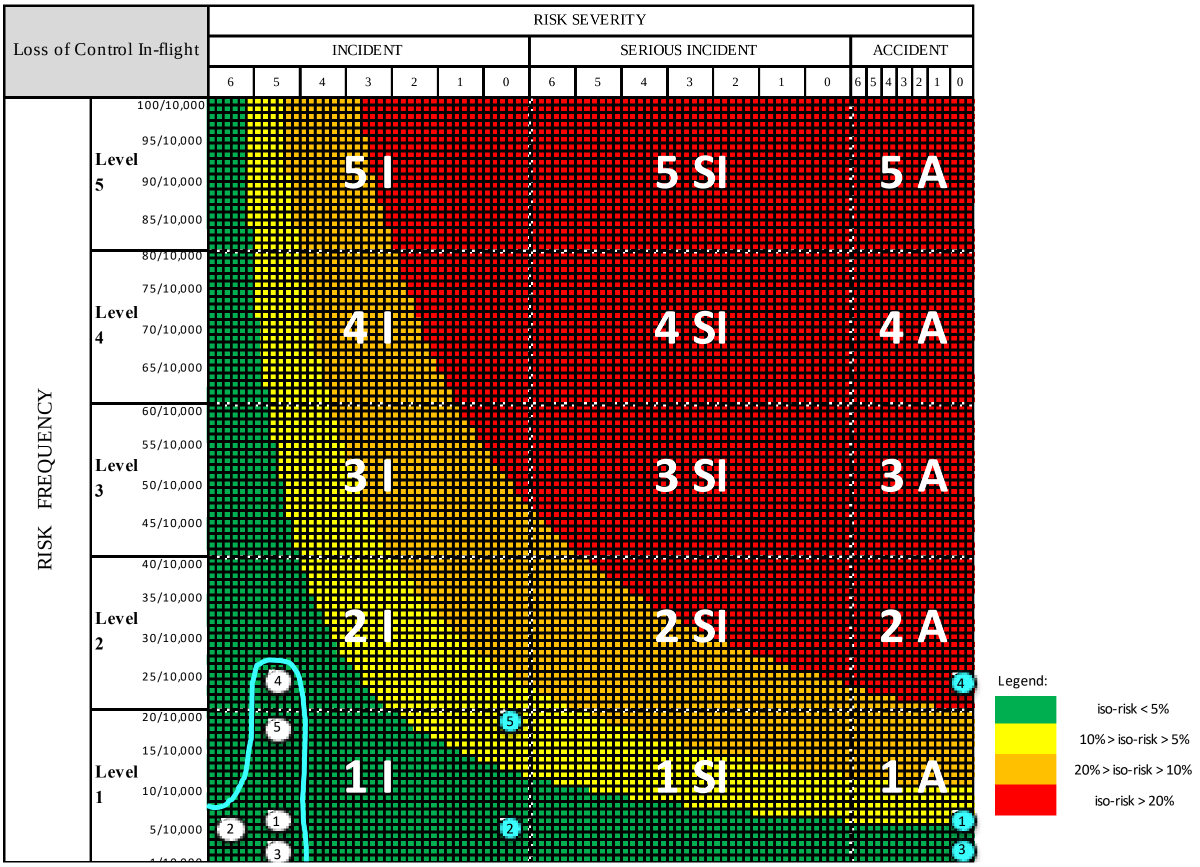

Figure 7.34 – LOC-I and the organization’s risk-exposure level

From the data in Table 7.7, it is possible to conclude that the risk-exposure map would require the accommodation of six mitigation and recovery measures in each division of the severity scale: Incident, Serious Incident, and Accident. Nevertheless, in opposition to what has been used in section 6.3 to explain the development of the “risk-exposure” map, maintaining a perfect division among the three areas is not necessary. This is because although the LOC-I hazard incorporates a potential catastrophic outcome, the probability of it promoting an accident is highly improbable, which is a good enough reason to reduce the accident scale width as no resolution capability is needed. The same cannot be applied to other hazards where accidents are far more frequent, however, namely ground collisions from GSE where the integrity of the structure of the aircraft is likely to be compromised or in the healthcare industry where treatment outcome frequently induces accidents involving patients.

After building the severity scale, using the information obtained from Table 7.7, analysts (or dedicated software) would plot every threat in the “risk-exposure” map, as section 6.4 explained. The plotting considers the forecasted “initial outcome” without any protective measures in place, and the observed (or forecasted) frequency. In this first step, every single threat is identified with a light-blue circle, as depicted in Figure 7.34 above. As an example, for threat number 1 – Fire, Smoke and Fumes, as a consequence of the risk analysis, the threat was classified as having the potential to generate an “accident” and as having an occurrence (or forecasted) rate of six events per 10,000 flights in the period under consideration of one year. Thus, the light-blue circle number 1 is plotted under the “accident” column accounting for zero protective measures, aligned with the frequency of six occurrences. In the second step, using a white circle to differentiate in order to build the exposure cloud, the same exercise as for threat number 1 was carried out. However, this time the five identified protective measures were considered. This exercise used the same observed or forecasted frequency, but the threat was plotted under the “incident” section due to the implemented defences (Table 7.7 – Final outcome column). After doing the same exercise for the whole set of threats, a light-blue line was drawn encapsulating the entire collection of threats, identifying the risk-exposure cloud, as detailed in Figure 7.35 below.

The previous two steps were detailed uniquely for explanatory purposes and to reinforce the example offered in section 6.4. An analyst or dedicated software would omit the first step and directly plot the white circles to draw the risk-exposure cloud. As illustrated in Figure 7.35, a black iso-risk line is presented after plotting the threats, representing the aggregate threat information. The yellow “T” circle symbolizes the exact position of the “total aggregate risk exposure”. The movement of the “T” circle will identify the hazard’s evolution tendency. Appendix L presents the method by which the indicator is calculated.

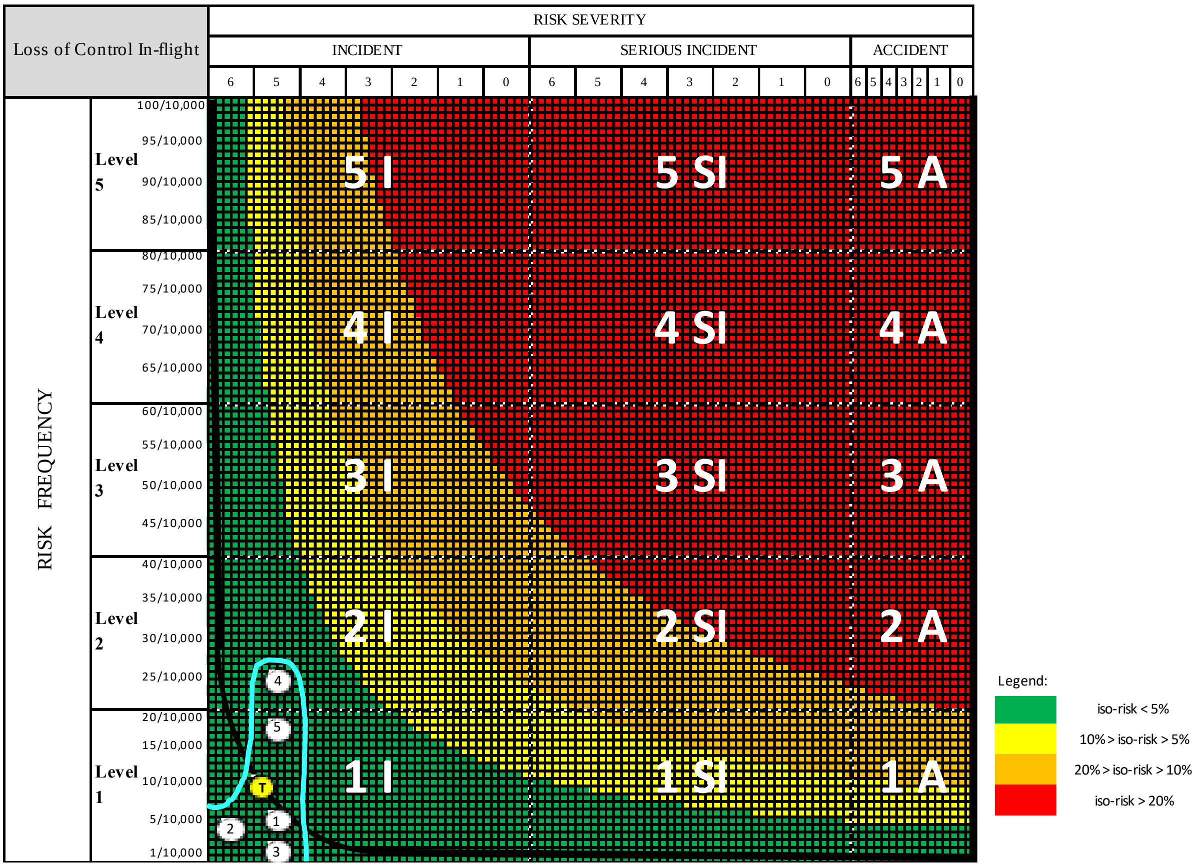

Figure 7.35 – LOC-I “risk-exposure” map

To conclude the risk-exposure map, the next step relates to the impact generated by the safety culture of the organization. As mentioned at section 6.6, no research has surfaced to show the relationship between safety culture/safety climate and the risk exposure affecting the organization. The best link attained was concerned with identifying weakness and strengths within safety culture. For this reason, in the example used in section 6.6, the decision was made to expand the risk-exposure cloud equivalent to a failure of a protective measure. Nevertheless, other methodologies may be used to help better understand the impact safety culture has on workforce performance.

The organization that kindly made available the data for the LOC-I hazard has not assessed the safety culture or safety climate of its workforce for the last 10 years. However, the organization measures the workforce safety culture through indirect indicators. When evaluating safety culture, although not considering it in a formal or structured manner during the risk-management process, the organization has developed indicators to measure the number of expected reports, the *ratio* between mandatory reports and the reports actually submitted, and indicators related to operational deviations. For pilot and cabin crew members, the organization considers that safety culture produces a positive working environment and assumes that it has a positive effect on the performance of the workforce. Therefore, the risk-exposure cloud has the potential to retract inwards. The dotted line in Figure 7.36 reflects the contribution of safety culture on the risk-exposure map. In this specific case, it was considered as one half of a protective and recovery measure.

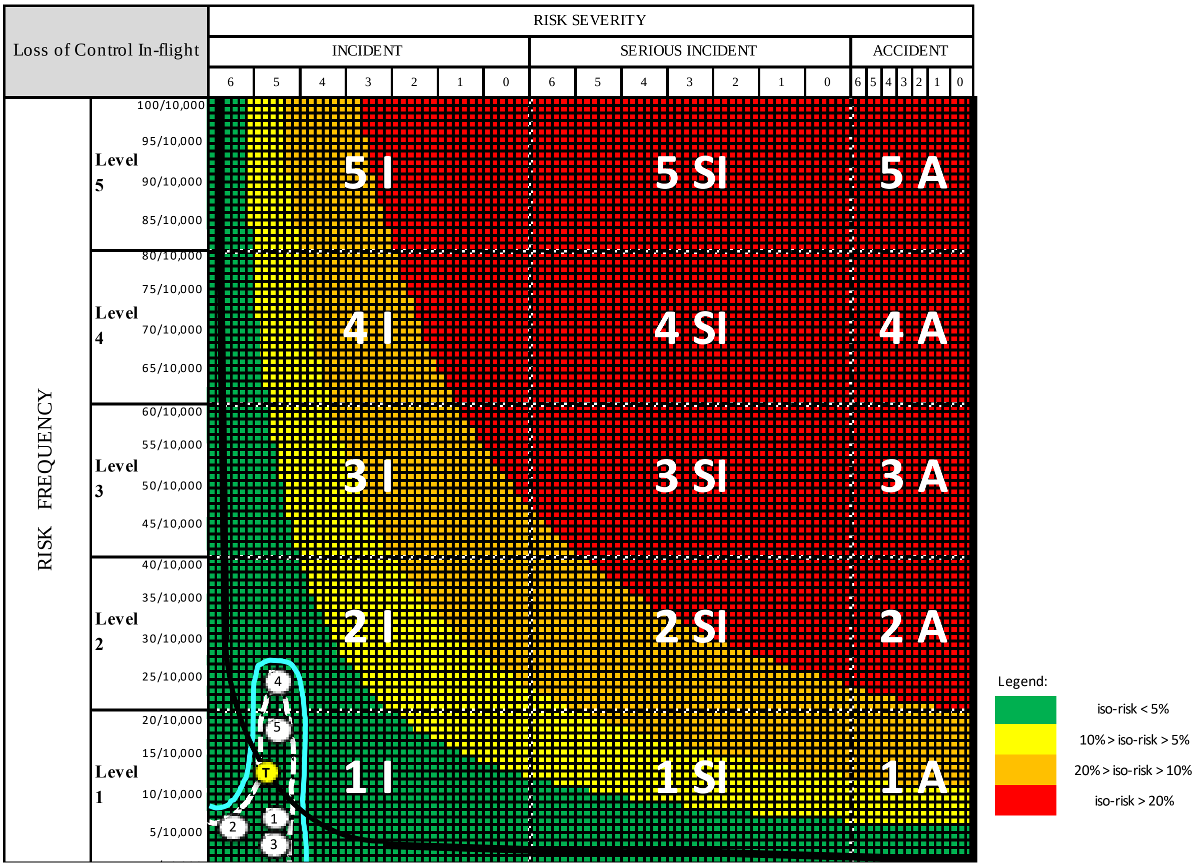

Figure 7.36 – LOC-I (complete) organizational risk-exposure map

With the complete risk-exposure map concluded, analysts would then proceed to the last stage of the risk assessment: the risk evaluation. The purpose of this stage is to support the decision-making process by way of a comparison between the obtained results and the initially established safety boundary. Several decisions may surface as a result:

- Do nothing and maintain the existing mitigation measures – that is, accept the current scenario.
- Consider further analysis to understand the risk-exposure the organization is facing.
- Consider other mitigation options (Risk Treatment – Stage 5).
- Reconsider the safety boundaries (stage 1).

As section 6.4 explained, to support the above decisions, several types of information could be extracted from the exposure map whether using aggregate or individual risk data, specifically:

- Exposure cloud: the exposure the organization faces is well within the devised risk appetite.
- Risk criticality: the exposure cloud occupies the two lowest levels of the incident event.
- Aggregate threat information: The LOC-I accounts for an aggregate risk exposure of approximately 1%,[119] which is represented by the yellow “T”[120] circle. The “T” is superimposed in the black iso-risk line, corresponding to the average of 11/10,000 events. Nevertheless, the aggregate risk level is the same along the entire black line.
- Specific threat information: the whole set of safety risks are located within the acceptable green iso-risk band.

The risk analysis shows that the established risk appetite defined upstream might be too permissive, or seen through an alternative lens, that it allows a significant increase in risk exposure without being noticed, which is due to the fact that the risk cloud is well within the acceptable green-risk band. On the other hand, data analysis may allow for the perception of the current safety margins, thereby consenting to the failure of a significant number of mitigation and recovery measures without being noticed, in which case the risk cloud will remain within the green (acceptable) band. Therefore, in the current example, a possible option would be to redefine the risk-exposure level for the LOC-I hazard, reducing the green band to a lower exposure level, instead of the initially selected one of $5*10^{-4}$. The example illustrates how interactive the process is, as phases interrelate with each other.

The decision whether to redefine the safety boundary will be supported according to the values and objectives of the organization, as identified in the previous section, and according to the sensitivity of the hazards, and thus point to how closely the hazards should be monitored. The defined level of acceptable risk, that is, the safety boundary, will be quite relevant for stage 7, where resources will be allocated on a comparison basis, as detailed

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[119] As Chapter 6 highlighted, using the analogy provided by Rasmussen’s “risk-management framework”, the higher the percentage the lower the “buffer zone”, that is, the distance between the unsafe performance boundary and the aggregate risk index.

[120] The “T” stands for the “Total” amount of risk.

under section 7.7. Figures 7.37 and 7.38 illustrate two possible definitions of the safety boundaries, whereby the risk-exposure map reflects a more stringent risk appetite.

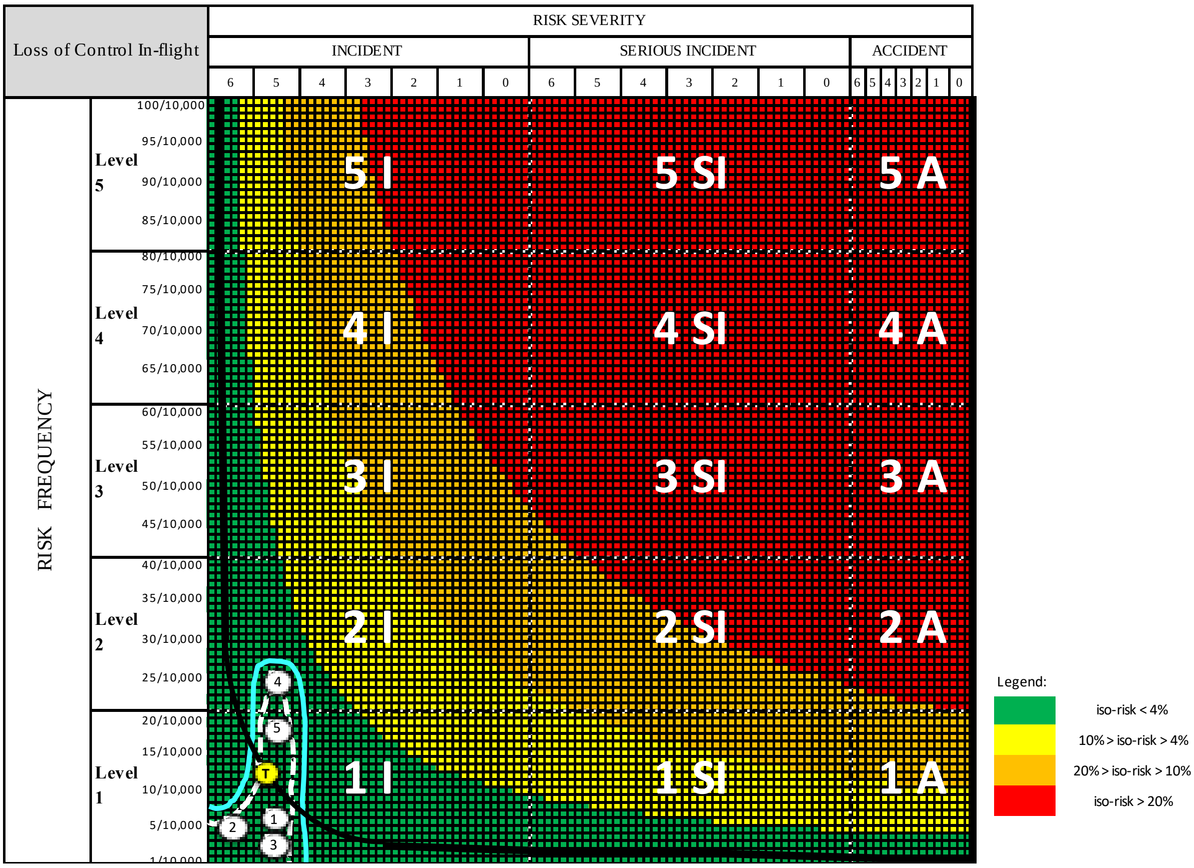

Figure 7.37 – LOC-I “risk-exposure” map – 4% green band

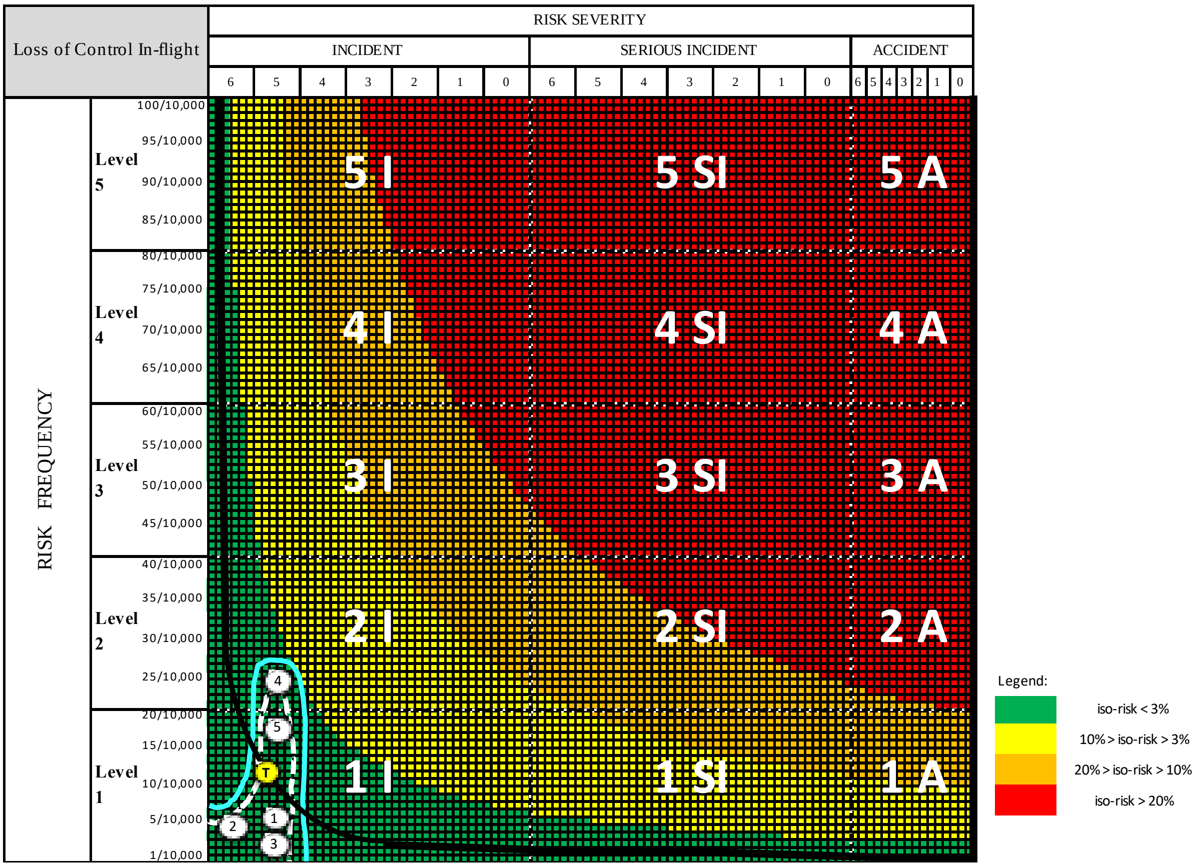

Figure 7.38 – LOC-I “risk-exposure” map – 3% green band

7.5 Risk Treatment (Stage 5)

The risk-treatment phase of the “Oyster Model” does not introduce changes or adjustments to the BSI (2018b) process. In this phase, the organization decides whether to tolerate, transfer, or further treat the risk by reducing its exposure level. In extreme situations, the option may include the termination of the risk by cancelling the origin (Hopkin, 2012). The risk-treatment phase involves an iterative process of:

- Identifying and selecting additional risk-treatment options.
- Implementing and assessing the effectiveness of the treatment (phase 6 – risk monitoring).
- Evaluating the acceptability of the remaining risk.
- Deciding on further treatment.

The phase ends with uploading the hazard to the risk register and works as the starting point for the next stage of the risk-monitoring, the phase discussed in the following section.

7.6 Risk Monitoring (Stage 6)

The risk-monitoring phase was examined at length at section 6.5, thus this phase will not be re-examined here. The purpose of the monitoring phase is to guarantee the effectiveness of, and improve the risk-management outcome. The process involves monitoring the aggregate and individual indicators contained in the risk-exposure map, specifically: the exposure cloud, risk criticality, and aggregate and specific threat data, as illustrated in Figures 6.26 and 7.36.

The “risk-exposure” map can receive safety data continuously during the monitoring stage, and, therefore, has the ability to carry out the evaluation and monitoring phases in parallel. Receiving data continuously and updating risk exposure in parallel allows safety analysts to perform a continuous risk-evaluation process in line with the organization’s risk appetite. This stance stands in contrast to the static features presented by current risk registers (Ale et al. 2015; EASA 2015). Making use of the two hazards discussed throughout Chapters 6 and 7 – runway excursion and loss of control in-flight –, Appendix G illustrates a potential design for a risk register that supports the new functionalities and characteristics brought by the “Oyster Model”.

The next stage is dedicated to managing the available resources and ensures that safety-risk remains within the defined risk appetite or safety boundaries of the organization.

7.7 Resource Allocation (Stage 7)

The resource-allocation phase is intimately interconnected with the previous phase – risk monitoring. As illustrated in the “Oyster Model”, see Figure 7.31 in section 7.1, the resource allocation is supported by the “Stack” map tool. However, in contrast to the BSI (2018b) risk process, the purpose of the resource-allocation tool is not to associate resources to each hazard. In a dynamic environment such as commercial aviation, the objective of the “Stack” map is to compare the whole set of threats monitored by the organization and to identify the same, using a risk-based approach, any threats that deviate from the organization’s defined objectives. Using an integrated perspective, analysts are able to allocate available resources in a much more informed way, directing resources to wherever they are needed most or, complementarily, to support a decision to invest in new ones.

For explanatory purposes, the available data from 2018, contained in Tables L.19 and 7.7, associated with the runway excursion and LOC-I hazards respectively, are presented below in Table 7.8.

Threats	Descriptors	2018	Initial Classification	Mitigation/ Recover	Forecasted Classification
1	RE-27 – High energy over threshold	35	Accident	9	Incident
2	RE-10 – Rejected take-off	5	Accident	6	Incident
3	RE-02 – Inappropriate aircraft configuration	0	Accident	5	Incident
4	RE-01 – Incorrect performance calculation	8	Accident	5	Accident
5	RE-30 – Abnormal runway contact	18	Accident	6	Serious Incident
6	RE-20 – Lateral deviation	12	Accident	5	Accident
7	RE-29 – Deep landing	22	Accident	10	Incident
1	LOC-01 – Fire, Smoke and Fumes	6	Accident	5	Incident
2	LOC-09 – Abnormal Operations	5	Incident	6	Incident
3	LOC-14 – Inadequate Aircraft Attitude	2	Accident	5	Incident
4	LOC-19 – Windshear	24	Accident	5	Incident
5	LOC-23 & 26 – Loss of Thrust & Engine Failure	18	Incident	5	Incident

Table 7.8 – Runway excursion and LOC-I: Dataset from 2018, occurrences per 10,000 flights

Opposed to the explanation offered in section 6.5.2, the demonstrative exercise incorporates data from two hazards with different risk-exposure maps, that is, with dissimilar risk appetite or safety boundaries. As the current thesis has upheld by way of explanation throughout, within the risk-management process it is quite normal to have risk boundaries customized for each hazard, depending on its nature and to what extent the organization is prepared to face the challenges presented by hazards and threats. Table 7.9, below, summarizes the risk boundaries shown in Figures 6.26 and 7.36.

Hazard	Risk Boundaries
Runway Excursion	
Green Band	Number of events < $10*10^{-4}$ events
Yellow Band	$10*10^{-4}$ events < Number of events < $25*10^{-4}$ events
Orange Band	$25*10^{-4}$ events < Number of events < $50*10^{-4}$ events
Red Band	Number of events > $50*10^{-4}$ events
Loss of Control In-Flight	
Green Band	Number of events < $5*10^{-4}$ events
Yellow Band	$5*10^{-4}$ events < Number of events < $10*10^{-4}$ events
Orange Band	$10*10^{-4}$ events < Number of events < $20*10^{-4}$ events
Red Band	Number of events > $20*10^{-4}$ events

Table 7.9 – Runway excursion and LOC-I risk boundaries

Before presenting the “Stack” map with the two sets of threats, it is deemed relevant to understand the rationale behind the comparison method used in the “Stack”-map risk tool. A rise in the frequency of the number of events and/or the inadequacy of the risk mitigation/recovery measures, or even a combination of both, implies an increase in the risk-exposure level. Using a magnified view of Figure 7.36, and threat number 4 as an example, it is perceptible that an upward movement in the vertical axis or a reduction in the number of available mitigation/recovery measures, that is, a right movement, will imply a reduction in the distance from the edge of the band, and consequently, an increase in the risk-exposure level. Figure 7.39, below, illustrates both movements.

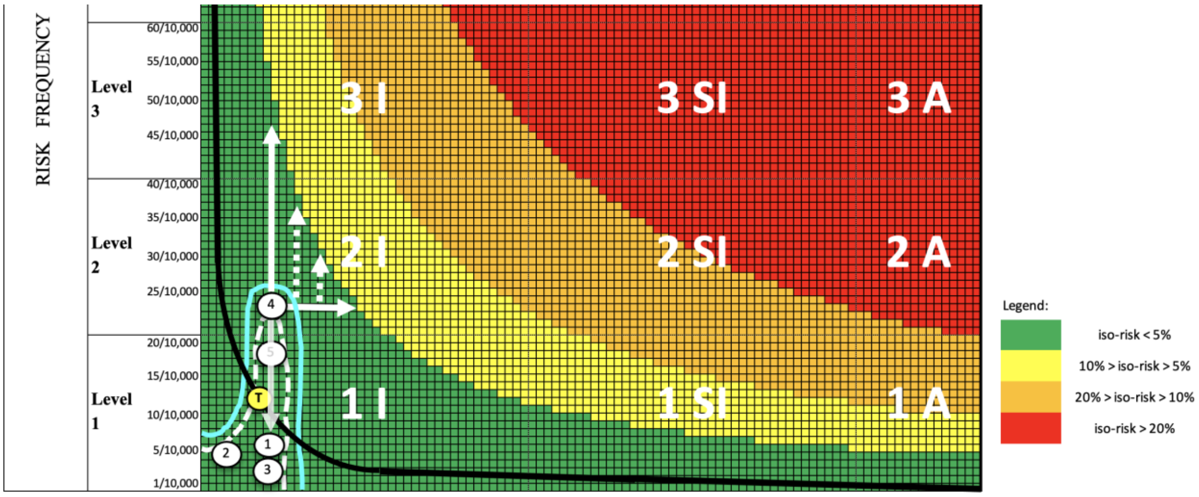

Figure 7.39 – Runway excursion and LOC-I risk boundaries

In the example used with threat number 4, it is perceptible that the circle representing the threat is plotted in the mid-distance of the vertical height within the green band. The band has a height of 50 events (or units), and the threat is placed in the 24th position.

A direct comparison among threats that concur for the same hazard is a relatively simple exercise. Using Figure 7.36’s data, threat 4 implies a higher exposure level than threat number 5, and threat number 5 denotes a higher exposure than the other three threats. For different hazards and, consequently, different risk-exposure maps, the comparison will analyse the vertical distance of each threat to the edge of the band where the threat is located. Therefore, it is possible to compare the relative position of each threat within the band independently of the chosen safety boundaries or risk appetite. Figure 7.40 presents the “Stack” map for both hazards: Runway excursion and LOC-I, plotted in white and light-blue, respectively.

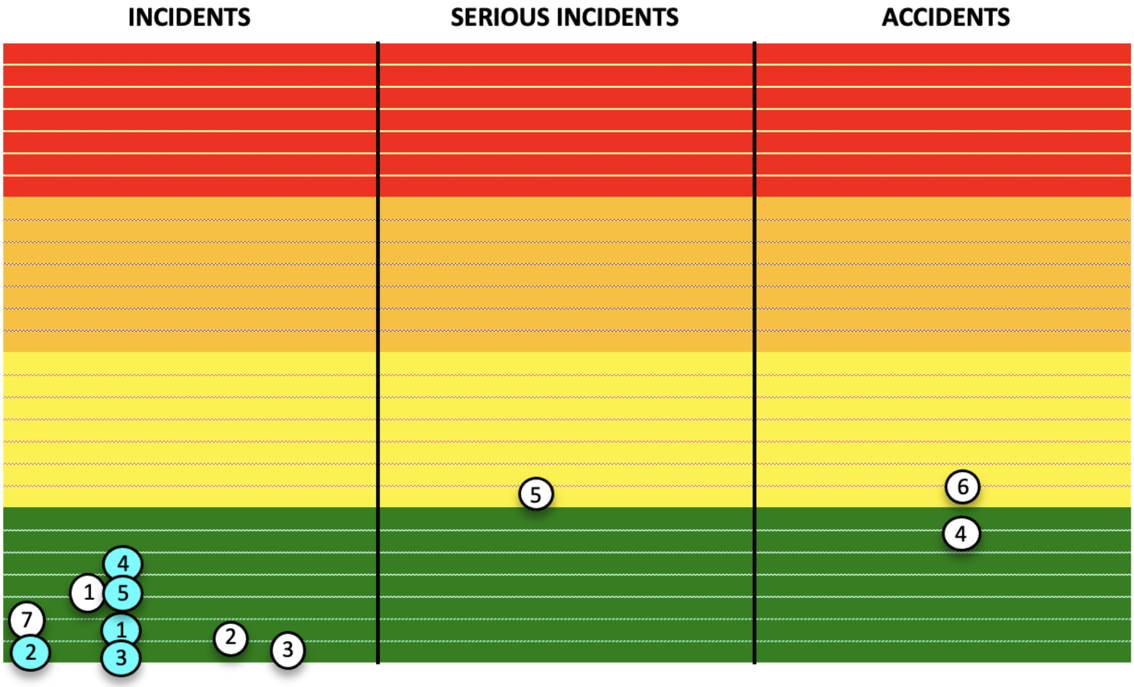

Figure 7.40 – Runway excursion and LOC-I “Stack” map

As explained at Section 6.5.2, the lateral position of the “Stack” map identifies the three severity categories, which also constitute a second indicator to prioritize safety risks and contribute to a more informed and systematic decision-making process.

The “Stack”-map display data from 2018. Despite being plotted in the same risk band (green) threat number 1, associated with the runway excursion hazard (white circle), which stands for ‘high energy over threshold’, implies a lower risk exposure than threat number 4 from LOC-I (windshear – blue circle). However, the former has a higher frequency than the latter. Table 7.9, below, presents the calculations that were developed to plot the whole set of threats.

Threats	Descriptors	Events 2018 (A)	Band height (B)	Band	Exposure Index = (A) / (B)
1	RE-27 – High energy over threshold	35	100	G	0,35
2	RE-10 – Rejected take-off	5	61	G	0,08
3	RE-02 – Inappropriate aircraft configuration	0	49	G	0
4	RE-01 – Incorrect performance calculation	8	9	G	0,89
5	RE-30 – Abnormal runway contact	18	25	Y	0,08
6	RE-20 – Lateral deviation	12	15	Y	0,2
7	RE-29 – Deep landing	22	100	G	0,22
1	LOC-01 – Fire, Smoke and Fumes	6	55	G	0,11
2	LOC-09 – Abnormal Operations	5	100	G	0,05
3	LOC-14 – Inadequate Aircraft Attitude	2	55	G	0,04
4	LOC-19 – Windshear	24	55	G	0,44
5	LOC-23 & 26 – Loss of Thrust & Engine Failure	18	55	G	0,33

Table 7.10 – “Stack”-map calculations

The safety protection concept brought by the current thesis ought to be understood as a management tool that is used to either allocate or relocate available resources, decide on new investments, and pinpoint where they are most needed. The perspective presented by the “Stack” map offers analysts the chance to identify which threats are the more significant and concerning, and thereby to manage safety investments from a more informed position [F3.1].

Both risk tools – the “risk-exposure” map and the “stack” map – work as a cumulative source of risk information, as both are capable of continuously receiving real-time data. Thus, the picture conveyed by both risk tools is expected to capacitate the development of a proactive perception.

7.8 Supporting Software

The “Oyster Model” does not require dedicated software. To support this claim, throughout chapters 6 and 7 manual-generated risk tools were presented. Nevertheless, integrating the model into a software suite with the capacity to develop a “risk-exposure” map, and to update the data as the risk-management activity is processed, would significantly improve the implementation and the daily operation of the “Oyster Model”. With the support of technology, it would be possible to use integrative functions to produce reports and manage data. Such processes would free risk analysts from repetitive administrative work, allowing them, therefore, to focus more on their expertise. Supportive software could streamline numerous activities: managing, classifying and displaying the protective measures in the “risk-exposure” map,[121] building the “Stack” map automatically, updating the information contained in the “risk-exposure” map and generating alerts, are some of the automated features that could streamline management of the model. The intention is to incorporate a facility in the existing software suite of the organization that currently supports its risk (and quality) management.

Although not integrated within a software suite, an illustrative package is available on the following site: https://oystermodel.com/[122], in order to present a perspective of the “Oyster Model’s” features relevant to the current thesis. Figures 7.41 and 7.42, below, present an example of a computer-generated “risk-exposure” map and “Stack” map, respectively.

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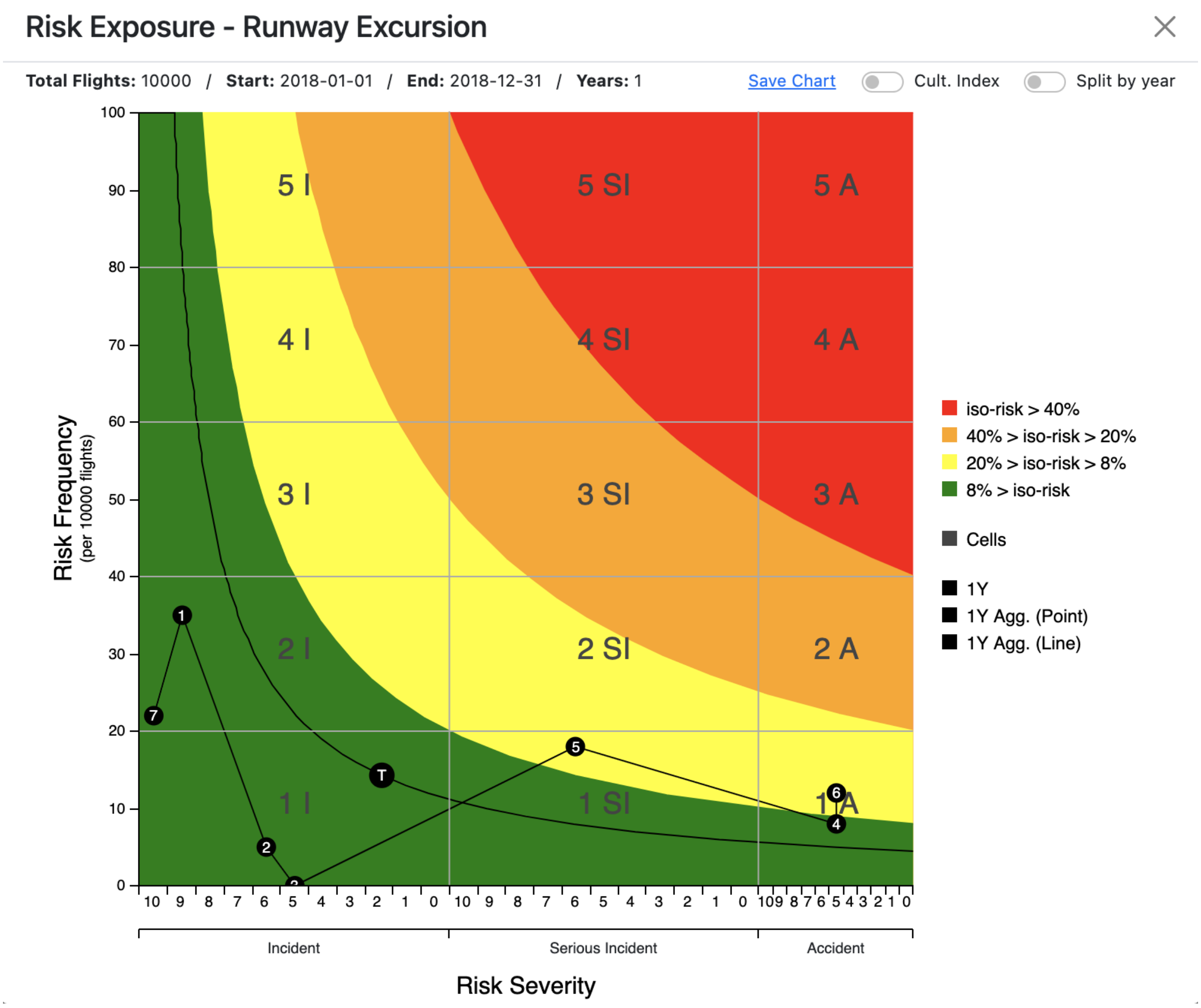
[121] For example, when a threat is selected, the software could automatically display the associated protective measures, which is a scenario that it is not possible to enact manually.

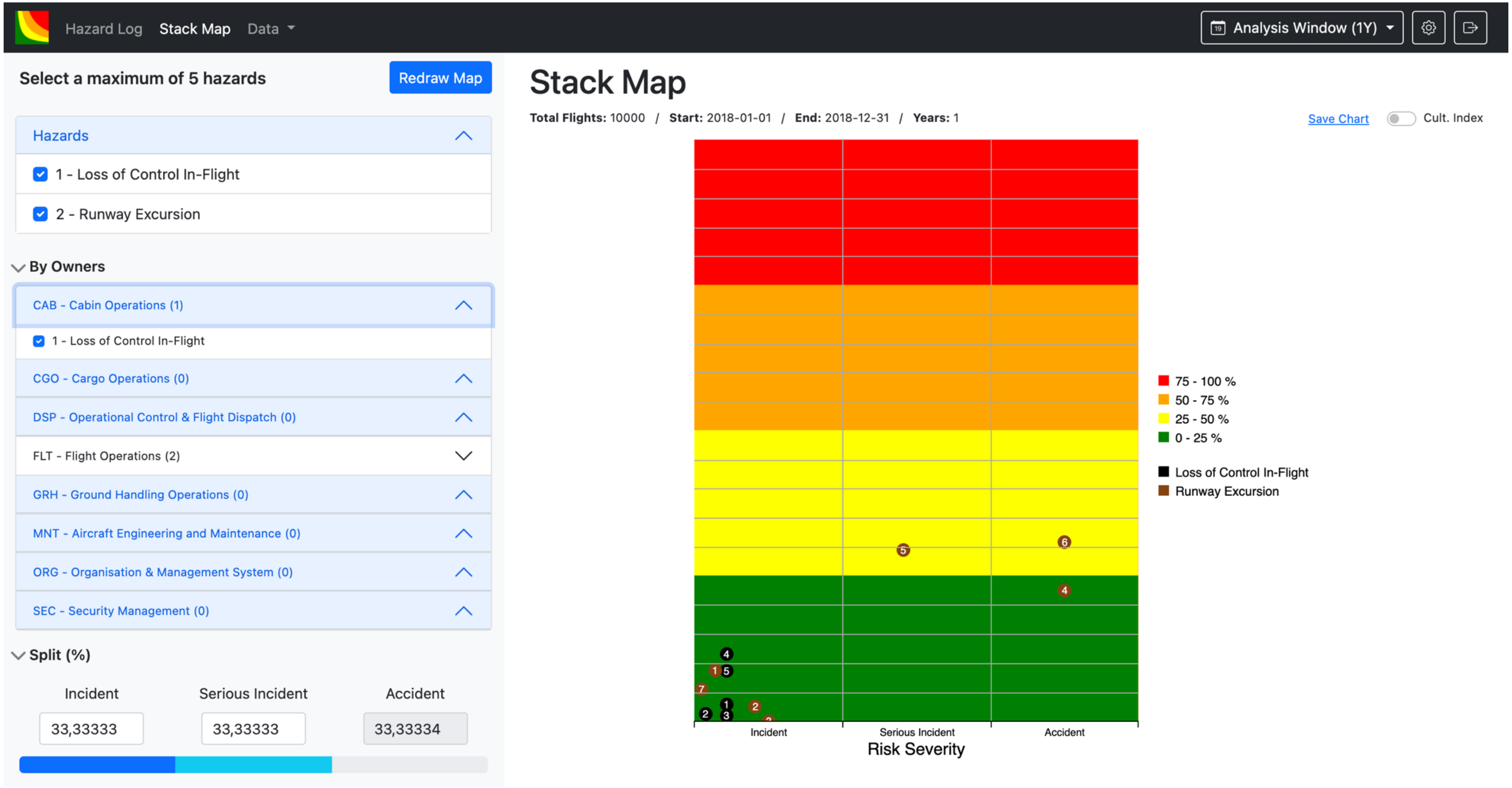
[122] To login use “public” as username and password.



Risk Exposure - Runway Excursion

Total Flights: 10000 / **Start:** 2018-01-01 / **End:** 2018-12-31 / **Years:** 1

Figure 7.41 – Example of computer-generated “risk-exposure” map



Select a maximum of 5 hazards

Hazards

☑ 1 - Loss of Control In-Flight

☑ 2 - Runway Excursion

By Owners

- CAB - Cabin Operations (1)
  - ☑ 1 - Loss of Control In-Flight
- CGO - Cargo Operations (0)
- DSP - Operational Control & Flight Dispatch (0)
- FLT - Flight Operations (2)
- GRH - Ground Handling Operations (0)
- MNT - Aircraft Engineering and Maintenance (0)
- ORG - Organisation & Management System (0)
- SEC - Security Management (0)

Split (%)

Incident	Serious Incident	Accident
33,33333	33,33333	33,33334

Stack Map

Total Flights: 10000 / **Start:** 2018-01-01 / **End:** 2018-12-31 / **Years:** 1

Figure 7.42 – Example of computer-generated “Stack” map

8 Contribution of the Thesis to the Business World and for the Body of Knowledge

The decision to research the area of risk management in the commercial airline industry was based on the researcher's empirical knowledge of the industry. The researcher suspected that the framework proposed by ICAO (2018b) was addressing the needs of operational staff in a degraded fashion. Accurately as it turned out, the researcher had assumed that the way the safety policy was developed, and the performance of the risk tool used for the risk assessment, presented deficiencies that had a direct impact on the outcome. As a result of the research performed in Documents 2 and 3 (Encarnação 2015b, 2016) to develop the SQs and the RQs, evidence surfaced that in both academia and in the industry the issue of safety was underdeveloped at the organizational level. Throughout, it was found that the published research papers and business literature was restricted to specific topics, identifying particular drawbacks, and that it failed to address the subject using a holistic approach. This view, reflected in the conceptual framework, paved the way for this fascinating research on the theme of risk-management.

The current thesis contributes to both the business world and the body of knowledge in the field of risk-management by providing a different approach to addressing safety risks. The focus of the research is on commercial aviation, an industry that has reached an ultra-safe[123] level (Amalberti 2001). With the continuous reduction in the number of accidents, the raw data for further improvement has reached a shallow threshold, jeopardizing innovative enhancements due to the lack of information. The current research positions itself at the organizational level, and develops a model that focuses on aspects of risk-management that currently lack clarity, debate, and dissemination of information. Therefore, the expectation after publication of the current thesis is that it would open new research avenues, for both academics and in the aeronautical community, in this under-explored area.

Regulators, manufacturers, trade associations and other stakeholders produce commercial aviation safety statistics to provide information about the rate and seriousness of the hazards faced by the industry. This information then becomes the beacon to orient the content of what legislative bills, actions, and recommendations ought to address. At the organizational level,

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[123] Systems that reached a safe level of less than one accident per 10 million operations.

the information is also highly relevant, providing guidance on where airlines should direct their attention. However, apart from this, it also highlights the reduction in added value organizations experience by not having a risk model which allows them to identify their risk exposure to the aforementioned hazards, as Chapter 1 underlines. Moreover, according to the characteristics of their activity, organizations must have the ability to identify proactively other hazards that may endanger the safety of their operations, and, ultimately, this will contribute to industry statistics.

As Vigar (2011) pointed out, continuous safety improvement and a high level of safety is only possible if organizations favour transparency and scrutiny and hold a healthy scepticism about the risk level of their operations. To maintain constant improvement in safety, openness and enquiry has to impregnate internally, and filter both up to the level of the executive board and down to operational staff from the highest level. However, having a commitment to safety alone is still not sufficient. The intention of the “Oyster Model” and the associated risk tools proposed in this thesis, is to allow the organization to carry out similar analyses at any level. This is not only based on accidents and fatalities, such as those the stakeholders mentioned earlier (EASA 2018a; Airbus 2018; Boeing 2018), but encompasses the entire set of precursors that are evaluated in a “risk-exposure” map.

The design of the “Oyster Model” is a safety-risk model that proposes to be “generic and transversal” to the entire commercial aviation industry, as well as to similar high-risk industries such as healthcare, allowing the specificities of each organization or industry to be accounted for. The “Oyster Model” brings an innovative approach to an overlooked issue, when it defines the safety boundaries for each type of hazard, transforming raw statistical data into meaningful and easily understandable figures for executive boards. In Jeremiah-AS’s words, it provided data *“translated into the language common to that level of management […].*”

Within an ultra-safe environment, organizations notoriously have difficulties in perceiving their risk exposure. This is compounded by the fact that success in safety tends to turn management’s awareness away from safety concerns (Reason 1997, 2016; Rasmussen 1997). Therefore, it is of the utmost importance to reconnect executive boards with their obligation to incorporate the subject of safety into their daily management practice. The need to customize the “risk-exposure” map and integrate it, and to validate continuously the defensive measures implemented in the field, brings an advance in the practice of the discipline of risk-management.

However, in ontological terms, it is important to mention that the model will be incapable of demonstrating the reality in a precise fashion. Nisula (2018, p. 163) acknowledged this limitation when he affirmed that: "*any model used for risk assessment would be highly simplistic compared to the extreme complexity of the real world*." The intention of the "Oyster Model" is to lend structure to risk-management and adjust it to the organization's needs, when it aggregates into a single "risk-exposure" map the contribution the threats made to an undesirable outcome. In doing so, it delivers an innovative perspective and leverages the current information to act as a guidance tool, grabbing the attention of stakeholders to focus on existing hazards as well as new ones.

The tool that supports the risk model has its inception in the tools already in use by the industry. It has the advantage that it can overcome the main drawbacks identified – subjectivity, consistency, integrity and has the ability to prioritize threats – and reflect the organization's risk appetite, as well as incorporate the level of protection the organization has already implemented in the field.

The picture conveyed by the "risk-exposure" map is another innovative feature brought by the "Oyster Model" in the way that it attracts operational staff's attention to the current risk exposure and promotes a proactive perspective brought by the continuous evolution of the risk exposure, which has the potential to capture insidious drifting (Dekker 2011). The clarity brought by the "risk-exposure" map and the "Stack" map enables identification and comparison between threats to pinpoint where investment is most needed. In Nicholas-AL's view, this type of information: *"would get the attention [of the executive board], which is what they are trained for, to understand aggregate data"*, thus linking management and operational staff in a mutual commitment to protect the organization.

The "Oyster Model" incorporates the lessons brought by the NAT, accepting that organizations are far from perfect, acknowledging that systems coexist within the boundary of an accident, and that there is a thin barrier between normal operations and catastrophic outcomes. However, the belief is that the continuous enhancement of safety boundaries, a healthy scepticism of protective measures, and the continual improvement endorsed by the safety-protection feature will enable constant improvement. These features incorporated into the "Oyster Model" will make the safety system more robust and postpone undesirable outcomes to a distant date.

The “Oyster Model’s” ability to transform purely qualitative data into a risk-based quantifiable reality is something several interviewees felt the industry needed to prioritize. Supported by a semi-quantitative approach, the model allows a comparison between threats to be established, setting an order of prioritization, and, at the same time, reducing the variability in risk-management. Finally, having the “risk-exposure” map as the outcome, the model offers a unique opportunity for stakeholders to correlate their safety culture with their organization’s risk exposure. The current proposal at this stage is certainly an “in progress” solution, restricted to an erosion or robustness figure equivalent to a number of protective measures. Other solutions are feasible, such as associating the size of the risk cloud with culture surveys, drawing potential scenarios, or even deriving formulae.

The intention of the “Oyster Model” is to provide a new vision for managing risk-management activities at the organizational level, to re-establish the pace of risk reduction commercial aviation had in previous decades, and to open up new avenues for future research.

8.1 Final Comments on Future Perspectives

Due to the non-uniform implementation of SMS, the current research has not addressed the “safety benchmarking” gap, which relates to the regulators’ monitoring responsibilities to assess the risk-exposure status of each airline. The philosophical stance and the features that support the “Oyster Model” will allow regulators to supervise and gain a clearer picture of the organization’s safety status. Specifically, authorities will be able to make informed assessments of the current exposure of each stakeholder, in particular in relation to the hazards that are common to their region and specific to their country. Regulators will be able to monitor different definitions of risk boundaries, assess the current exposure, decide on the type, and come to a decision about how to monitor the implemented measures in the field, for each individual or aggregated threat. Ultimately, the “Oyster Model” will allow regulators to track and validate the organization’s risk exposure in a much more informed way. The expectation is that the aviation industry will welcome the model, not least because it provides opportunities for making improvements in safety and involve the contributions of other stakeholders.

Other issues related to risk-management emerged during the research. Concerns were raised about sharing data among stakeholders, which is particularly relevant when organizations contract third-party service providers to fulfil assignments on its behalf. Since organizations do not have a uniform means of undertaking an evaluation of this risk, there is acknowledgement of the potential for this to create a breach in the organization’s safety system. Thus, within the premise of the “Oyster Model”, efforts were made to streamline and securitize the exchange of information.

Beyond the concerns elicited from data sharing, the research also identified a lack of safety knowledge at the executive level that has the potential to hinder managers’ capacity to administer the SMS of the airline effectively. The training deficiency has the potential to be compounded by the design of the organizational structure, since it has the potential to harbour vested interests that, ultimately, might impede information reaching the executive management. These emergent subjects were addressed in the hope that they might stimulate other scholars and practitioners to undertake further research in the future, as these have the potential to widen the gap between management and operational staff.

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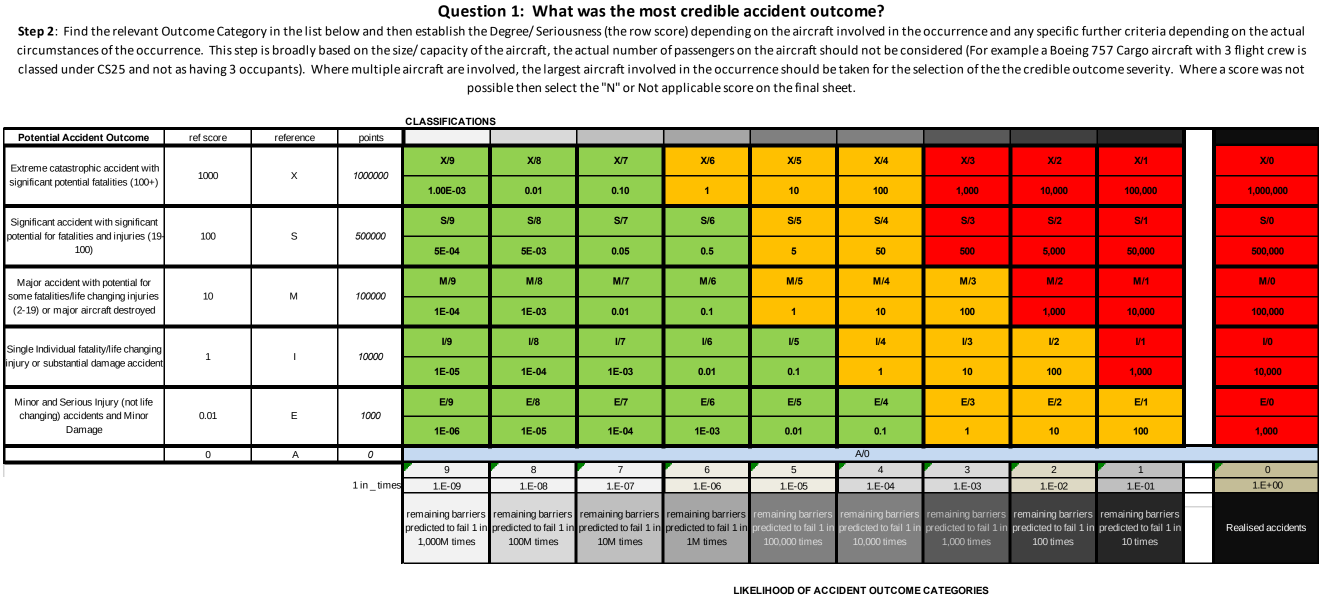
10 Appendixes

A European Risk Classification Scheme (ERCS)

The ERCS is based on the ARMS methodology and suffers from similar deficiencies, where the consistency at appraising of potential outcome as well as the reliability of each safety barrier, is a challenging task to determine. The method was presented by the head of Safety Analysis and Performance of EASA in the 7th Workshop of the Internal Occurrence Reporting System (IORS) (Fanklin 2017).



Question 1: What was the most credible accident outcome?

Step 2: Find the relevant Outcome Category in the list below and then establish the Degree/ Seriousness (the row score) depending on the aircraft involved in the occurrence and any specific further criteria depending on the actual circumstances of the occurrence. This step is broadly based on the size/ capacity of the aircraft, the actual number of passengers on the aircraft should not be considered (For example a Boeing 757 Cargo aircraft with 3 flight crew is classed under CS25 and not as having 3 occupants). Where multiple aircraft are involved, the largest aircraft involved in the occurrence should be taken for the selection of the the credible outcome severity. Where a score was not possible then select the "N" or Not applicable score on the final sheet.

CLASSIFICATIONS

Potential Accident Outcome	ref score	reference	points											
Extreme catastrophic accident with significant potential fatalities (100+)	1000	X	*1000000*	X/9 1.00E-03	X/8 0.01	X/7 0.10	X/6 1	X/5 10	X/4 100	X/3 1,000	X/2 10,000	X/1 100,000		X/0 1,000,000
Significant accident with significant potential for fatalities and injuries (19-100)	100	S	*500000*	S/9 5E-04	S/8 5E-03	S/7 0.05	S/6 0.5	S/5 5	S/4 50	S/3 500	S/2 5,000	S/1 50,000		S/0 500,000
Major accident with potential for some fatalities/life changing injuries (2-19) or major aircraft destroyed	10	M	*100000*	M/9 1E-04	M/8 1E-03	M/7 0.01	M/6 0.1	M/5 1	M/4 10	M/3 100	M/2 1,000	M/1 10,000		M/0 100,000
Single Individual fatality/life changing injury or substantial damage accident	1	I	*10000*	I/9 1E-05	I/8 1E-04	I/7 1E-03	I/6 0.01	I/5 0.1	I/4 1	I/3 10	I/2 100	I/1 1,000		I/0 10,000
Minor and Serious Injury (not life changing) accidents and Minor Damage	0.01	E	*1000*	E/9 1E-06	E/8 1E-05	E/7 1E-04	E/6 1E-03	E/5 0.01	E/4 0.1	E/3 1	E/2 10	E/1 100		E/0 1,000
	0	A	*0*	A/0										
				9	8	7	6	5	4	3	2	1		0
			1 in _ times	1.E-09	1.E-08	1.E-07	1.E-06	1.E-05	1.E-04	1.E-03	1.E-02	1.E-01		1.E+00
				remaining barriers predicted to fail 1 in 1,000M times	remaining barriers predicted to fail 1 in 100M times	remaining barriers predicted to fail 1 in 10M times	remaining barriers predicted to fail 1 in 1M times	remaining barriers predicted to fail 1 in 100,000 times	remaining barriers predicted to fail 1 in 10,000 times	remaining barriers predicted to fail 1 in 1,000 times	remaining barriers predicted to fail 1 in 100 times	remaining barriers predicted to fail 1 in 10 times		Realised accidents

LIKELIHOOD OF ACCIDENT OUTCOME CATEGORIES

Figure A.43 – European Risk Classification Scheme (ERCS) Matrix (Franklin 2017)

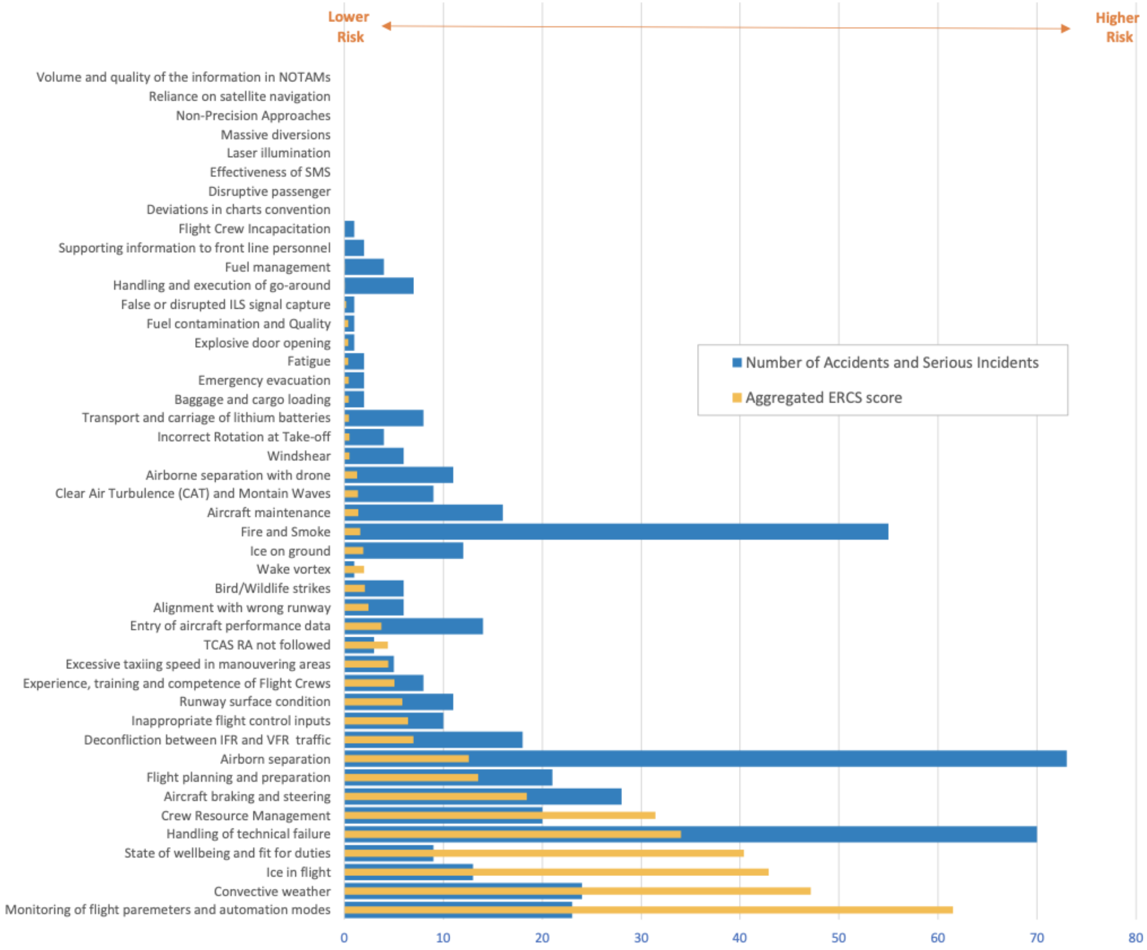


Figure A.44 – Comparison of number of accidents and serious incidents and aggregated ERCS score per safety event (EASA 2019b)

B Relevant Key Concepts and Definitions

B.1 Safety Hazard

The British Standard Institution's (BSI 2009, p. 6) definition of a hazard is a "source of potential harm"; it observes that a hazard can also be a risk source. The Society of Risk Analysis (SRA 2018, p. 6), a multidisciplinary, scholarly and international society dedicated to risk analysis, has a similar understanding, describing a hazard as "a risk source where the potential consequences relate to harm". Another view comes from the International Civil Aviation Organization (ICAO), a body mandated by the United Nations to develop and improve upon recommended practices and international aeronautical standards. ICAO (2018b, p. vii), is more specific, defining a hazard as "a condition or an object with the potential to cause or contribute to an aircraft incident or accident". One conclusion to draw from the analysis of the different definitions is that there is generally consensus among organizations of what constitutes a hazard. Therefore, for the thesis, the ICAO's definition – "a condition or an object with the potential to cause or contribute to an aircraft incident or accident" – is used.

It is relevant, however, to stress that hazards by themselves do not produce a loss or an undesirable outcome. A blizzard, a monsoon, or a dust storm are examples of hazards arising from the natural world. The hazardous conditions that create the perils and threats are precursors to what may lead to an undesirable outcome. For example, the presence of the hazards from natural phenomena may impair visibility or could develop icy conditions on a runway. However, the effect of the hazard on an airline operating aircraft capable of landing in conditions of poor visibility will not be the same as the effect on a similar organization flying aircraft not so equipped. Therefore, the potential context or scenarios created by the hazard – where potential contributing factors or precursors and causal chains are developed and studied – is what a safety analyst will be assessing. This is why it is essential to appreciate, how and why a hazard or threat affects organizations differently that the risk assessment does not apply to the threat or hazard per se, and that organizations should assess the scenario or the context created by the threat, instead.

Perils and threats are synonyms of the same reality used interchangeably. Further information on hazards can be found in the Safety Management International Collaboration Group document (SMICG 2018), which details the hazards presented by the aviation sector.

B.2 Safety Risk

Risk is a wide-ranging concept that encompasses different types of perceptions, including financial, technological, reputational, health risks, and the like (Hopkin 2012). Risk is a dominant concept for the majority of scientific fields; however, no consensus has been reached on how to interpret and define the concept to achieve an interdisciplinary understanding of the term (Aven & Renn 2009; Šotić & Rajić 2015). Although there is ongoing (endless) debate about how to define risk and the soundness of each definition (Johansen & Rausand 2014), the perspective presented in this section of the thesis has its underpinnings in the approaches put forward by well-respected stakeholders to develop an aeronautical-practitioner standpoint.

The British Standard Institution (BSI 2018b) defines risk as an "effect of uncertainty on objectives". The perspective brought by the standard allows a positive or a negative deviation from the planned outcome, in other words, the "effect". Additionally, the BSI expresses risk in terms of their sources, potential events, consequences, and likelihood. Risk is seen as a single element or a combination of elements (hazards) that have the potential to give rise to the undesirable event. Risk is something triggered by one or a set of occurrences that may lead to several consequences, which can be expressed quantitatively or qualitatively. From this perspective, risk is seen as a measurable variable. Thus, when dealing with the second gap (SQ 2), the perspective brought by the BSI will be quite relevant, as the tool used to assess risk must have a measurable capability.

The deviation concept expressed by the BSI is embodied objectively within other organizations' risk definitions. The Institute of Risk Management (IRM 2018), an independent practitioner and non-profit organization, when defining the concept of risk, goes a step further. In addition to the BSI's definition, the IRM identifies what effects might be produced by a materialization of a risk: "Effect of uncertainty on objectives. The effect may be positive, negative or a deviation from the expected." In the same vein, the Institute of Directors Southern Africa (IoDSA 2016), a professional body for directors, and a non-profit organization promoting corporate governance best practices, conceptualise risk as the:

> "Uncertainty of events; including the likelihood of such events occurring and their effect, both positive and negative, on the achievement of the organisation's objectives. Risk

> includes uncertain events with a potential positive effect on the organisation (i.e. opportunities) not being captured or not materialising.”

The Orange Book[124] which has been a cornerstone of risk implementation within governmental organizations in the United Kingdom (UK) and provides instrumental guidance for the financial sector, presents a definition that is in line with those of the IRM and IoDSA (HM Treasury 2004, p. 49). It defines risk as an:

> “Uncertainty of outcome, whether positive opportunity or negative threat, of actions and events. It is the combination of likelihood and impact, including perceived importance.”

The previous definitions contextualise risk as incorporating uncertainty about the outcome, which arises from external or internal factors and other influences, over which the organization does not have entire control. Those impacts might ultimately lead to delay, or fail to achieve its objectives (Purdy 2010). Moreover, the future perspective is also noteworthy; therefore, if the outcome is known in advance (historical fact), a gain or a loss should be mentioned instead (ARMS 2011). Finally, two similar events might generate different levels of risk exposition or perceived importance. To be able to differentiate and compare similar risks, the risk tool used to measure risks ought to incorporate a comparison feature.

To differentiate a safety risk from the legal, financial, reputational and other risks, the ICAO (2018b) defines a safety risk as “the predicted probability and severity of the consequences or outcomes of a hazard”. This definition is equivalent and in line with the definitions formerly cited, assuming risks are uncertain, and subjected to an assessment in terms of their likelihood and consequence. Nevertheless, opposed to the definitions presented previously, the ICAO only considers risks that have the prospective to contribute to an adverse outcome: that is they exclude opportunity risks, related to projects and investments, from the safety scope.

Hereinafter, a safety risk will be seen as an uncertain occurrence that is assessed through the interaction of (at least) two variables – the consequence of the outcome and the likelihood (or probability) of the occurrence – and which (shadowing ICAO’s definition) are considered to have only the potential to present an adverse outcome. For the current research, a risk will

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[124] *The Orange Book*, published in the UK by HM Government, produced by the Government Finance Function, addresses the concept of “Management of Risk – Principles and Concepts”.

denote a “safety risk”, and the contributing factors or precursors of these will be defined as “threats” and “perils”, as stated above.

B.3 Safety Risk Management

“Risk management” is a concept used widely throughout the current thesis. Taking a simple approach, one can define it as the management of safety risks. However, it is essential to understand what this encompasses and how different organizations approach this ancient concept.

As Bernstein suggests, the genesis of “risk management” goes back thousands of years, when traders attempted to manage and assess the consequences of the futures business (see Simkins & Ramirez 2008), and merchants dealt with future commodities in India in about 2000 BCE (Duffie 1989). Additionally, at the medieval trade fairs of around the 12th century, sellers signed agreements, known as *letters de faire*, on the delivery of goods sold at a future date. In the 1600s, Japanese feudal lords signed future agreements to control volatility in the price of rice during conflicts and foul weather (Simkins & Ramirez 2008).

Currently, risk management is an explicit, systematic, and proactive activity: explicit because activities are documented under predetermined rules; systematic as it relies on approved plans and standards; and proactive because mitigation measures[125] are implemented before risk activation (Flouris & Yilmaz 2009). A wide range of professionals and industries apply risk management practices, which explains why the number of approaches used is equal to the number of areas where it is practised. Thus, the risk management framework can vary significantly among industries and organizations. Thus, to achieve a broad perspective, it is relevant to scrutinise the most relevant definitions and codes of practice, specifically probing into industries where catastrophes and high-profile examples of poor governance and misconduct have led to disastrous results for a large number of stakeholders (FRC 2018). Below four different approaches are put forward:

- The British Standard Institution (BSI 2018b, pp. 1 & 8) sees risk management as a set of “coordinated activities to direct and control an organization with regard to risk”. The BSI also considers that the process involves the “systematic application of

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[125] “Mitigation measures” are rules, functions, equipment, constructions or other devices implemented in a system that aim to arrest the development of an incident or accident. These devices can be designated interchangeably by “barriers” or “protective measures”.

management policies, procedures and practices to the activities of communicating and consulting, establishing the context and assessing, treating, monitoring, reviewing, recording and reporting risk”.

- Within the scope of *The Orange Book* (HM Treasury 2004, p. 49), risk management is seen as the set of “all the processes involved in identifying, assessing and judging risks, assigning ownership, taking actions to mitigate or anticipate them, and monitoring and reviewing progress”.
- The IRM (see Hopkin 2012, p. 38) describes risk management as a “process which aims to help organizations understand, evaluate and take action on all their risks with a view to increasing the probability of success and reducing the likelihood of failure”.
- The Financial Reporting Council (FRC 2018, pp. 10, 12) code states that: “The board should establish procedures to manage risk, oversee the internal control framework, and determine the nature and extent of the principal risks the company is willing to take to achieve its long-term strategic objectives.” This entity, which sets the UK’s Corporate Governance and Stewardship Codes and promotes high-quality risk management, states in addition that: “The board should monitor the company’s risk management and internal control systems and, at least annually, carry out a review of their effectiveness and report on that review in the annual report.”

The four concepts set out above range across different activities, which accounts for the differences among them. The first and second approaches introduce a conceptual structure for how to manage the risk, presenting a set or a sequence of interrelated processes. The third one sees risk management from a holistic perspective – encompassing all opportunity and hazard risks (Hopkin 2012). An explanation for this universal scope could relate to the philosophical stance espoused by the organization, whereby all risks that may have the potential to impact upon the organizations’ objectives, core processes, and critical dependencies are managed under a common framework. This method is known as Enterprise Risk Management (ERM). The final approach, supported by a financial regulator, emphasises the tolerability perspective, or to use the jargon from the banking sector, the organization’s “risk appetite”, which ultimately the board of directors must determine. The perspective brought by this last definition is quite relevant to the current research: Gap 1 [SQ 1] addresses how executive management defines and transmits the level of risk the board is willing to accept throughout the organization.

While acknowledging the different background from which each definition arises, the presence of four distinct phases of risk management is notable: identification, assessment, treatment, and monitoring phase. The last of these phases appears explicitly in the FRC approach, which encompasses an additional outstanding aspect – the definition of the acceptable level of risk exposition – that is, the risk appetite and the identification of the person who holds accountability to define that level of risk exposure.[126] While this may seem a detail of minor importance, it implies, however, that the commitment of the management staff derives directly from the management system.

The ICAO has no formal risk-management definition. Instead, its safety-risk management framework takes a different approach, identifying uniquely the phases incorporated in the risk-management process: “hazard identification; safety risk assessment; safety risk mitigation and risk acceptance” (ICAO 2018b, p. 2-10). Although the four phases mirror the approach shared by the BSI, HM Treasury, and the IRM, ICAO has moved the position of accountability, in order to define the organizational risk exposure, to the first pillar of the framework. The level of risk exposure is based on the organization’s safety policy, which is endorsed by the executive committee, and on its safety objectives. The framework of the ICAO is described in detail in Appendix M. This presents the four pillars and 12 elements that comprise the minimum requirements for a fully operative Safety Management System (SMS).

Consequently, under the premises of the current research, the recommendation is that the safety risk-management process should contain “a systematic set of coordinated activities undertaken within an organization with the aim of identification, analysis, evaluation, mitigation, and monitoring of safety risks to a level[127] defined by the organization or imposed by the stakeholders”.

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[126] Although not explicit, the BSI (2018b) considers the acceptable level of risk under the risk criteria definition.

[127] A safety risk level is equivalent to a safety risk exposure. Therefore, when defining the safety boundaries, one is establishing the acceptable safety risk exposure.

It is important to note that according to the BSI definition of risk, the risk assessment phase incorporates three activities: risk identification, analysis,[128] and evaluation.[129]

B.4 Safety Boundaries

The concept of “safety boundaries” (or “risk appetite”, which is the same thing) is something organizations have to specify and communicate at all levels to make known what level and which type of risk they are willing to tolerate in line with the objectives of the organization (BSI 2018b). In simple terms, one can assert that “safety boundaries” represent the level of risk exposure an organization is willing to accept in pursuit of its objectives.

The “risk appetite” concept is borrowed from the banking sector (EBA 2017; HM Treasury 2004) and the corporate governance institutions (FRC 2018; IoDSA 2016) and is used extensively within the ERM framework (COSO 2004; IRM 2011; IRM 2017). Due to the fact that within the aviation field there are no opportunity (or investment) risks and no one has a preference for a strictly negative outcome (Leitch 2009; Aven 2013), it may seem counter-intuitive to use the term “risk appetite”. However, the term “safety boundary”, coined in the current research and used throughout, will be privileged with defining the concept under analysis – although both have a common inception and could be used conversely.

Aviation is characterised as a constantly changing system. As a consequence of management decisions, hazards are introduced at a rapid pace, and associated safety risks alter their incidence over time (ICAO 2018b; Reason 1997). Thus, opposed to the traditional view conveyed by the matrices of the ICAO (see Figure 2.10), safety risks are not static, and safety professionals must be able to identify both what the current risk exposure is and the nature of their tendency. Throughout, the literature defines the level of acceptable risk as the “safety objectives”.[130] These high-level commitments or looked-out-for outcomes serve as guidelines for the organization’s activities, which ideally ought to be aligned with the organization’s

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[128] “The purpose of risk analysis is to comprehend the nature of risk and its characteristics including, where appropriate, the level of risk. Risk analysis involves a detailed consideration of uncertainties, risk sources, consequences, likelihood, events, scenarios, controls and their effectiveness. An event can have multiple causes and consequences and can affect multiple objectives” (BSI 2018b, p. 12).

[129] “The purpose of risk evaluation is to support decisions. Risk evaluation involves comparing the results of the risk analysis with the established risk criteria to determine where additional action is required” (BSI 2018b, p. 12).

[130] According to ICAO other similar expressions could be used, including “safety goals”, “safety targets”, and the like (ICAO 2018b, p. 4-4). Those objectives constitute the strategic or desired outcomes in relation to specific safety concerns in the operational context of the organization.

safety policy (ICAO 2018b, pp. 4-3, 9-3). According to the framework of the ICAO, these objectives should combine process- and outcome-oriented measures. This is because the ultimate aim of these objectives is to allow an organization to present evidence (and receive feedback) to ensure that the safety performance of its SMS is improving or, at least, is not degrading its level of protection. The ICAO recommends that evaluation and monitoring of the performance of the SMS is carried out using the safety objectives SPI and SPT (ICAO 2018, p. 9-20). Based on a SMART approach to define its safety objectives (Doran 1981), and depending on the type of data available, the ICAO recommends the existence of both quantitative and qualitative indicators,[131] despite its preference for the former.

The approach conveyed by the ICAO promotes a stance whereby every single event presents the exact same level of risk exposure. Each occurrence is classified under the same title, for example: “Quantitative indicators can be expressed as a number (x incursions) or as a rate (x incursions per n movements)” (ICAO 2018b, p. 4-5), and each event represents the same level of risk exposure independently of the predicted outcome, whether using a realistic or worst-case scenario. The perspective put forward by the concept “safety boundaries” diverges from the framework of the ICAO, since accounting for the risk is not according to a mere frequency of events but as a set of risk-based occurrences that have the potential to contribute to an adverse outcome. The collection of events, rather than an overview restricted to a single event, forms a “risk-exposure cloud”, as Figures 6.26 and 6.27 illustrate.

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[131] The evaluation of safety culture is an example of a qualitative indicator whereas occurrences and rates constitute quantitative indicators.

C Strategic & Research Questions: Evolutionary Process

GAP 1 – Safety Boundaries

Document #1

SQ 1	How are the safety risk boundaries and associated decision process defined?
RQ 1.1	How is the risk tolerance decided?
RQ 1.2	How is the safety level communicated / disseminated throughout the company?

Document #2

SQ 1	How is the risk level defined and communicated?
RQ 1.1	How are safety risk tolerance and acceptability defined?
RQ 1.2	How could the risk matrix be enhanced to become a better risk-communicating tool?

Document #3

SQ 1	How is the safety risk level defined and communicated?
RQ 1.1	How are the safety limits defined?
RQ 1.2	How is the safety risk level communicated / disseminated throughout the organization?

Document #4

SQ 1	How are the safety boundaries defined and communicated?
RQ 1.1	How is the actual safety risk exposure defined?
RQ 1.2	How is the actual safety risk exposure communicated throughout the organization?

GAP 2 – Risk Matrices

Document #1

SQ 2	Are the safety risk matrices adequate to assess safety hazards?
RQ 2.1	Is it possible to improve safety risk matrices?
RQ 2.2	Should companies use a quantitative or a qualitative method? Or should they use a mixed method?

Document #2

SQ 2	What tool or combination of tools should be used to assess safety hazards?
RQ 2.1	Is it possible to improve safety risk matrices?
RQ 2.2	Should airlines use qualitative or semi-quantitative methods?

GAP 2 – Risk Tools

Document #3

SQ 2	What risk tool or combination of tools should be used to assess safety hazards?
RQ 2.1	Are the risk tool or combination of tools able to prioritize and evaluate safety risks effectively?
RQ 2.2	What method best suits airlines?

Document #4

SQ 2	What risk tool or combination of tools should be used to assess safety risks?
RQ 2.1	What characteristics should risk tools have to assess safety risks effectively?
RQ 2.2	What methods best suit airlines?

GAP 3 – Balance between protection vs production

Document #1

SQ 3	How could companies achieve a balance between production and protection?
RQ 3.1	How are the safety investments decided?
RQ 3.2	What is the minimum safety level?

Gap 3 Safety Protection

Document #2

SQ 3	How could companies achieve a balance between production and protection?
RQ 3.1	How are the safety investments decided?
RQ 3.2	What is the minimum safety level?

Document #3

SQ 3	How could companies achieve a balance between production and protection?
RQ 3.1	How are the safety investments decided?
RQ 3.2	How is the company’s minimum safety level determined?

Document #4

SQ 3	How could companies achieve a balance between production and protection?
RQ 3.1	How are the safety investments decided?
RQ 3.2	How can the organization’s safety risk exposure be minimized?

GAP 4 – Safety Benchmarking

Document #1

SQ 4	What is the minimum risk level acceptable for the airline / industry?
RQ 4.1	What safety indicators should be used to standardize the airline / industry safety risk level?
RQ 4.2	What entity(s) ought to regulate and to inspect the standardization of the airline / industry risk level?

Document #2

SQ 4	What is the minimum safety standard for the industry?
RQ 4.1	What safety indicator should be used to standardize the industry?
RQ 4.2	What entity ought to define and to inspect the safety standard?

Document #3

Decided to postpone the Safety Benchmarking Gap for future research.

GAP 4 – Safety Culture

Document #4

SQ 4	How does organizational safety culture impact on the risk management process?
RQ 4.1	How can safety boundaries account for the impact exerted by safety culture?
RQ 4.2	How can risk tools incorporate the influence exerted by the organizational culture?

D Research Philosophical Traditions Summary

The table below summarizes the main assumptions of each research tradition in social science.

Assumptions	**Research Traditions**			
	Positivism	**Interpretivism**	**Pragmatism**	**Critical Realism**
Axiology: The study of values (Blackburn 2016)	Value-free (etic) The researcher is free from his or her own sets of values and beliefs. The researcher is not influenced by the research or methods chosen. (Holden & Lynch 2004)	Value-laden (emic) The researcher is embedded and is part of the research, the elements cannot be separated.	Etic and emic Researcher adopts either a subjective and/or objective stance.	Value-cognizant The researcher is biased by their cultural values and social interaction.
Ontology: “[T]he nature of reality.” (Hart 1998, p. 81)	External, objective; captured by social actors’ senses; excludes values from the perimeters of science; reality independent of social actors.	Subjective, socially constructed.	External, multiple views (objective and subjective), depending on the research question.	Objective reality, which exists beyond human perception, but which, however, is subjectively interpreted.
Epistemology: “[H]ow knowledge can be acquired of that reality and therefore what counts as valid knowledge.” (Hart 1998, p. 81)	Based on empirical observations, establishing cause-and-effect relationships. (O’Mahoney 2011)	Based on multiple, subjective meanings of social phenomena.	Practice is the source of knowledge (Resher 2000). Multiple methods of data collection, depending on the research questions.	Observable phenomena framed by the context.
Methodology:	Quantitative	Qualitative	Qualitative and/or Quantitative Mixed or multi-method design (Wahyuni 2012)	Qualitative or Quantitative

Table D.11 – Summary of research on philosophical traditions

E Interviews support material and data

E.1 Research Questions

NOTTINGHAM
TRENT UNIVERSITY

Confidential and anonymous[132] interview for academic research

RESEARCH QUESTIONS

Introduction

I would like to thank you and highlight my profound appreciation for making yourself available for this interview, where we will talk openly about issues and activities related to our professional area.

The interview should be undertaken as a conversation between two professionals with similar concerns, based on open questions about your activity, allowing you to speak freely about the subject matter under analysis.

Question 1 – Introduction

<u>Grand tour approach</u>

Before addressing the main subjects of the research, I would like to ask you to describe [to] me, in general terms, as a Director (or as member responsible for safety), when you are confronted with the "aviation safety" concept, what ideas, images, opinions or other issues come to your mind?

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[132] Anonymity relates to the identification of respondents, their names and locations, whereas confidentiality relates to the researcher not disclosing his or her sources (Fisher 2010; Diener & Crandall 1978).

Mini tour approach

- If the SMS "Risk Management" component is addressed in the answer, I will ask the interviewee to further elaborate on it.
- If the SMS "Risk Management" component is not addressed, I will rephrase the question:
    - Still on the subject of "aviation safety", if you link the concept to the "Risk Management" component of the SMS, I would like to ask you: What are the main challenges brought to your company by the SMS framework?
    - In general terms, what do you think about the support and directives given by the international and local institutions, namely the ICAO, EASA, IATA, the International Organization for Standardization – ISO, and also your national aviation authority?

Critical incident approach

Do you consider the framework presented by the ICAO (Doc. 9859 – Safety Management Manual) helped your company to identify the main hazards faced by your operation? What are your top priorities?

Question 2 – Safety Boundaries

Grand tour approach

Now I would like to ask you a more specific question concerning the risk management component of the SMS: What is your understanding of the "safety boundaries" concept, i.e. safety limits, or in ICAO's jargon, performance criteria? Would you tell me what level of importance and relevance, and the impact that this concept has in your organization?

Mini tour approach

- (CEO) How [does] the process interconnect with [your] company strategy and the business model? (OPS) Do you have a documented process to define the safety boundaries? Can you give me an example?

- (CEO) Does your company have a communications strategy? Can you elaborate on your communications strategy? (OPS) How are the “safety boundaries” communicated and disseminated throughout the company?

- How do you take into account [your] company safety culture when defining the safety boundaries?

- Has your company implemented any kind of metrics to monitor the safety level? Do you have a specific process to develop them? How are they approved? How are they monitored?

- What importance do your collaborators give to it? Do you think they are familiar with the safety objectives of [your] company?

Critical incident approach

- Can you tell me about the last time safety boundaries were discussed? For example, the last time your company was faced with a new safety risk,[133] how was it defined in your [company’s] new safety boundaries? And, how have you disseminated the information?

- (CEO) Has your company been faced with any breach of safety boundaries? What happened? Can you give me an example?

- (OPS) Can you recall a time when you brought the question of safety boundaries to the attention of the executive board / peers? What happened?

- How do you think peer companies draw up safety boundaries?

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[133] Examples of accidents and/or incidents faced by the company/organization.

Question 3 – Risk tools

Grand tour approach

Now I would like to change the interview subject to a more practical matter. Can you tell me how your company assesses, mitigates and monitors the safety risks detected within your operation?

Mini tour approach

- If the "risk tools" subject, i.e., the tools used to assess, mitigate, and monitor hazards, is addressed in the answer, I will ask the interviewee to elaborate on it.
- If the subject of "risk tools" is not addressed, I will return to the question using a more direct approach:
  - What are the tools used by your company to assess, mitigate and monitor safety risks?
  - What are the main features that you consider essential for the risk tools?
  - Are the risk tools used in your organization able to rank safety risks in order of priority, and are they able to discriminate, to identify those that exceed your company's safety boundaries?
  - Would you tell me whether the outcome matches your expectations?
  - Can you tell me what the pros and cons of the tools used in your organization are?
  - Do the risk tools incorporate (or in some way attenuate) the influence exerted by [your] organization's culture?

Critical Incident approach

- Can you give me an example of the last time you discussed safety risk prioritization in your organization? Has this issue been brought to the attention of the executive board / peers?

- Can you give me an example of a safety risk that has exceeded your company’s safety boundaries? How did you handle it?

- Does your company benchmark its risk tools against other organization’s risk tools?

Question 4 – Safety Protection

Grand tour approach

The last group of questions relates to the safety level your organization has defined – its “safety boundaries”. From your perspective, how does your organization perform in this respect? Is your company above, below, or achieving the proposed safety level defined by the executive board (CEO)? What criteria does your company use to allocate resources to the Safety Department (OPS)? What kind of argument or supporting data do you use to request allocation of additional resources?[134] How does your company decide [on] its safety investments?

Mini tour approach

- If “control charts” or another tool is mentioned in the answer, I will ask the interviewee to elaborate on it.

- If “control charts” or another tool is not mentioned, I will go back to the question using a more direct approach:

    - When your safety objectives have not been met, what procedure is taken? Do you consider any safety investment – people, material, or financial?

    - What kind of tools does your company use to monitor the safety level, and to decide upon a safety investment?

    - Does your company allocate a budget for safety investments?

    - Do you consider the SPI as a monitoring tool? What kind of guidance have you used to implement them?

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[134] People, material, financial.

- The Safety Risk Management in particular (and the SMS in general) is rather a technical subject that requires specific knowledge to guarantee that each stakeholder is able to fulfil his or her specific safety responsibilities. Therefore, if I brought into the discussion the subject of training, framed as a safety investment, what would you have to say about this matter?

- As a member of the Board of Directors (or as member responsible for safety), what kind of academic training (related to the risk management and SMS) have you attended? Do you consider recurrent training? How often?

- Still within the realms of safety protection, if you acknowledge the implementation of "The Three Lines of Defence" model,[135] benchmarked from the banking industry, would you consider [it] a helpful management strategy?

- Safety protection goes beyond the boundaries of your airline; therefore, do you require Safety Providers to have an implemented SMS? If so, how do you make sure they are achieving your [level of] required safety performance?

Critical Incident approach

- Have you discussed the safety targets with your aviation authority? Can you give me an example?

- How do you think peer companies establish their safety targets? Are they more stringent than your own company's?

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[135] The 1st line of defence (LoD) is intended to provide operational staff and management ownership, responsibility and accountability for assessing, mitigating and controlling risks. The intention is to assign basic control and risk management responsibilities to line personnel.
The 2nd LoD, plays an essential role if the 1st becomes ineffective or is absent. It encompasses functions such as risk management, compliance, security and other similar functions that monitor the correct implementation of effective risk management practices by operational management and assists risk owners to report risk-related information.
The 3rd LoD is performed by the internal audit function. This provides the organization's executive board and senior management assurance on how the organization effectively assesses and manages its risks (Chartered Institute of Internal Auditors 2013; Arndorfer & Minto 2015).

Question 5 – Closing questions

To conclude the interview, I would like to give you the opportunity to address any matter that I might have overlooked and to allow you to express your personal point of view about the matters under debate.

Do you think that the research might contribute to the body of knowledge and lead to Safety Risk Management Framework improvement?

Doorknob question

If you were advising your organization about the main risks or the main deficiencies your airline may face in the near future what would be your top priorities?

If you had the opportunity to modify anything related to risk management in your organization, what are the main improvements or changes that you would advocate?

Snowball question

Finally, I would like to ask you whether there is anyone else you would like to suggest who you feel would be interesting for me to interview as part of this research?

References:

Diener, E. and Crandall, R., 1978. *Ethics in Social and Behavioral Research*. Chicago: University of Chicago Press.

Fisher, C., 2010. *Researching and Writing a Dissertation: An Essential Guide for Business Students*, 3rd ed. Essex: Pearson Education.

E.2 Letter to Interviewees

NOTTINGHAM
TRENT UNIVERSITY

LETTER TO INTERVIEWEES

TITLE OF PROJECT: “Closing the gap between management and operational safety staff: a structured risk management model, promoting an efficient risk level definition, analysis, evaluation, and resource allocation.”

I would like to invite you to participate in this research project. Before you decide whether to take part in the research, it is important that you understand the reason why this research is being carried out and what your participation will involve. I would be grateful if you would take time to read the following information carefully and discuss it with colleagues or other people if you wish. Please feel free to get back to me if anything is unclear, and to take as much time as necessary to decide whether you wish to take part.

What is the purpose of the study?

Joaquim Grade participates in this research at Nottingham Trent University. This study arises from the scarcity of research into the Safety Management System (SMS) framework. The research examines the Safety Risk Management component of the SMS, addressing three gaps identified within commercial aviation – safety boundaries, risk tools, and safety protection. The purpose of the study is to document and produce a structured risk management model that will allow aviation organizations to define their “safety boundaries” in an efficient fashion; specifically, a standard form for defining what is acceptable and what is not. Moreover, the study aims to identify the drawbacks associated with the risk assessment tools used to analyse and evaluate commercial aviation safety risks. The objective is to develop an assessment tool capable of ranking and prioritizing risks and to identify those that are beyond aviation organizational safety boundaries. Finally, intertwined with the two previous objectives, the study aims to help aviation organizations define the level of resources required to achieve the defined safety protection.

To support the researcher in developing a general understanding of aviation organizational practices, the elected method of gathering information is via semi-structured interviews.

The project commenced on February 2015, and will run until February 2019.

Why have I been chosen to take part?

I am asking you to participate in this research because you fulfil the criteria set for the current study: your knowledge and experience of commercial aviation, as well as the safety profession and your professional experience. I would therefore like to ask you to participate as one of approximately twenty people I am inviting to take part in this study.

Do I have to take part?

Your participation is voluntary. If you decide to take part, you will be given this information sheet to keep, and you will also be asked to sign a consent form. You will still be free to withdraw at any time: this includes the right to withdraw your interview from the study even after it has taken place.

If you decide not to take part, or to withdraw at any stage, I will not ask you to give me any reasons for doing so.

What do you want me to do?

I would like you to take part in an interview, lasting approximately one hour. The event will take place at your workplace, scheduled for a time convenient to you. I will ask for your written permission to tape the interview to ensure that the information you provide is accurately recorded.

What will happen to the information I give in my interview?

I will transcribe the recorded interview and then analyse the information and feed it into my results.

At the end of the study, all transcripts will be anonymized before they are archived. Any information that identifies you or your organization, or that offers any clues as to your identity, will be removed. I am confident that these precautions will ensure that no one will be able to trace your transcript back to you or your organization.

How will you protect my confidentiality and anonymity?

I will handle both the recording and the transcript of the recording alone in line with data protection principles and the approved research protocol. Hard copies of research notes are kept in locked filing cabinets, and electronic files are kept on password-protected computers, which are not accessible to any other university staff.

Once the transcripts have been deposited in the archive, the tape of your interview will be destroyed and the relevant files erased from our computers.

You will not be named or otherwise identified in any publication arising from this project unless your role forms part of a narrative that is already in the public domain (e.g., if you were the named author of a published document or gave evidence to a public inquiry relevant to the study). No unpublished opinions or information will be attributed to you, either by name or position.

I will exercise all possible care to ensure that you and the organization you work for cannot be identified by the way I write up my findings.

What are the possible benefits?

I hope that you will find the interview interesting, and that you will derive some satisfaction from helping to develop knowledge around this important topic. The outcome of the study will benefit the aviation safety community and will contribute to developing the body of knowledge on aviation risk management. Therefore, I hope that you will find the results of the project helpful to your work.

What will happen to the results?

It is anticipated that the results will be useful to a wide range of aviation organizations.

Articles will appear in journals that are widely read by practitioners and managers interested in the subject of aviation risk management.

How can I find out more about this project and its results?

For more information about this project, please feel free to email me:
joaquim.gradedaencarnacao2014@my.ntu.ac.uk

Has anyone reviewed the study?

This study has been reviewed by my academic supervisors and been approved by the College Research Degree Committee and the College Research Ethics Committee.

Researcher contact details

Joaquim Grade Encarnação, e-mail: joaquim.gradedaencarnacao2014@my.ntu.ac.uk, Mobile: +351 917 60 66 86

Supervisors' contact details

Doctor Roy Stratton (roy.stratton@ntu.ac.uk) and Professor Alistair Mutch (alistair.mutch@ntu.ac.uk), Nottingham Business School, Nottingham Trent University. Burton Street, Nottingham NG1 4BU, United Kingdom.

E.3 Informed Consent Form

NOTTINGHAM
TRENT UNIVERSITY

INFORMED CONSENT FORM

Name of the site:

Please read and confirm your consent to being interviewed for this project by initialling the appropriate box and signing and dating this form.

1. I confirm that the purpose of this project has been explained to me, that I have been given information about it in writing, and that I have had the opportunity to ask questions about the research. ☐

2. I understand that my participation is voluntary, and that I am free to withdraw at any time without giving any reason and without any implications for my legal rights. ☐

3. I give permission for the interview to be voice-recorded by the researcher, on the understanding that the recording will be destroyed at the end of the project. ☐

4. I agree to take part in this project. ☐

____________________	____________________	____________________
Name of respondent	Date	Signature
Joaquim Grade Encarnação Researcher taking consent	____________________ Date	____________________ Signature

Researcher contact details:
Joaquim Grade Encarnação, e-mail: joaquim.gradedaencarnacao2014@my.ntu.ac.uk, Mobile: +351 917 60 66 86

Supervisors’ contact details:
Doctor Roy Stratton (roy.stratton@ntu.ac.uk) and Professor Alistair Mutch (alistair.mutch@ntu.ac.uk), Nottingham Business School, Nottingham Trent University. Burton Street, Nottingham NG1 4BU, United Kingdom.

E.4 Interviewee Profiles

<table>
<tr><th>Interview</th><th>Date</th><th>Sector</th><th>Position</th><th>Pseudonym-Code</th><th>Language</th></tr>
<tr><td>1</td><td>21-Dec-16</td><td>Airline</td><td>CEO</td><td>Martin-AB</td><td>Portuguese</td></tr>
<tr><td colspan="6">Martin is a member of the board of directors and accountable manager (CEO) of a medium-sized airline that operates regional, medium and long haul flights. Martin has a background in maintenance; he was formerly a CEO of the airline, was a manager and later a director of a regional airline. He holds a degree in aeronautical engineering and a Master’s in human resources management. He has over 20 years of professional experience.</td></tr>
<tr><td>2</td><td>27-Jan-17</td><td>Airline</td><td>Safety Manager</td><td>Thomas-AS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Thomas is a safety manager of a leading company and has had an extensive flying career. Formerly an officer in the air force, Thomas has broad flight safety experience. Joining the commercial aviation sector in 1999, he has been involved with flight safety since that time. Over the course of his long career, he has been a type-rating instructor pilot of several aircraft and attended a broad range of aeronautical training courses. He has over 40 years of professional flying experience and has clocked up over 15,000 flying hours.</td></tr>
<tr><td>3</td><td>27-Jan-17</td><td>Airline</td><td>Deputy Safety Manager</td><td>Jack-AS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Jack is currently the deputy safety manager of a regional airline. He began his career as a flight attendant and became a first officer in 2000. His flying experience equals approximately 20 years and in the last five years Jack’s role has been dedicated to flight safety. He has a degree in mechanical engineering.</td></tr>
<tr><td>4</td><td>27-Jan-17</td><td>Airline</td><td>Safety Analyst</td><td>Yolanda-AA</td><td>Portuguese</td></tr>
<tr><td colspan="6">A safety analyst for a medium-sized airline, Yolanda’s career began as a software developer, and she then worked as an IT consultant for a leading European IT company and an IT engineer in the automotive industry. She was formerly a safety analyst for the national aviation authority in her home country. Yolanda holds a master’s in electrical and computer engineering along with two other postgraduate qualifications. She holds an airline transport license (CPL/IR (A)) and has over eight years of aviation experience.</td></tr>
</table>

<table>
<tr><th>Interview</th><th>Date</th><th>Sector</th><th>Position</th><th>Pseudonym-Code</th><th>Language</th></tr>
<tr><td>5</td><td>06-Fev-17</td><td>Handling</td><td>General Director</td><td>Tavares-AB</td><td>Portuguese</td></tr>
<tr><td colspan="6">Tavares is general director of the handling and cargo operations of a leading service provider in the Iberian Peninsula. Former director and deputy station manager of a main Portuguese airport, he holds a degree in business management and an MBA in air transport management. He has over 20 years of professional experience.</td></tr>
<tr><td>6</td><td>13-Feb-17</td><td>Lecturer</td><td>CEO Executive Education</td><td>Lary-AB</td><td>Portuguese</td></tr>
<tr><td colspan="6">Currently CEO of executive education for a leading European university of business and economics, Lary lectures in business strategy and positive psychology. Formerly he was the CFO and an executive board member of a European flagship carrier that operated more than 75 aircraft, holding responsibility for the maintenance repair station and airport support services (seven years); before this, he was marketing director for a leading telecoms enterprise. Lary holds an MBA and several other postgraduate qualifications. He has over 20 years of professional experience.</td></tr>
<tr><td>7</td><td>17-Feb-17</td><td>Airline</td><td>Board Member</td><td>John-AB</td><td>English</td></tr>
<tr><td colspan="6">Chief operations officer (COO) and member of the executive committee of a European flagship carrier, John was formerly executive vice president of customer services and a member of the executive committee of a major South American airline. Before this, he was senior director of customer services for a start-up airline in a South American country, responsible for establishing bases/branches across the nation. He was formerly the vice president of a logistics company in North America. John has over 25 years of experience in the aeronautical sector.</td></tr>
<tr><td>8</td><td>08-Mar-17</td><td>Airline / Maintenance</td><td>Board Member</td><td>George-AB</td><td>Portuguese</td></tr>
<tr><td colspan="6">Vice president of quality and safety for a major European maintenance and repair organization, a position George has held for over 13 years. He is the chairman of the European Engineering & Maintenance subcommittee for EASA. Formerly he was commercial manager and production manager in an engine maintenance unit. George holds a bachelor degree in mechanical engineering, has an airline transport license (PPL/IR (A)) and has 29 years of professional experience.</td></tr>
<tr><td>9</td><td>05-Apr-18</td><td>Airline / Maintenance</td><td>Safety Analyst</td><td>India-AS</td><td>Portuguese</td></tr>
<tr><td colspan="6">India is a safety analyst for a major European maintenance-repair organization and was formerly a specialist in human resources, an area she worked in for over 15 years. With a high degree of knowledge about safety, she has over 20 years of professional experience.</td></tr>
</table>

<table>
<tr><th>Interview</th><th>Date</th><th>Sector</th><th>Position</th><th>Pseudonym-Code</th><th>Language</th></tr>
<tr><td>10</td><td>05-Apr-17</td><td>Airline</td><td>Safety Manager</td><td>Kostas-AS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Currently responsible for the safety department of a leading European private jet airline, Kostas is a highly experienced aviation safety expert with a successful career in several challenging subjects such as in air accident investigation and safety management systems. He is the founder and owner of an aviation consultancy company. He is currently chair of the European working group at EASA overseeing flight data-monitoring matters. He was formerly an aviation accident investigator and adviser for the regions of Europe, Africa and the Middle East of one of the world's leading aircraft construction companies. In the course of his work, Kostas has been involved in over 60 safety investigations. Also a former consultant and lecturer in human factors for maintenance organizations, he is recognized by EASA as an Independent External Expert and a trusted evaluator of Horizon 2020 project proposals by the European Commission. Kostas holds an aerospace degree and a master's in air transport management. He has over 20 years of professional experience.</td></tr>
<tr><td>11</td><td>21-Apr-17</td><td>Airline</td><td>Safety Manager</td><td>Gary-AS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Gary is the safety manager for one of the leading flagship carriers in Europe, for which he was formerly risk manager and safety investigator for the flight operations branch. He has been associated with the implementation team for the SMS and LOSA programmes. He is a former type-rating instructor. He has over 20 years of commercial pilot experience.</td></tr>
<tr><td>12</td><td>27-Apr-17</td><td>Airline</td><td>Board Member</td><td>Charles-AB</td><td>Portuguese</td></tr>
<tr><td colspan="6">Head of the operational safety department for a major airline on the South American continent for which formerly he was safety manager. Charles holds a bachelor's degree in aeronautical sciences. He has over 20 years of professional experience, of which the last ten have been dedicated to working in the area of safety.</td></tr>
<tr><td>13</td><td>27-Apr-17</td><td>Airline</td><td>Safety Manager</td><td>Barros-AS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Safety manager for one of the top five airlines on the South American continent. Previously a lecturer in a South American University, Barros holds a bachelor's degree in Aeronautical Sciences and an MBA. He has a great deal of experience in the area of safety, based on more than 16 years of professional experience in executive and commercial aviation. Barros has clocked up more than 8,000 flying hours.</td></tr>
<tr><td>14</td><td>10-May-17</td><td>Airline</td><td>Safety Analyst</td><td>Bentes-AA</td><td>Portuguese</td></tr>
<tr><td colspan="6">Currently a safety analyst (2011–2017) for a national flagship operator, Bentes holds a master's in aerospace engineering, having started his career as an intern for a maintenance repair operator. Bentes has over seven years of professional experience.</td></tr>
</table>

<table>
<tr><th>Interview</th><th>Date</th><th>Sector</th><th>Position</th><th>Pseudonym-Code</th><th>Language</th></tr>
<tr><td>15</td><td>10-May-17</td><td>Healthcare</td><td>Lecturer</td><td>Paul-HL</td><td>Portuguese</td></tr>
<tr><td colspan="6">Paul holds doctorate in public health, lectures in patient safety and risk management, and holds the position of the scientific director of the master’s and doctorate programmes for public health. He has published many academic papers and books on patient safety and quality improvement. Paul is a member of an investigation centre dedicated to public health and is a WHO-recognized expert in quality and patient safety. Paul has over 25 years of professional experience.</td></tr>
<tr><td>16</td><td>18-May-17</td><td>Maintenance</td><td>Safety Analyst</td><td>India-AS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Ibid. (see also profile 9). The second interview was dedicated to understanding how the organization structured its risk analysis / assessments. The interview involved discussion about how the risk tool of the organization was developed.</td></tr>
<tr><td>17</td><td>30-May-17</td><td>Airline</td><td>Safety Manager</td><td>Jeremiah-AS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Airline captain for a major flagship carrier in Europe; formerly a safety manager for the same airline. Before this, Jeremiah was a flight safety officer. He is considered an expert in his field, having been involved in several safety projects. Jeremiah is the co-author of a book about flying anxiety. He has over 25 years of professional experience in aviation, of which over ten years have been dedicated to safety.</td></tr>
<tr><td>18</td><td>31-May-17</td><td>Healthcare</td><td>Safety Manager</td><td>Sabine-HS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Head of the patient safety office in a cluster of six hospitals, Sabine was formerly a member of the risk-management office for the same group of hospitals (2009–2016). Before this, Sabine was audit coordinator for internal audits. She has been part of investigating teams in the area of risk management and patient safety and lectured on these subjects. Sabine has published several articles and holds a master’s in infectious diseases and two further postgraduate qualifications, one of which is in patient safety. She has over 30 years of professional experience, 16 of which are in risk management.</td></tr>
<tr><td>19</td><td>05-Jun-17</td><td>Healthcare</td><td>Safety Manager</td><td>Sabine-HS</td><td>Portuguese</td></tr>
<tr><td colspan="6">Ibid. (see also profile 18). The second interview was dedicated to understanding how the organization structured its risk analysis / assessments. The interview involved discussion about how the risk tool of the organization was developed.</td></tr>
</table>

Interview	Date	Sector	Position	Pseudonym-Code	Language
20	06-Jun-17	Airline	Safety Manager	Santini-AS	Portuguese
Safety manager for a European charter airline. A former military pilot with a great deal of experience in safety based on more than 30 years of practice, Santini holds a degree in military aeronautical sciences. He has over 35 years of professional experience.					
21	14-Jun-17	Airline	Safety Manager	Dimitri-AS	English
Dimitri is a senior pilot with extensive experience in the industry. He started his career as a mechanical engineer specializing in mechatronics. Before joining the commercial aviation industry, Dimitri studied for a master's degree in propulsion. He is an experienced pilot (clocking up over 6,500 flying hours) who has been involved in flight safety for more than nine years, and been airline safety manager for the last five years. The airline has more than 40 aircraft and performs over 200 flights daily.					
22	14-Jun-17	Airline	Safety Analyst	Gordon-AA	English
Gordon is a junior pilot, clocking up more than 3,000 flying hours so far. Before entering the commercial aviation industry, Gordon studied for a master's degree in engineering, specializing in aviation. Joining the safety department two years ago, he has since become a safety analyst. The airline has more than 40 aircraft and performs over 200 flights daily.					
23	22-Jun-17	Healthcare	Researcher/Psychologist	Alexis-HO	Portuguese
Assistant clinical professor (adjunct) in the field of psychiatry and behavioural neuroscience, Alexis has dedicated his career to research. In the last ten years, he has worked with children and adolescents in the private and public health sector. He has published several scientific papers; currently, the focus of his attention is on the fields of patient safety and quality in health care. He has over 20 years of professional experience.					
24	17-Jun-17	Airline	CEO	Nicholas-HL	English
Manager of a consultancy enterprise, lecturer, and currently studying for his doctorate at a European University, Nicholas is an entrepreneur in the field of risk management. His work experience in safety is extensive and he has conducted extensive research into the area. He has worked for more than ten years in supporting airlines in setting-up their Safety Management Systems (SMS) and has been associated with several developments to improve safety. He was formerly a representative of the EASA review group. Nicholas holds a master's in aeronautical engineering and has over 25 years of safety experience.					

Interview	Date	Sector	Position	Pseudonym-Code	Language
25	20-Jul-18	Healthcare	Risk Manager	Louise-HS	Portuguese
Currently responsible for the risk office in a private hospital unit, Louise has been heavily involved with patient safety and has attended two commissions for patient safety and investigation. Louise has a long professional career supported by more than 30 years of practice and has worked intensively in the areas of quality, infection control, and patient safety. She holds a master’s in error management and is the author of several published articles related to patient safety. Over the course of her career, Louise has won several accolades and prizes for her work in the area of risk management.					
26	24-Aug-17	Airline	Deputy Safety Manager	Peter-AS	Portuguese
Deputy safety manager for a leading regional airline carrier and former flight attendant for a flagship carrier, Peter was promoted to captain five years ago and has 25 years of professional experience.					

Table E.12 – Interviewee profiles

Legend of codes (e.g. “Louise-HS” stands for Health Care & Safety Manager):

- First letter (industry):
  - A – Airline.
  - H – Health care.
- Second letter (function):
  - B – Board member.
  - S – Safety manager.
  - A – Safety analyst.
  - L – Lecturer.
  - O – Other.

E.5 Interview Data

Number	Date	Sector	Position	Pseudonym	Function	Language	Tape File (x.MP3)	Transcript File (x.doc)	Number Pages	Size Time	Word Count		
											Total	1st code	2nd code
1	21-Dec-16	Airline	CEO	Martin	AB	Portuguese	Int #1	Int #1	29	01:00:07	8,537	1,244	370
2	27-Jan-17	Airline	Safety Manager	Thomas	AS	Portuguese	Int #2-4	Int #2-4	147	03:04:21	36,245	2,621	818
3			Safety Manager Deputy	Jack	AS								
4			Safety Analyst	Iolanda	AA								
5	06-Feb-17	Handling	General Director	Tavares	AB	Portuguese	Int #5	Int #5	43	01:04:34	11,944	750	194
6	13-Feb-17	Lecturer	CEO Executive Education	Lary	AB	Portuguese	Int #6	Int #6	27	00:45:43	7,232	1,658	656
7	17-Feb-17	Airline	COO	John	AB	English	Int #7	Int #7	29	00:46:32	8,976	1,577	354
8	08-Mar-17	Maintenance	Board Member	George	AB	Portuguese	Int #8	Int #8	94	02:24:25	27,329	4,273	1,666
9	05-Apr-17	Maintenance	Safety Analyst	India	AS	Portuguese	Int#9	Int #9	55	01:32:53	16,884	1,453	564
10	05-Apr-17	Airline	Safety Manager	Kostas	AS	Portuguese	Int #10	Int #10	48	01:05:58	10,527	2,668	770
11	21-Apr-17	Airline	Safety Manager	Gary	AS	Portuguese	Int #11	Int #11	64	01:46:57	18,375	2,789	1,654
12	27-Apr-17	Airline	Board Member	Charles	AB	Portuguese	Int #12	Int #12	45	01:00:14	10,065	1,909	493
13	27-Apr-17	Airline	Safety Manager	Barros	AS	Portuguese	Int #13	Int #13	43	00:42:00	8,849	1,319	297
14	10-May-17	Airline	Safety Analyst	Bentes	AA	Portuguese	Int #14	Int #14	98	01:23:25	19,483	2,508	848
15	10-May-17	Health Care	Lecturer	Paul	HL	Portuguese	Int #15	Int #15	48	01:15:03	14,263	1,291	451
16	18-May-18	Maintenance	Safety Analyst	India	AS	Portuguese	Int #16	Int #16	92	01:42:57	19,411	876	148
17	30-May-17	Airline	Safety Manager	Jeremiah	AS	Portuguese	Int #17	Int #17	74	02:19:54	22,109	3,227	1,929
18	31-May-17	Health Care	Safety Manager	Sabine	HS	Portuguese	Int #18	Int #18	87	01:51:08	20,345	2,376	954

Number	Date	Sector	Position	Pseudonym	Function	Language	Tape File (x.MP3)	Transcript File (x.doc)	Number Pages	Size Time	Word Count		
											Total	1st code	2nd code
19	05-Jun-17	Health Care	Safety Manager	Sabine	HS	Portuguese	Int #19	Int #19	59	01:19:59	13,502	1,167	428
20	06-Jun-17	Airline	Safety Manager	Santini	AS	Portuguese	Int #20a Int #20b	Int #20a+b	80	02:19:05 00:07:19	23,989	3,114	1,083
21	14-Jun-17	Airline	Safety Manager	Dimitri	AS	English	No record	Int #21 & #22	9	00:00:00	1,357	913	348
22	14-Jun-17	Airline	Safety Analyst	Gordon	AA	English					1,289	1,066	636
23	22-Jun-17	Other	Researcher	Alexis	HO	Portuguese	Int #23	Int #23	19	00:39:13	6,265	598	40
24	17-Jun-17	Other	CEO	Nicholas	AL	English	Int 24	Int #24	20	00:34:19	6,576	2,881	1,485
25	20-Jul-17	Health Care	Safety Manager	Louise	HS	Portuguese	Int #25	Int #25	82	01:58:35	18,437	2,597	997
26	24-Aug-17	Airline	Safety Manager Deputy	Peter	AS	Portuguese	Int #26	Int #26	61	01:13:33	13,534	1,609	406
								Totals:	1353	31:58:14	345,523	46,484	17,589

Table E.13 – Interview data

"Function" column Legend:

- First letter:
    - A – Airline.
    - H – Healthcare.
- Second letter:
    - B – Board member.
    - S – Safety manager.
    - A – Safety analyst.
    - L – Lecturer.
    - O – Other.

E.6 Interview Coding

CODING	INTERVIEWS																								DATA		
	1	2-4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Sub-Total	% Sub-Total	% Total
Gap 1 - Safety Boundaries																											
01 - General / Introduction										1		2													3	2,26%	0,47%
02 - Bridging the Gap			1	5	1	1		1	1						5									2	17	12,78%	2,64%
03 - Development of Safety Boundaries	5	2	1	1	3	10	2	3	4	4	4		1		5		1	5		1		5	5	1	63	47,37%	9,77%
04 - Blurred Boundaries															3	6		3			1	1			14	10,53%	2,17%
05 - Safety Assessment	1	1			1	2			1	3			3		2	1		5	1	1	1	1			24	18,05%	3,72%
06 - Safety Promotion			1	1		1	1	1	1				1		2						2			1	12	9,02%	1,86%
Subtotal	6	3	3	7	5	14	3	5	7	8	4	2	5	0	17	7	1	13	1	2	4	7	5	4	133	100,00%	20,62%
Gap 2 - Risk Tools																											
01 - General / Introduction		1					1		2			3		2				1		1		1		3	15	10,20%	2,33%
02 - Characteristics of the risk tool			1		1	7																2			11	7,48%	1,71%
03 - Type of approach - Qual vs Quant				1					1												1	1			4	2,72%	0,62%
04.01 - Risk Matrix - General		1										2		1	1	5		3							13	8,84%	2,02%
04.01.01 - Risk Matrix - Pros & Cons	1									1	2					1	1	3					3	3	15	10,20%	2,33%
04.01.02 - Risk Matrix - Subjectivity	1	4							1	1			2			4	1	2		2					18	12,24%	2,79%
04.01.03 - Risk Matrix - Prioritization		1					1		2		1		2		2	1				3					13	8,84%	2,02%
04.02 - ARMS		2						2	6			15			2							3			30	20,41%	4,65%
04.03 - Bow Tie										1															1	0,68%	0,16%
04.04 - FMEA																1							6		7	4,76%	1,09%
04.05 - Control Charts		3							2			5	1		1							1			13	8,84%	2,02%
04.06 - Other tools								1					2					1	1	1			1		7	4,76%	1,09%
Subtotal	2	12	1	1	1	7	2	3	14	3	3	25	7	3	6	12	2	10	1	7	1	8	10	6	147	100,00%	22,79%

CODING	INTERVIEWS																								DATA		
	1	2-4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Sub-Total	% Sub-Total	% Total
Gap 3 - Safety Protection																											
01 - General / Introduction									1			1			1								2		5	3,68%	0,78%
02 - Safety Investments	1	1		1	2	5	3	2	4	1	1	6	1	2	8	3	5	1	2	1	1	1	3	4	59	43,38%	9,15%
03 - Longitudinal Monitoring	1			2				1	3	1			3	2		5	7	7		1		1	3		37	27,21%	5,74%
04 - Fuzzy Frequency	1	3				1		2					2	2	4				4			2	5	1	27	19,85%	4,19%
05 - Service Providers							1	3	1						2			1							8	5,88%	1,24%
Subtotal	3	4	0	3	2	6	4	8	9	2	1	7	6	6	15	8	12	9	6	2	1	4	13	5	136	100,00%	21,09%
Gap 4 - Safety Culture																											
01 - General / Introduction									1		3												2		6	9,84%	0,93%
02 - Sustainable factor		1		1	2			2	1	2	3		3		2	1		1			2	2		2	25	40,98%	3,88%
03 - A sociological approach						5					1				1		3	1							11	18,03%	1,71%
04 - Embedding safety culture in RM		1	1	1		1	3		4		1					3			1	1		1		1	19	31,15%	2,95%
Subtotal	0	2	1	2	2	6	3	2	6	2	8	0	3	0	3	4	3	2	1	1	2	3	2	3	61	100,00%	9,46%
Emergent Subjects																											
01 - General	5	7	6	2	1	7	3	4	2				1	3	4	3	1	2	1			2	2	7	63	37,50%	9,77%
02 - Org. Issues - Conflict of interests				1		5	1	4	2	1	1		2			1		2	1						21	12,50%	3,26%
03 - Org. Issues - Training	1	4		1	3	1		1		6	1		1		3	7		2	2	2	4		2	2	43	25,60%	6,67%
04 - Org. Issues - Challenges	1	2				7	1	2	7	6	2				1	1		2	1			4	3	1	41	24,40%	6,36%
Subtotal	7	13	6	4	4	20	5	11	11	13	4	0	4	3	8	12	1	8	5	2	4	6	7	10	168	100,00%	26,05%
Grand Total	18	34	12	17	15	53	17	29	49	30	22	34	25	12	49	43	19	43	14	14	12	28	37	28	**645**		**100,00%**

Table E.14 – Interview coding

F Research on Safety Boundaries

Research of the literature for factors affecting “safety boundaries” was carried out using Web of Science, Google Scholar, NTU Library Onesearch and several academic journals. The keywords of the literature search were “aviation safety boundaries”, “aviation risk acceptability”, “aviation risk tolerance”, and “aviation risk appetite”. To widen the scope of the research, the keyword “aviation” was extended/replaced to include “company”, “organizational”, and “aeronautical”.

Most of the papers found did not focus on an organizational perspective, they were related to a project or an activity (Pauley et al. 2008; Diamantidis et al. 2000; Ji et al. 2011). On other occasions, while the literature related to risk exposure and acknowledged the need to manage bandwidths and envelopes, it failed to define upstream the level of acceptable risk. The majority focused on rare events such as incidents or accidents (Lofquist 2010; Pettersen & Schulman 2019), thus frustrating the attempt to find more factors that might contribute to, or influence the establishment of an organization’s safety boundaries. Ultimately, studies have failed to unite theory and practice, leading to a missed opportunity in enhancing organizational safety performance and setting apart management and operational staff. Research for the current thesis was carried out in the following journals:

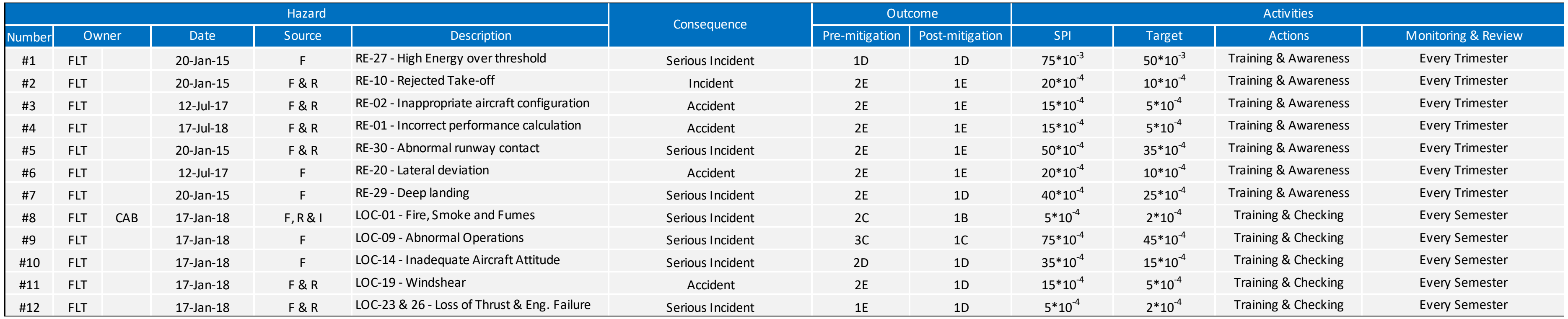
- *Accident Analysis and Prevention*
- *Journal of Air Transport Management*
- *Journal of Economics and Policy*
- *Journal of Loss Prevention in the Process Industrie*s
- *Journal of Safety Research*
- *Reliability Engineering and System Safety*
- *Risk Analysis: An International Journal*
- *Safety Science*
- *The Journal of Risk*
- *Transportation Research*

G EASA Risk Register

The risk register functions as a source of aggregate data, providing a holistic view of the airline's total risk exposure. Taking advantage of data provided in Chapters 6 and 7, respectively, runway excursion and loss of control in-flight hazards, Tables G.15 and G.16, below, present two examples based on European recommendations. The former uses the format EASA (2015) advocates, while the latter uses the design in use by the airline that provided the LOC-I dataset. However, as both examples illustrate, their static nature turns out to be of little use in managing risk.

Hazard		Incident Sequence Description	Existing Controls	Outcome (Pre-mitigation)			Additional Mitigation	Outcome (Pos-mitigation)			Action & Owners	Monitoring & Review Requirements
Number	Description			Frequency	Severity	Risk		Frequency	Severity	Risk		
#1	RE-27 - High Energy over threshold	Runway excursion	3, 5, 6, 7, 8, 10, 11 & 12	3	E	3E	9	1	D	1D	Training & Awareness / Flight Operations	Every Trimester
#2	RE-10 - Rejected Take-off	Runway excursion	4, 7, 8 & 12	2	E	2E	1 & 9	1	E	1E	Training & Awareness / Flight Operations	Every Trimester
#3	RE-02 - Inappropriate aircraft configuration	Runway excursion	4, 7, 8 & 12	2	E	2E	9	1	E	1E	Training & Awareness / Flight Operations	Every Trimester
#4	RE-01 - Incorrect performance calculation	Runway excursion	7, 10 & 12	2	E	2E	1 & 9	1	E	1E	Training & Awareness / Flight Operations	Every Trimester
#5	RE-30 - Abnormal runway contact	Runway excursion	6, 7, 8 & 10	2	E	2E	1 & 9	1	E	1E	Training & Awareness / Flight Operations	Every Trimester
#6	RE-20 - Lateral deviation	Runway excursion	4, 7 & 8	2	E	2E	1 & 9	1	E	1E	Training & Awareness / Flight Operations	Every Trimester
#7	RE-29 - Deep landing	Runway excursion	2, 3, 4, 5, 6, 7, 8, 10 & 11	2	E	2E	1	1	D	1D	Training & Awareness / Flight Operations	Every Trimester
#8	LOC-01 - Fire, Smoke and Fumes	Loss of Control In-Flight	2, 3 5 & 8	2	C	2C	1	1	B	1B	Training & Checking / Flight & Cabin Operations	Every Semester
#9	LOC-09 - Abnormal Operations	Loss of Control In-Flight	3, 4, 5 & 7	3	C	3C	1 & 6	1	C	1C	Training & Checking / Flight Operations	Every Semester
#10	LOC-14 - Inadequate Aircraft Attitude	Loss of Control In-Flight	3, 4, 5 & 7	2	D	2D	1	1	D	1D	Training & Checking / Flight Operations	Every Semester
#11	LOC-19 - Windshear	Loss of Control In-Flight	3, 4, 5 & 7	2	E	2E	1	1	D	1D	Training & Checking / Flight Operations	Every Semester
#12	LOC-23 & 26 - Loss of Thrust & Eng. Failure	Loss of Control In-Flight	3, 5 & 8	1	E	1E	1	1	D	1D	Training & Checking / Flight Operations	Every Semester

Table G.15 – EASA risk register



Hazard						Consequence	Outcome		Activities			
Number	Owner		Date	Source	Description		Pre-mitigation	Post-mitigation	SPI	Target	Actions	Monitoring & Review
#1	FLT		20-Jan-15	F	RE-27 - High Energy over threshold	Serious Incident	1D	1D	$75*10^{-3}$	$50*10^{-3}$	Training & Awareness	Every Trimester
#2	FLT		20-Jan-15	F & R	RE-10 - Rejected Take-off	Incident	2E	1E	$20*10^{-4}$	$10*10^{-4}$	Training & Awareness	Every Trimester
#3	FLT		12-Jul-17	F & R	RE-02 - Inappropriate aircraft configuration	Accident	2E	1E	$15*10^{-4}$	$5*10^{-4}$	Training & Awareness	Every Trimester
#4	FLT		17-Jul-18	F & R	RE-01 - Incorrect performance calculation	Accident	2E	1E	$15*10^{-4}$	$5*10^{-4}$	Training & Awareness	Every Trimester
#5	FLT		20-Jan-15	F & R	RE-30 - Abnormal runway contact	Serious Incident	2E	1E	$50*10^{-4}$	$35*10^{-4}$	Training & Awareness	Every Trimester
#6	FLT		12-Jul-17	F	RE-20 - Lateral deviation	Accident	2E	1E	$20*10^{-4}$	$10*10^{-4}$	Training & Awareness	Every Trimester
#7	FLT		20-Jan-15	F	RE-29 - Deep landing	Serious Incident	2E	1D	$40*10^{-4}$	$25*10^{-4}$	Training & Awareness	Every Trimester
#8	FLT	CAB	17-Jan-18	F, R & I	LOC-01 - Fire, Smoke and Fumes	Serious Incident	2C	1B	$5*10^{-4}$	$2*10^{-4}$	Training & Checking	Every Semester
#9	FLT		17-Jan-18	F	LOC-09 - Abnormal Operations	Serious Incident	3C	1C	$75*10^{-4}$	$45*10^{-4}$	Training & Checking	Every Semester
#10	FLT		17-Jan-18	F	LOC-14 - Inadequate Aircraft Attitude	Serious Incident	2D	1D	$35*10^{-4}$	$15*10^{-4}$	Training & Checking	Every Semester
#11	FLT		17-Jan-18	F & R	LOC-19 - Windshear	Accident	2E	1D	$15*10^{-4}$	$5*10^{-4}$	Training & Checking	Every Semester
#12	FLT		17-Jan-18	F & R	LOC-23 & 26 - Loss of Thrust & Eng. Failure	Serious Incident	1E	1D	$5*10^{-4}$	$2*10^{-4}$	Training & Checking	Every Semester

Table G.16 – Airline risk register based on EASA (2015) recommendations

Opposed to the static approach conveyed by the risk register of EASA (2015), the one put forward in Figure G.17, below, encompasses the stance espoused by Complexity Theory and Systems Thinking. The innovative design of the “Oyster Model” considers risk aggregation and continuous risk monitoring to bring about the explanatory and predictive power of systems behaviour. With the support of the two risk tools, decision-makers will be able to make better informed and systematic decisions about acceptable risk exposure and resource allocation.

The illustrative package available at https://oystermodel.com/[136] presents a perspective of the “Oyster Model” that is relevant to the current thesis.

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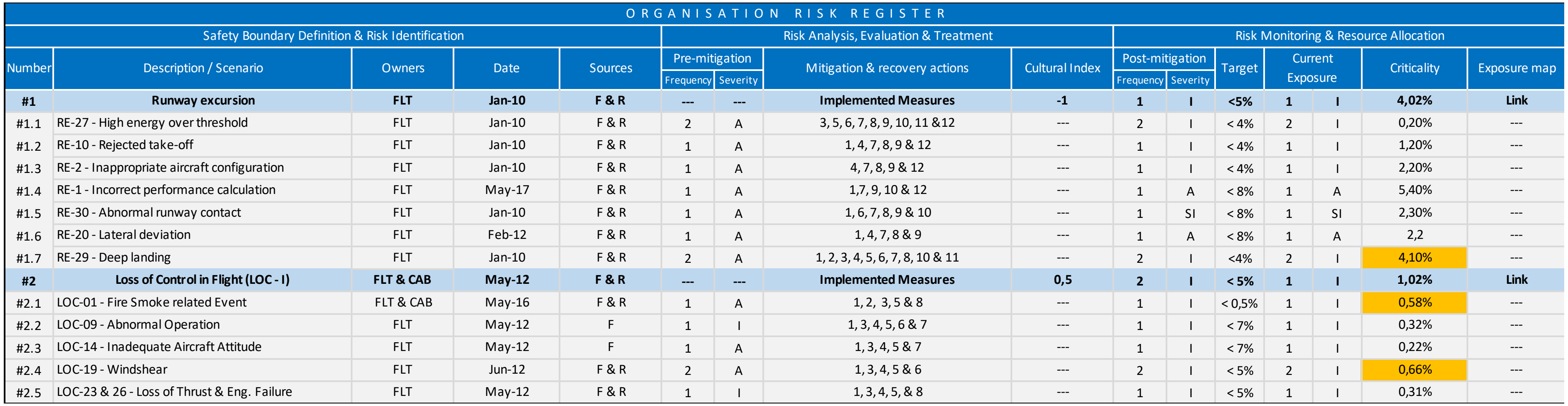
[136] To login use “public” as username and password.



ORGANISATION RISK REGISTER															
Safety Boundary Definition & Risk Identification					Risk Analysis, Evaluation & Treatment				Risk Monitoring & Resource Allocation						
Number	Description / Scenario	Owners	Date	Sources	Pre-mitigation		Mitigation & recovery actions	Cultural Index	Post-mitigation		Target	Current Exposure		Criticality	Exposure map
					Frequency	Severity			Frequency	Severity					
#1	**Runway excursion**	**FLT**	**Jan-10**	**F & R**	**---**	**---**	**Implemented Measures**	**-1**	**1**	**I**	**<5%**	**1**	**I**	**4,02%**	**Link**
#1.1	RE-27 - High energy over threshold	FLT	Jan-10	F & R	2	A	3, 5, 6, 7, 8, 9, 10, 11 &12	---	2	I	< 4%	2	I	0,20%	---
#1.2	RE-10 - Rejected take-off	FLT	Jan-10	F & R	1	A	1, 4, 7, 8, 9 & 12	---	1	I	< 4%	1	I	1,20%	---
#1.3	RE-2 - Inappropriate aircraft configuration	FLT	Jan-10	F & R	1	A	4, 7, 8, 9 & 12	---	1	I	< 4%	1	I	2,20%	---
#1.4	RE-1 - Incorrect performance calculation	FLT	May-17	F & R	1	A	1,7, 9, 10 & 12	---	1	A	< 8%	1	A	5,40%	---
#1.5	RE-30 - Abnormal runway contact	FLT	Jan-10	F & R	1	A	1, 6, 7, 8, 9 & 10	---	1	SI	< 8%	1	SI	2,30%	---
#1.6	RE-20 - Lateral deviation	FLT	Feb-12	F & R	1	A	1, 4, 7, 8 & 9	---	1	A	< 8%	1	A	2,2	---
#1.7	RE-29 - Deep landing	FLT	Jan-10	F & R	2	A	1, 2, 3, 4, 5, 6, 7, 8, 10 & 11	---	2	I	<4%	2	I	4,10%	---
#2	**Loss of Control in Flight (LOC - I)**	**FLT & CAB**	**May-12**	**F & R**	**---**	**---**	**Implemented Measures**	**0,5**	**2**	**I**	**< 5%**	**1**	**I**	**1,02%**	**Link**
#2.1	LOC-01 - Fire Smoke related Event	FLT & CAB	May-16	F & R	1	A	1, 2, 3, 5 & 8	---	1	I	< 0,5%	1	I	0,58%	---
#2.2	LOC-09 - Abnormal Operation	FLT	May-12	F	1	I	1, 3, 4, 5, 6 & 7	---	1	I	< 7%	1	I	0,32%	---
#2.3	LOC-14 - Inadequate Aircraft Attitude	FLT	May-12	F	1	A	1, 3, 4, 5 & 7	---	1	I	< 7%	1	I	0,22%	---
#2.4	LOC-19 - Windshear	FLT	Jun-12	F & R	2	A	1, 3, 4, 5 & 6	---	2	I	< 5%	2	I	0,66%	---
#2.5	LOC-23 & 26 - Loss of Thrust & Eng. Failure	FLT	May-12	F & R	1	I	1, 3, 4, 5, & 8	---	1	I	< 5%	1	I	0,31%	---

Table G.17 – Airline risk register supported by the “Oyster Model”

Table G.17 Legend

1. Number: sequencing number of hazards and subset of threats that concur to the main hazard.
2. Description / Scenario: a description of the undesirable outcome.
3. Owner: responsible entity to manage the hazard.
4. Date: the beginning of monitoring.
5. Sources: hazard identification origin: A-audit, F-FDM, I-investigation, R-reporting, S-survey, Z-other source.
6. Pre-mitigation (frequency/severity): risk-exposure level without mitigation & recovery measures. Frequency levels are associated with the number of levels implemented in the “risk-exposure” map. Severity codes stand for: A – accident, I – incident and SI – serious incident.
7. Mitigation and recovery actions: implemented measures, identified in the “risk-exposure” map. In the current example, the decoding appears in Table 7.6 and Appendix L.

8. Cultural index – The impact generated by local culture. Values are allowed to vary between -1 and 1. Negative values expand the risk-exposure cloud, while positive values contract it.
9. Post-mitigation (frequency / severity): forecast outcome after implementing mitigation & protective measures.
10. Target: The desired exposure level.
11. Current exposure: The overall (aggregate threat – "T") and/or individual current threat-level exposure.
12. Criticality: the highest severity- and frequency-level achieved by the aggregate ("T") and individual threat. The cell changes to red whenever the value exceeds the defined target.
13. Exposure Map: Link to the "risk-exposure" map.

Note:

"Stack" map: The "Stack" map will be available through an independent link. When selecting the "Stack" map for an individual hazard, the information presented is analogous to that obtained from monitoring the "risk-exposure" map. For the purposes of comparison, analysts may choose a specific set of hazards/threats, the entire set of hazards/threats associated with a particular area or multiple areas, or even the organization's whole set of hazards/threats.

H Safety Performance Indicators

This kind of data may allow the inference of organization's weaknesses. Therefore, airlines are very reluctant to share their indicators. The list below was shared without associated figures (i.e. the aimed for targets) and on the condition of not containing any direct or indirect reference to the organization. The sole purpose is to understand how indicators are developed within the industry.

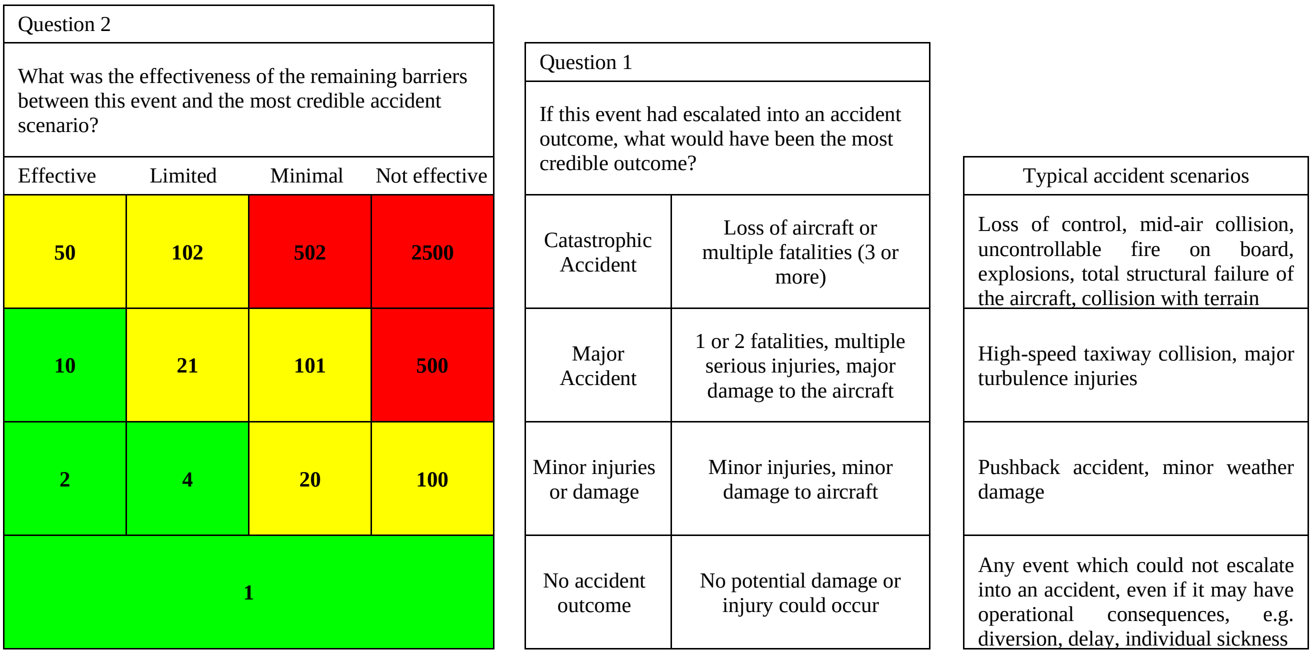
The organization developed their risk level status based on 20 major indicators. No precursors were established. All the indicators are based on a frequency approach, without considering the exposure risk level.

Target	Definition of operational safety targets
#1	Number of inadvertent slide deployments / 1,000 flights
#2	Number of on-board injuries / 1,000 flights
#3	Ratio of technical incidents / 1,000 flights
#4	MEL items with operational procedure (2 or more items per cycle) / 1,000 flights
#5	DG without NOTOC or incorrect NOTOC or non-declared DG / 1,000 flights
#6	Cargo mishandling and/or luggage / 1,000 flights
#7	Leakage from cargo and/or luggage / 1,000 flights
#8	Error or missing on board documentation / 1,000 flights
#9	Weight and balance error / 1,000 flights
#10	Captain's additional fuel / 1,000 flights
#11	Extension of Flight Duty Period / 1,000 flights
#12	EGPWS and GPWS warnings / 1,000 flights
#13	Unstable approach / 1,000 flights
#14	Total of Go-Arounds from unstable approaches / Number of unstable approaches
#15	Ground Aircraft Damage / 1,000 flights
#16	Misapplication of armed & custodian passengers / per flight with passengers
#17	Illicit acts / 1,000 flights
#18	Crewmember with fatigue / 1,000 flights
#19	Accidents and serious incidents / 1,000 flights
#20	Abnormal occurrences on Ground / 1,000 flights

Table H.18 – Safety performance indicators

I Airline Risk Management Solutions (ARMS)

Basic ARMS (2011) is supported by two fundamental questions. The first identifies what would have been the most credible outcome had the event not been detected by the operational staff, whereas the second identifies the strengths of the barriers installed in the system.



Question 2

What was the effectiveness of the remaining barriers between this event and the most credible accident scenario?

Question 1

If this event had escalated into an accident outcome, what would have been the most credible outcome?

Effective	Limited	Minimal	Not effective	Question 1		Typical accident scenarios
🟨 **50**	🟨 **102**	🟥 **502**	🟥 **2500**	Catastrophic Accident	Loss of aircraft or multiple fatalities (3 or more)	Loss of control, mid-air collision, uncontrollable fire on board, explosions, total structural failure of the aircraft, collision with terrain
🟩 **10**	🟨 **21**	🟨 **101**	🟥 **500**	Major Accident	1 or 2 fatalities, multiple serious injuries, major damage to the aircraft	High-speed taxiway collision, major turbulence injuries
🟩 **2**	🟩 **4**	🟨 **20**	🟨 **100**	Minor injuries or damage	Minor injuries, minor damage to aircraft	Pushback accident, minor weather damage
🟩 **1**				No accident outcome	No potential damage or injury could occur	Any event which could not escalate into an accident, even if it may have operational consequences, e.g. diversion, delay, individual sickness

Figure I.45 – Basic ARMS – Event Risk Classification (ERC)

ARMS + represents an evolution of the basic tool and is based on three questions:

- What were the actual consequences of this occurrence?
- If this event had escalated into an accident outcome, what would have been the most credible outcome?
- What was the effectiveness of the remaining barriers between this event and the most credible accident scenario?

ARMS + adds an extra question – the evaluation of the actual consequences – which is measured in the last column, and expands the "post-accident-outcome" possibilities as well as the barriers evaluation approach based on a frequency. The outcome of the analysis incorporates the results from both questions. Numerical values are used to perform comparison among locations and type of events.

Potential Accident Outcome							
Extreme catastrophic accident with significant potential fatalities (100+)	**0.1**	**10**	**1000**	**10 000**	**100 000**		**1 000 000**
Significant accident with significant potential for fatalities and injuries (10-100)	**0.01**	**1**	**100**	**1000**	**10 000**		**100 000**
Major accident with potential for some fatalities or life changing injuries (2-9) or major aircraft destroyed	**1E-03**	**0.1**	**10**	**100**	**1000**		**10 000**
Single individual fatality or life changing injury or substantial damage aircraft accident	**1E-04**	**0.01**	**1**	**10**	**100**		**1000**
Minor and serious injury (not life changing) accidents and minor damage	**1E-06**	**1E-04**	**0.01**	**0.1**	**1**		**10**
No consequence	**1E-08**						
	Excellent barriers (Remaining barriers predicted to fail less than 1 in 1M times)	**Good Barriers** (Remaining barriers predicted to fail less than 1 in 10 000 times)	**Moderate Barriers** (Remaining barriers predicted to fail more than 1 in 10 000 times)	**Ineffective Barriers** (Remaining barriers predicted to fail more than 1 in 100 times)	**No effective Barriers** (Remaining barriers predicted to fail more than 1 in 10 times)		**Realized accidents**

Figure I.46 – ARMS + – Event Risk Classification (ERC)

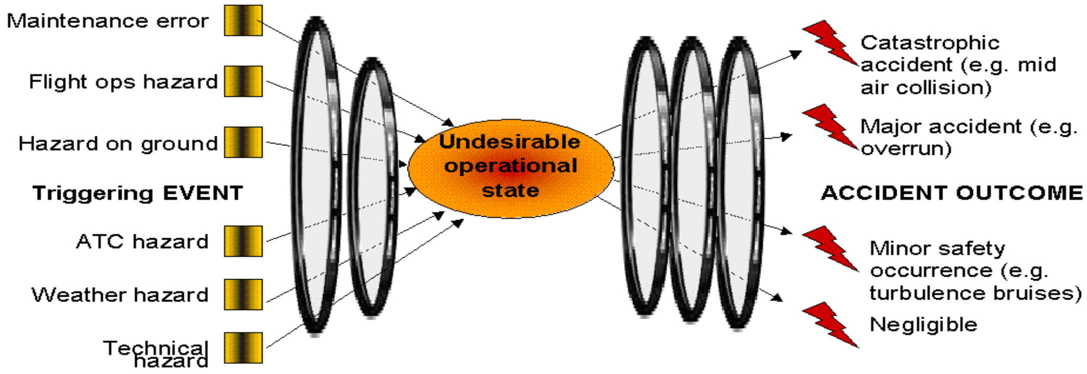
	Safety Issue Risk Assessment (SIRA) Tool					
1	**Safety Issue title:**					
2	**Define/Scope of SI:**					
	Description of hazard(s)					
	Description of scenario					
	A/c types					
	Location					
	Time period under study					
	Other					
3	**Analysis of Potential Accident Scenario**					
	3.1 Triggering Event		3.2 Undesirable Operational State		3.3 Accident outcome	
						
4	**Describe the barriers**					
		4.1 To avoid the UOS		4.2 To recover from the accident		
5	**Risk Assessment**					
	The estimated frequency of the triggering event (per flight sectors) is:	The barriers will fail in avoiding the UOS…		The barriers will fail in recovering the situation before the accident	The accident severity would be	
	Virtually every flight	Once in 100 times		Once in 1000 times	Negligible	
	1.E+00	**1.E-02**	**UOS Frequency**	**1.E-03**	**Mean accident frequency**	**Stop**
			1.E-02		**1.E-05**	**Improve**
6	**Result**					**Secure**
	6.1 Resulting risk class	**Accept**				**Monitor**
	Comments on actions					**Accept**

Figure I.47 – Basic ARMS – Safety Issue Risk Assessment (SIRA)

Based on the figures below, the decision-making process for the Basic ARMS is supported by the following calculations:

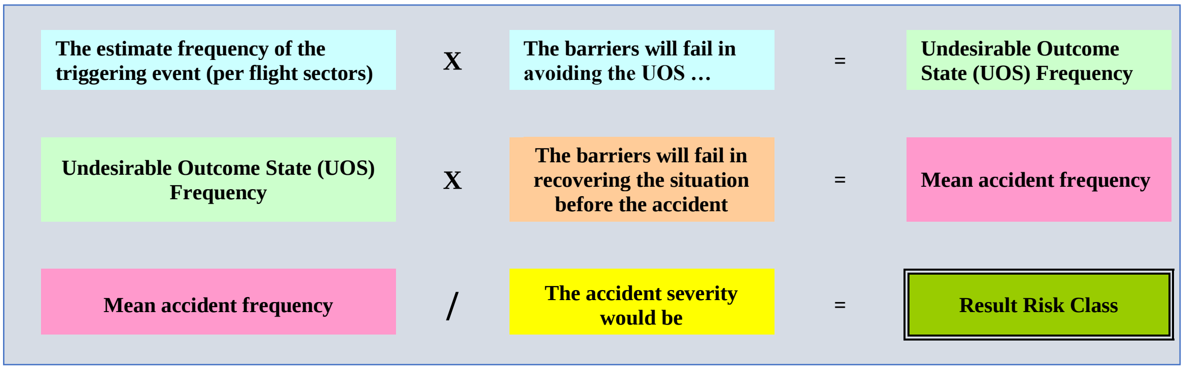


Figure I.48 – ARMS Risk Class calculation

The estimate frequency of the triggering event (per flight sectors) is:		The barriers will fail in Avoiding the UOS…		The barriers will fail in recovering the situation before the accident	
Virtually every flight	1.E+00	Practically always	1.E+00	Practically always	1.E+00
Almost every flight	1.E-01	Once every 10 times	1.E-01	Once every 10 times	1.E-01
About every 100 sectors	1.E-02	Once in 100 times	1.E-02	Once in 100 times	1.E-02
About every 1000 sectors	1.E-03	Once in 1000 times	1.E-03	Once in 1000 times	1.E-03
About every 10000 sectors	1.E-04	Once in 10 000 times	1.E-04	Once in 10 000 times	1.E-04
About every 100000 sectors	1.E-05	Once in 100 000 times	1.E-05	Once in 100 000 times	1.E-05
About every 1M sectors	1.E-06	Once in 1M times	1.E-06	Once in 1M times	1.E-06
About every 10 M sectors	1.E-07	Once in 10M times	1.E-07	Once in 10M times	1.E-07

Figure I.49 – ARMS Occurrence figures

The accident severity would be:	Tolerability Limit	Short Definition	Difference with tolerability limit	Consequence
Catastrophic	1.E-09	3 fatalities or more	1.E-02	Accept
Major	1.E-07	Serious injuries	1.E-01	Monitor
Minor	1.E-05	Minor injuries	1.E+00	Secure
Negligible	1.E+00	Negligible	1.E+01	Improve
			1.E+02	Stop

Figure I.50 – ARMS Tolerability decision-making

J ICAO Annex 13: Accident, Incident and Serious Incident Definitions

The definitions and “Attachment C”, below, were obtained from ICAO’s Annex 13 – Aircraft Accident and Incident Investigation (ICAO 2020). The European Parliament and the Council Regulation 996/2010 published on 20 October, on the investigation and prevention of accidents and incidents in civil aviation present the same definition. Nevertheless, the descriptions included in the European Regulation are quite similar to those already presented by the ICAO, which is why they are not included in this appendix.

“**Accident**. An occurrence associated with the operation of an aircraft which, in the case of a manned aircraft, takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, or in the case of an unmanned aircraft, takes place between the time the aircraft is ready to move with the purpose of flight until such time as it comes to rest at the end of the flight and the primary propulsion system is shut down, in which:

a) a person is fatally or seriously injured as a result of:
   - being in the aircraft, or
   - direct contact with any part of the aircraft, including parts which have become detached from the aircraft, or
   - direct exposure to jet blast, except when the injuries are from natural causes, self-inflicted or inflicted by other persons, or when the injuries are to stowaways hiding outside the areas normally available to the passengers and crew; or

b) the aircraft sustains damage or structural failure which:
   - adversely affects the structural strength, performance or flight characteristics of the aircraft, and
   - would normally require major repair or replacement of the affected component, except for engine failure or damage, when the damage is limited

to a single engine (including its cowlings or accessories), to propellers, wing tips, antennas, probes, vanes, tires, brakes, wheels, fairings, panels, landing gear doors, windscreens, the aircraft skin (such as small dents or puncture holes), or for minor damages to main rotor blades, tail rotor blades, landing gear, and those resulting from hail or bird strike (including holes in the radome); or

c) the aircraft is missing or is completely inaccessible.

Note 1 – For statistical uniformity only, an injury resulting in death within thirty days of the date of the accident is classified, by ICAO, as a fatal injury.

Note 2 – An aircraft is considered to be missing when the official search has been terminated and the wreckage has not been located.

Note 3 – The type of unmanned aircraft system to be investigated is addressed in 5.1.

Note 4 – Guidance for the determination of aircraft damage can be found in Attachment E.”

“**Incident**. An occurrence, other than an accident, associated with the operation of an aircraft which affects or could affect the safety of operation.

Note – The types of incidents which are of main interest to the International Civil Aviation Organization for accident prevention studies are listed in Attachment C.”

“**Serious incident**. An incident involving circumstances indicating that there was a high probability of an accident and associated with the operation of an aircraft which, in the case of a manned aircraft, takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, or in the case of an unmanned aircraft, takes place between the time the aircraft is ready to move with the purpose of flight until such time as it comes to rest at the end of the flight and the primary propulsion system is shut down.

Note 1 – The difference between an accident and a serious incident lies only in the result.

Note 2 – Examples of serious incidents can be found in Attachment C.”

“**Attachment C** – List of Examples of Serious Incidents

1. The term serious incident is defined in Chapter 1 as follows: […]

3. The incidents listed are examples of what may be serious incidents. However, the list is not exhaustive and, depending on the context, items on the list may not be classified as serious incidents if effective defences remained between the incident and the credible scenario.

   Near collisions requiring an avoidance manoeuvre to avoid a collision or an unsafe situation or when an avoidance action would have been appropriate.

   Collisions not classified as accidents.

   Controlled flight into terrain only marginally avoided.

   Aborted take-offs on a closed or engaged runway, on a taxiway[137] or unassigned runway.

   Take-offs from a closed or engaged runway, from a taxiway or unassigned runway.

   Landings or attempted landings on a closed or engaged runway, on a taxiway or unassigned runway or on unintended landing locations such as roadways.

   Retraction of a landing gear leg or wheels-up landing not classified as an accident.

   Dragging during landing of a wing tip, an engine pod or any other part of the aircraft, when not classified as an accident.

   Gross failures to achieve predicted performance during take-off or initial climb.

   Fires and/or smoke in the cockpit, in the passenger compartment, in cargo compartments or engine fires, even though such fires were extinguished by the use of extinguishing agents.

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[137] Excluding authorized operations by helicopters

Events requiring the emergency use of oxygen by the flight crew.

Aircraft structural failures or engine disintegrations, including uncontained turbine engine failures, not classified as an accident.

Multiple malfunctions of one or more aircraft systems seriously affecting the operation of the aircraft.

Flight crew incapacitation in flight:

a) for single pilot operations (including remote pilot); or

b) for multi-pilot operations for which flight safety was compromised because of a significant increase in workload for the remaining crew.

Fuel quantity level or distribution situations requiring the declaration of an emergency by the pilot, such as insufficient fuel, fuel exhaustion, fuel starvation, or inability to use all usable fuel on board.

Runway incursions classified with severity A. The *Manual on the Prevention of Runway Incursions* (Doc 9870) – contains information on the severity classifications.

Take-off or landing incidents. Incidents such as under-shooting, overrunning or running off the side of runways.

System failures (including loss of power or thrust), weather phenomena, operations outside the approved flight envelope or other occurrences which caused or could have caused difficulties controlling the aircraft.

Failures of more than one system in a redundancy system mandatory for flight guidance and navigation.

The unintentional or, as an emergency measure, the intentional release of a slung load or any other load carried external to the aircraft.”

K The Eight-Entrances Risk Tool

Below, Figure K.51 includes eight entrances for each type of event. Each protective measure accounts four units, and the column ‘0’ representing a complete absence of measures accounts five units, with the exception of the one related with accidents, which has an extra unit.

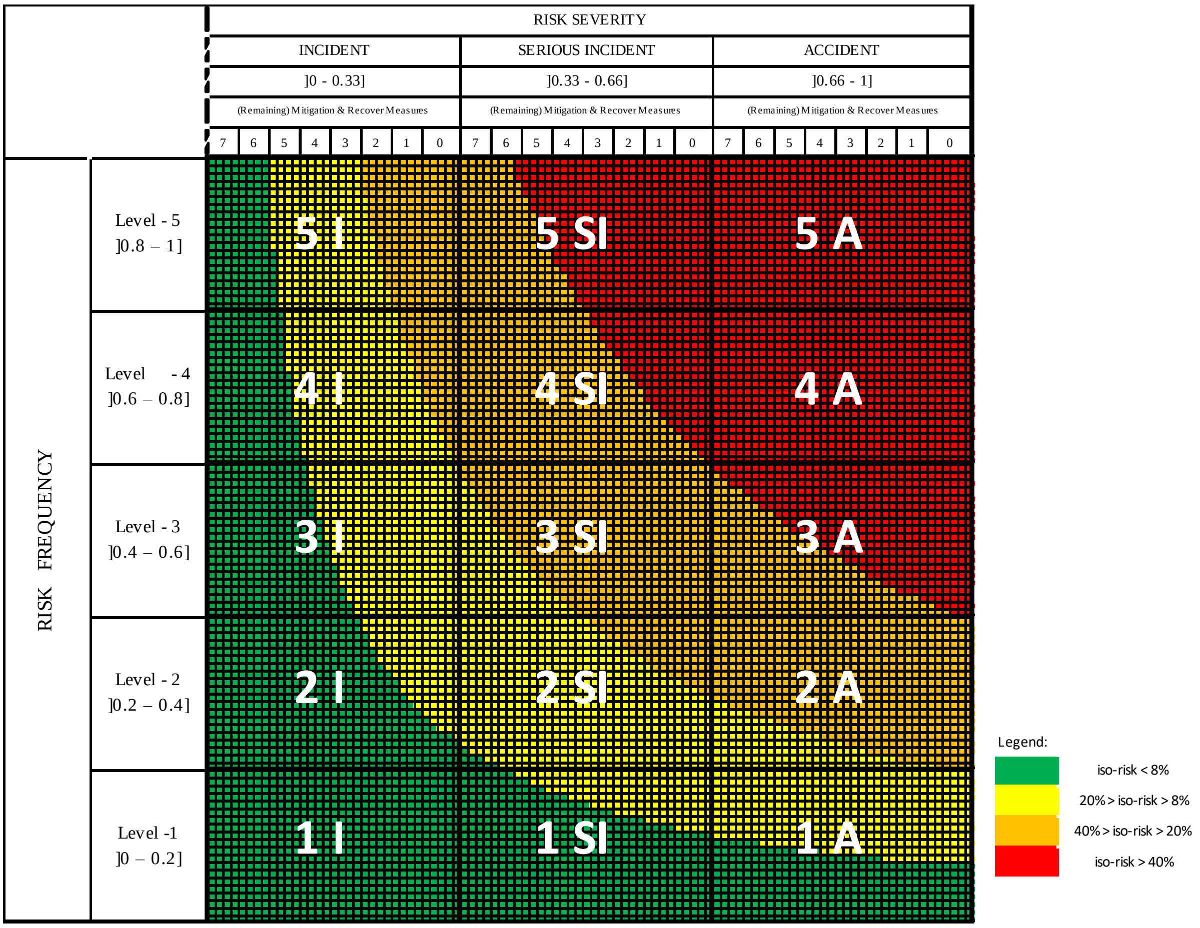

Figure K.51 – The eight-entrances risk tool

L Runway Excursion Datasets for 2018 and 2019

The data contained in the Table L.19, below, refers to the 2018 period. It was obtained from two sources: reporting and from Flight Data Monitoring (FDM). Their use has a proactive perspective in the sense that an analyst can observe trends and behaviours from the "risk-exposure" map that is used to present the information.

Threats	Descriptors[138]	Number of Events 2018	Initial Outcome	Mitigation / Recover Measures	Final Outcome
1	RE-27 – High energy over threshold	35	Accident	9	Incident
2	RE-10 – Rejected take-off	5	Accident	6	Incident
3	RE-02 – Inappropriate aircraft configuration	0	Accident	5	Incident
4	RE-01 – Incorrect performance calculation	8	Accident	5	Accident
5	RE-30 – Abnormal runway contact	18	Accident	6	Serious Incident
6	RE-20 – Lateral deviation	12	Accident	5	Accident
7	RE-29 – Deep landing	22	Accident	10	Incident

Table L.19 – Runway-excursion threats: Dataset from 2018, occurrences per 10,000 flights

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[138] Descriptors were extracted from the EASA EOFDM (2020) Guidance document on how to implement the FDM programme. The majority of the 34 descriptors that constitute the runway-excursion set are at a developmental stage, and airlines are incapable of implementing the whole range of precursors. In the current example, the scenario considers the development of means to:

- "Estimate height, airspeed and ground speed while crossing the runway threshold (RE-27).
- Identify rejected take-offs (RE-10).
- Detect inappropriate aircraft configurations (lifting devices, pitch trim) which could cause takeoff and landing performance problems (…) (RE-02).
- Detect erroneous data entry or calculation errors which could lead to incorrect thrust settings, incorrect V speeds or incorrect target approach speeds (RE-01).
- Identify and quantify bounced (main or nose wheels), tail and wingtip strikes, off-centre, nose-first or asymmetrical landings (RE-30).
- Identify excessive lateral deviations or oscillations during the Take-off, rejected Take-off and landing taking in consideration the runway width (RE-20).

Estimate the distance from the runway threshold until the touchdown point and also the runway length available after touchdown (RE-29)." EASA EOFDM (2020).

Threats	Descriptors	Number of Events 2018	Initial Outcome	Mitigation / Recover Barriers	Forecasted Outcome	Number of Events 2019	Remaining Mitigation / Recovery Barriers	Assessed Outcome
1	RE-27 – High energy over threshold	35	Accident	9	Incident	30	8	Incident
1						10	4	Incident
1						7	3	Serious Incident
2	RE-10 – Rejected take-off	5	Accident	6	Incident	12	2	Incident
3	RE-02 – Inappropriate aircraft configuration	0	Accident	5	Incident	0	5	Incident
4	RE-01 – Incorrect performance calculation	8	Accident	5	Accident	9	2	Serious Incident
5	RE-30 – Abnormal runway contact	18	Accident	6	Serious Incident	10	3	Serious Incident
6	RE-20 – Lateral deviation	12	Accident	5	Accident	3	4	Serious Incident
7	RE-29 – Deep landing	22	Accident	10	Incident	15	8	Incident

Table L.20 – Runway-excursion threats: Datasets from 2018 and 2019, occurrences per 10,000 flights.

Threats	Descriptors	Implemented Defensive Measures (Barriers)												Total
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	
1	RE-27 – High energy over threshold			✓		✓	✓	✓	✓	✓	✓	✓	✓	9
2	RE-10 – Rejected take-off	✓			✓			✓	✓	✓			✓	6
3	RE-02 – Inappropriate aircraft configuration				✓			✓	✓	✓			✓	5
4	RE-01 – Incorrect performance calculation	✓						✓		✓	✓		✓	5
5	RE-30 – Abnormal runway contact	✓					✓	✓	✓	✓	✓			6
6	RE-20 – Lateral deviation	✓			✓			✓	✓	✓				5

Table L.21 – Runway excursion mitigation and recovery, protective measures implemented in the field

Implemented Defensive Measures (Barriers) Legend:

1 – Specific training & checking
2 – Landing distance calculation
3 – Landing configuration selection
4 – Runway selection
5 – Braking selection
6 – Stabilization criteria
7 – Pilot monitoring
8 – Instrument guidance
9 – Safety awareness
10 – Go-around / Full power (recovery)
11 – Runway Overrun Warning (ROW/ROP) (recovery)
12 – Runway end safety area (RESA) (recovery)

Threats	Descriptors	Frequency (F)	Severity (S)	(F) x (S)
1	RE-27 – High energy over threshold	0.35	0.05	0.0175
2	RE-10 – Rejected take-off	0.05	0.14	0.007
3	RE-02 – Inappropriate aircraft configuration	0	0.17	0
4	RE-01 – Incorrect performance calculation	0.08	0.83	0.0664
5	RE-30 – Abnormal runway contact	0.18	0.47	0.0846
6	RE-20 – Lateral deviation	0.12	0.83	0.0996
7	RE-29 – Deep landing	0.22	0.02	0.0044
	Total	1.0	---	0.28
	Average	**≈ 14**	---	**≈ 0.04**

Table L.22 – Runway excursion aggregate threat: Dataset from 2018, occurrences per 10,000 flights

Table L.22: Explanation of calculations.

In the example using threat number 1, the table indicates 35 events in 2018 and implementation of nine mitigation/recovery barriers.

The risk exposure [(F) x (S)] of “0.0175” is obtained from the product of the frequency of 35 events (0.35) by the severity of 9 measures (0.05). The latter value is achieved by counting the number of entries from the beginning of the “Y” axis to 9 recovery and protective measures, that is, five entries (0.05). Note that the specific “risk-exposure” map got each mitigation/recovery barrier, by design, accounts for three entries as a consequence of the number of implemented measures. Therefore, three units for the 10th measure and two additional for the 9th measure, where threat number 1 is plotted.

The total frequency of 1.0 represents 100 events that result from the sum of the whole set of events. The result 0.28 is the sum of the seven products (F) x (S). Finally, to obtain and plot the “T” circle representing the aggregate threat information, one has to divide each result by the number of threats that concur for the hazard. In the example, 7 threats: 1.0 / 7 ≈ 14 and 0.28 / 7 = 0.04.

M ICAO’s SMS Framework

ICAO’s SMS Manual (ICAO 2018b) recommends four pillars and 12 elements, as a minimum framework for a full SMS implementation, specifically:

1. “Safety policy and objectives:
    - 1.1. Management commitment and responsibility.
    - 1.2. Safety accountabilities.
    - 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.”