Development of an Aerodrome Risk Assessment Tool

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Thesis to obtain the Master of Science Degree in

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In memory of my grandfather José Alberto Abreu de Freitas.

Wherever you are, I hope you are proud.

Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Resumo

O complexo mundo da aviação comercial está, constantemente, sujeito a um ritmo de desenvolvimento consideravelmente elevado onde, a cada dia, se exige mais celeridade no transporte de passageiros e bens, nunca abdicando dos elevados padrões de segurança inerentes a este tipo de atividade.

Ao departamento de segurança dos operadores aéreos cabe a responsabilidade de realizar, de forma completamente imparcial, o estudo de segurança no sentido de prevenção, executando uma atividade independente de qualquer outra direção.

Um operador que exerça atividade em diversos destinos requer do departamento de Segurança Operacional uma contínua análise dos seus aeródromos de eleição. Sendo esta uma análise extremamente multifacetada, para além do âmbito da segurança, é necessário abordar todas as características de um aeródromo como meteorologia, desempenho, meios de assistência, capacidade, acomodações, licenças específicas, distância a aeródromos alternantes, acessibilidade, entre outros.

Com esta tarefa em mente, definiu-se como objectivo deste projeto o desenvolvimento e a implementação de uma ferramenta que permitisse efetuar, de forma padronizada e com reduzida subjectividade, uma análise mais quantitativa do risco da operação em cada aeródromo, de modo a mantê-lo dentro dos limites definidos como aceitáveis.

Após a implementação desta ferramenta verificou-se a obtenção de resultados de risco coerentes com os padrões de segurança da empresa à qual esta se destina, demonstrando assim potencial para integração na rotina de operação do departamento de Segurança Operacional da mesma, assim como potencial para uma base de desenvolvimento de ferramentas alternativas destinadas à análise de risco de rotas aéreas, aeronaves e tripulações.

Palavras-chave: Segurança, Aeródromo, Análise de Risco, *Checklist*, Procedimento, Imparcialidade.

Abstract

The complex world of commercial aviation is constantly subject to a considerably high pace of development where, every day, is required faster transport of passengers and goods, never relinquishing the high safety standards inherent in this type of activity.

The airline operator's safety department has the responsibility to carry out, in a completely impartial manner, the safety study in the sense of prevention, performing an activity independent of any other department.

An operator operating in different destinations requires the safety department to continuously analyse its aerodromes of choice. This being an extremely multifaceted analysis, in addition to the safety scope, it is necessary to address all the characteristics of an aerodrome such as meteorology, performance, means of assistance, capacity, accommodations, specific licenses, distance to alternates, accessibility, among others.

With this task in mind, the objective of this project was defined as the development and implementation of a tool that would allow to carry out, in a uniform way and with reduced subjectivity, a quantitative analysis of the risk of the operation at each aerodrome, in order to keep it within the limits defined as acceptable.

After the implementation of this tool, risk results were found to be consistent with the safety standards of the company to which it is intended, thus demonstrating the potential for integration into the safety department's operational routine, as well as potential support for the development of alternative tools for risk analysis of air routes, aircraft and crews.

Keywords: Safety, Aerodrome, Risk Assessment, Checklist, Procedure, Impartiality.

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Nomenclature

Greek symbols

α Perceived risk exponential factor.

Roman symbols

E Exposure level.

P Probability level.

R^2 Coefficient of determination.

R_N Risk number.

R_S Risk score.

S Severity level.

t Time step.

Glossary

AAL Above Aerodrome Level.

ADREP Accident/Incident Data Reporting.

ADRM Aerodrome (ADREP Occurrence Category).

AIP Aeronautical Information Publication.

AMSL Above Sea Level.

AOB Aerodrome Operation Briefing.

AOG Aircraft On Ground.

ARAS Aerodrome Risk Assessment Summary.

ARAT Aerodrome Risk Assessment Tool.

ARP Aerodrome Reference Point.

ASN Aviation Safety Network.

CFIT Controlled Flight Into Terrain (ADREP Occurrence Category).

DRMD Dynamic Risk Management Dashboard.

EASA European Aviation Safety Agency.

ECCAIRS European Coordination Centre for Accident and Incident Reporting Systems.

F-POST : Fire/smoke POST-impact (ADREP Occurrence Category).

FAA Federal Aviation Administration.

FDM Flight Data Monitoring.

FDR Flight Data Recorder.

FSF Flight Safety Foundation.

GTOW Glider TOWing related events (ADREP Occurrence Category).

ICAO International Civil Aviation Organization.

ICE Icing (ADREP Occurrence Category).

LDA Landing Distance Available.

LOC-I Loss of Control - Inflight (ADREP Occurrence Category).

LOLI Loss of lifting conditions en-route (ADREP Occurrence Category).

MoC Management of Change.

MRO Maintenance and Repair Organization.

OTHR Other (ADREP Occurrence Category).

QAR Quick Access Recorders.

RFFS Rescue and Fire Fighting Services.

RI Runway Incursion (ADREP Occurrence Category).

SARP Standards and Recommended Practice.

SCF-PP System Component Failure - Powerplant (ADREP Occurrence Category).

SEC Security (ADREP Occurrence Category).

SMM Safety Management Manual.

SMS Safety Management System.

SOP Standard Operating Procedure.

SRM Safety Risk Management.

UNK Unknown or undetermined (ADREP Occurrence Category).

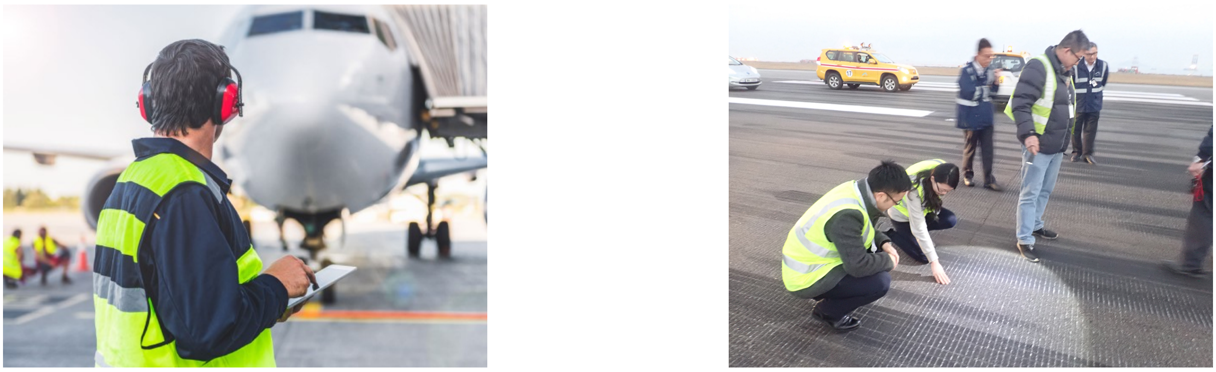
USOS Undershoot/Overshoot (ADREP Occurrence Category).

WSTRW Windshear or Thunderstorm (ADREP Occurrence Category).

Chapter 1

Introduction

One of the key objectives pursued by airline companies is the reduction of the risk associated to the air transportation related operations. The mentioned operation risks encompass not only the safety of the aircraft itself but also safety factors external to the aircraft such as the safety of operation in a specific aerodrome. This means that, if aircraft need to fulfil certain safety requirements before entering operation (example in figure 1.1a), the same must happen to the aerodromes (example in figure 1.1b). Aerodromes are locations in which any type of aircraft flight operation takes place, regardless of whether it involves air cargo, passengers or neither. All airports are also aerodromes, with the particularity that these meet specific regulatory requirements.



(a) Aircraft safety oversight

(b) Aerodrome safety oversight

Figure 1.1: Safety oversight procedures.

Each company has defined its safety requirements and, based on these, the company can decide not to operate a certain aircraft model, as well as, decide not to operate to a determined aerodrome. The focus in this thesis is the analysis of the aerodromes safety status, specifically the aerodromes with conditions to handle commercial flights (international and domestic airports), as well as the risk associated to the civil air transport operation in these locations. Figure 1.2 presents an example of a comparison between aerodromes with higher and lower risk of operation, respectively.

(a) Madeira Airport (LPMA)

(b) Faro Airport (LPFR)

Figure 1.2: Example of aerodromes with higher vs lower risk of operation.

1.1 Motivation

All airline companies have a concept of safety and which risks are acceptable or not. However, there are situations when risk interpretation may become subjective. Generally, risk identification and interpretation is majorly performed by members of the safety departments of the airline companies who usually have enough experience so that their subjective interpretations of risk do not differ much from each other and from the real risk. Nonetheless, the best approach to risk interpretation is the mathematical form based on risk models, created with the collected risk information and safety related occurrences data in the global aviation history. This involves the establishment of risk levels and risk acceptance criteria, completely eliminating the subjective interpretation of any safety department member and possible discordance. This is the objective sought by Portugália Airlines.

When it comes to the risk assessment of the operation in a specific aerodrome, the safety department is currently able to determine, in a qualitative form, the acceptance of the aerodrome operation but does not have a risk assessment tool to determine the quantitative risk value. This required the development of an Aerodrome Risk Assessment Tool (ARAT) that enabled the safety department to assess the risk of operating each aerodrome, answering to a series of questions related to the multiple safety components of an aerodrome operation, and that calculated automatically the risk scores, also defining the acceptance of the operation in such aerodrome. All these assessments should be able to be performed regularly and the results should be stored in order to study the evolution of the safety status of each aerodrome.

However, performing a complete analysis to the risk of operating an aerodrome surely becomes an embracing task due to the continuously increasing size and complexity of the aerodromes nowadays. This means that, in order to perform a complete analysis, components of an aerodrome operation such as Security, Ground Operations, Flight Operations, Engineering Operations, Environmental Hazards, Historical Data and many others have to be taken into account which means that the developed risk assessment tool will have to be shared with the different airline departments responsible for each of these subjects. With this is mind, the necessary tool to perform the aerodrome risk assessments has to be enough elaborate, effective and accurate to validate the safety of operating to a certain aerodrome but also concise, efficient and simple in order to be handled by the safety delegates of all the involved departments on a monthly basis, consuming the least possible amount of their time.

1.2 Aerodrome Safety Management Overview

The operation of an aircraft at or near an aerodrome is an activity that, as many others, has risks associated. The usually mentioned state of ”complete safety” during an operation can be misleading because, in fact, it does not exist and that is the reason why Safety Management Systems (SMS) were developed, to reduce and control risks to an acceptable level.

The Safety Management System is an organisational function subdivided in the components of Safety Policy and Objectives, Safety Risk Management, Safety Assurance and Safety Promotion. This function, that merely consists of principles, processes and measures to identify and decrease risks, can be applied to any type of organisation obviously requiring adaptation to the type of operation of each organisation. In the case of the safety management in aviation operations, required by European Regulation EASA 965/2012 [1], the main focus is the safety of flights and all other services like air navigation services and aerodrome operations management that support this activity. Naturally, being this thesis focused on analysing the risk of operation in an aerodrome, major relevance will be given to the aerodrome safety management.

Safety Risk Management is the component of the Safety Management process of most interest for this project. It is a process that must be included in the Safety Management System of all companies that either provide a product or a service. This process is mainly composed by the identification of the hazards associated to the product or service provided, the assessment of the risk associated to the hazards and, lastly, either the acceptance or mitigation of this risk.

Three techniques are involved in the Risk Management process: reactive, proactive and predictive. These consist of different methods of identifying hazards and assessing risks and the major difference that distinguishes them is the focus on hazards that already resulted (reactive), are resulting (proactive) or may result (predictive) in safety related occurrences. In an ”ideal world” all these methods should be constantly explored. However, each particular method requires availability of resources that can go from detailed historical data to high computational power. The available resources decide which method can be explored in each specific situation.

1.3 Objectives

There are three key objectives for this project that consist, primarily, in the development of an Aerodrome Risk Assessment Tool (ARAT) with questions related with safety concerns from each department in a checklist form, to be answered by the safety delegates in each department. This tool consists of an excel file and each aerodrome assessment should be performed individually in different versions of this file. The second key objective is the development of an Aerodrome Risk Assessment Summary

(ARAS) tool that will be used to compile the risk results of each aerodrome ARAT file, thus, facilitating the comparison of the risk status of each aerodrome. The final major objective is to perform actual Aerodrome Validation analysis obtaining risk results and compare this new developed risk assessment methodology and the obtained results with the previous ones obtained by Portugália Airlines. After these comparisons, optimisations can be performed depending on the feedback of the safety department members.

Naturally, each of these key objectives has specific sub-objectives. First of all, for the development of the ARAT file, it will be necessary to define the checklist Parts that correspond to the different departments of the company and the checklist Sections that sub-divide the Parts according to the themes of the questions. Then, together with the different departments of the company, all the questions, as well as the answer options, need to be developed so that all the safety concerns from each department that are deemed necessary to be assessed are taken into account. Because not all questions represent the same risk, weighting factors have to be established to each one and this requires the development of a methodology to determine these factors, which involves, for each question, the identification of the hazards and the identification of the potential outcomes. Having the weighting factors attributed to each question it is necessary to develop the method of calculation of the risk that each question and correspondent answer represent. This method has to associate the risk represented by each question with the exposure given by each corresponding answer, consequently calculating each risk score. Additionally, these risk scores will be taken into account in the calculation of the risk score of each Section and, consequently, each Section score will be taken into account in the calculation of the risk score of each Part. Once all the risk scores have been calculated, it will be necessary to adopt or develop a risk acceptance criteria. Despite, in general, aviation being one of the most safe industries, there is no guarantee of an operation without risk. All operations in aviation industry have some level of risk associated and the definition of the borderline between a safe or unsafe operation is what an acceptance criteria mainly consists of. In addition to this, an acceptance criteria can also define sub levels between acceptable and unacceptable depending on the implementation of mitigation measures and recommendations, which is going to be the case of the ARAT. The ARAT file is also supposed to be editable and improved in the future as the industry adapts to new safety requirements so editing features will be developed so that a user with a more considerable knowledge of the operation of this tool can add new questions, sections or parts and delete questions, sections or parts that may have become obsolete. A crucial part of the ARAT file is also the post-processing of the obtained results in the assessments. This consists of developing features that enable an easier interpretation and comparison of the obtained results in different assessments over time, facilitating the study of the safety development of the aerodromes. This will also require the development of a record of previous assessments and possibly the integration of a database of safety related occurrences in ICAO aerodromes to analyse their safety progress.

At some point during the development of the ARAT file, it will be necessary to perform a statistical analysis to a database of aviation safety related occurrences in order to determine the probability of occurrence and severity level associated to the hazards represented in each question of the checklist. The most complete and credible source of this type of information is ICAO so a database from this organisation will be analysed and a method will be developed in order to conjugate this data with the severity and probability criteria and, consequently, enable the determination of the weighting factors to attribute to each question.

As previously mentioned, the second main objective is the development of an Aerodrome Risk Assessment Summary (ARAS). Since the ARAT type files will be developed to deal with one aerodrome at a time (one ARAT file per aerodrome), the main objective of the ARAS file is going to be the management, compilation and presentation of the risk assessment results contained in the various ARAT files. This will require the development of a method to summarise all the assessments, a method to import the results from the ARAT files to the ARAS and the integration of an easy access to the different ARAT files from inside the ARAS. Having this done, as in the previous case, it would be quite useful to have a simple comparison of the risk assessment results between different aerodromes which requires the development of post processing features. Besides this, an additional useful feature to develop using the summary of the aerodrome assessment results should be the analysis of the combined risk of an operation from one aerodrome to another taking into account the latest risk assessments of both the departure and arrival aerodrome.

Finally, the last main objective is the Aerodrome Validation which implies testing both the Aerodrome Risk Assessment Tool (ARAT) and the Aerodrome Risk Assessment Summary (ARAS) with real situations, i.e, perform risk assessments of some of the most critical aerodromes operated by Portugália Airlines and also some less critical. Performing these assessments will enable the understanding of the accuracy and effectiveness of this risk assessment tool and make evident possible necessity of optimisation and tweaking. Only after these modifications have been implemented and the tool validated by the safety manager, the comparison between the current risk results obtained by Portugália using their aerodrome validation method can be compared with the results of the tool developed in this project.

1.4 Literature Review

During the entire development of this thesis it was required constant support from information provided either by personnel with considerable experience from Portugália Airlines, or by documentation. In this section, it is given highlight to the documents that were the source of all the information that helped during the progress of this project, while also mentioning in which steps of the project each one had its contribution.

For the development of a solid aerodrome safety background it was required knowledge about the safety management system adopted by aviation companies. This way, documents such as ICAO's Doc 9859: Safety Management Manual [2], ICAO's Annex 19: Safety management [3], FAA's Advisory Circular 120-92B [4] and Portugália Airlines' Safety Management Manual [5] were vital to understand the mechanisms that enable the implementation and practice of safety in the day to day operation of an airline company. This way it became perceptible the role of an Aerodrome Risk Assessment Tool in the safety management process and the foundations for its development. In addition, articles such as the "Challenges of improving safety in very safe transport systems" [6], "Airport surface operations:

A holistic framework for operations modeling and risk management" [7], "Regulating airport safety: the case of Schiphol" [8], "Solar photovoltaics in airport: Risk assessment and mitigation strategies" [9] and "Risk Analysis in Take-Off Procedure with Electronic Flight Bag" [10] provided the state of the art of risk assessment methods that are being implemented in many other aviation (and other means of transport) related subjects and also other documents like the "Safety Management and the Concept of Dynamic Risk Management Dashboards" [11] and "ADREP 2000 Taxonomy" [12] made available the basic tools to start the development of the ARAT.

In order to start the development of the ARAT it was studied an already existing checklist from EASA designed for a different purpose of analysing the risk of aircraft operation, instead of aerodrome operation, but with the same objective of performing risk assessments. This was the Pre-Departure Risk Assessment Checklist from the European Helicopter Safety Implementation Team [13], which propelled the initiation of the ARAT development.

Started the development of the ARAT, other documents turned out to provide crucial information about the major safety concerns in the operation of an airline company, thus helping the development of the most relevant questions to include in the checklist of this tool. These documents were, once again, the Safety Management Manual (SMM) of Portugália Airlines [5] and Portugália Airlines' Operations Manual Part A [14], Portugália Airlines' Operations Manual Part C Route and Aerodrome Competence [15], ICAO's Aerodrome Design Manual Part 1 Runways [16], ICAO's Aerodrome Design Manual Part 2 Taxiways, Aprons and Holding Bays [17], ICAO's Annex 14 to the convention on international civil aviation: Aerodromes [18], ICAO's Annex 11 to the convention on international civil aviation: Air Traffic Services [19], "GROUND HANDLING AND FLIGHT SAFETY - BASICS, BEST PRACTICES AND AWARENESS-RAISING" [20], ICAO's Runway Safety Programme – Global Runway Safety Action Plan [21], EASA's European Plan for Aviation Safety (EPAS) 2019-2023 [22], EUROCONTROL's European Action Plan for the Prevention of Runway Incursions [23], ICAO's Manual on the Prevention of Runway Incursions [24], ANAC's Plano Nacional de Segurança Operacional SSp 2019-2021 [25] and EASA's Easy Access Rules for Air Operations [26].

The document Accident Statistics Europe - EASA Member States from EASA [27] was useful in order to visualise a statistical type analysis to aviation safety related occurrences and motivate the execution of a similar type but much more extensive one.

After the development of the ARAT, the Operations Manual Part C Route and Aerodrome Competence from Portugália Airlines [15] became an important source of information acquired through the experience of the company's personnel that helped answering the questions in the checklist as a safety department member, thus enabling the testing of the results obtained with the tool.

Besides this, due to an additional requirement of implementing and adapting a specific CFIT Checklist from FSF [28] to this tool, it was mandatory to resort to this document.

Finally, in order to provide a summarised explanation of the ICAO's taxonomy used during the development of the ARAT to refer to and categorise safety related occurrences, it was necessary to resort to the lists "VL for AttrID 430 - Occurrence category" [29], "V4 CD Damage aircraft" [30], "VL for AttrID 391 - Event Phases" [31], "VL for AttrID 431 - Occurrence Classes" [32] and "VL for AttrID 451 - Injury level"

[33], available in the main document ”ADREP 2000 Taxonomy” from ICAO / ECCAIRS [12].

1.5 Thesis Outline

This section is destined to refer the structure of this thesis, specifically briefly mention and explain the contents of each chapter and the contribution of each one for the development, formulation, implementation and testing of the Aerodrome Risk Assessment Tool that is going to be developed. In total, 6 chapters and 3 appendices make up this thesis.

The current, Chapter 1 consists of a brief introduction to the subject of the thesis presenting the main motivation for the development of this tool, a concise overview of the safety and risk management in an organisation, the presentation of the defined objectives for the mentioned tool and the review of the resorted literature.

Chapter 2 presents a theoretical background on the safety management in organisations with focus on the aviation industry and also focuses on the theoretical background of safety risk management, which is the foundation of the operation of any type of risk assessment tool.

The logic and process of development of the Aerodrome Risk Assessment Tool (ARAT) was thoroughly explained in Chapter 3.

In Chapter 4, a statistical analysis was performed to the safety related occurrences in all ICAO aerodromes since 2008 to 2019, with resort to a database from this organisation.

In Chapter 5 were performed all the deemed necessary aerodrome validation tests using the developed Aerodrome Risk Assessment Tool and implemented the optimisations and suggestions of the safety department members. In addition, the risk results obtained with this tool where compared with the previous results obtained with the previous method used by the company.

Chapter 6 includes the conclusion of the project and the summary of the achievements of this work, with the addition of a few notes on future work and suggestions of possible aspects to improve.

Lastly, but not less important, 3 appendixes are included after the 6 main chapters, containing as much relevant information.

Appendix A presents two additional analyses performed to the safety related occurrences database from ICAO. The first one consists of an analysis to past CFIT occurrences and the integration of a CFIT related checklist in the ARAT, motivated by the great concern, demonstrated by the airline company, about this occurrence category and its associated consequences. The second one consists of a study to determine the influence of the predetermined aerodrome category on the probability of safety related occurrences and, consequently, on the weighting factor of the ARAT checklist’s questions.

Appendix B contains information about the developed features for the ARAT and the indispensable complementary ARAS tool. Instructions are also provided in order to facilitate the use of these features and to update or modify the ARAT’s checklist to follow the progress of the safety requirements of the company.

Finally, appendix C presents the tables that contain a summary of the research and development process for the formulation of the ARAT’s checklist.

Chapter 2

Aerodrome Safety Background

In this chapter, the initial focus is to present the safety theory that is behind the daily operation of aircraft in aerodromes, describing the major components of the Safety Management System (SMS) of the aerodromes. Then, it is presented the greater significance of one of these components, the Safety Risk Management, for the goal set for this thesis of developing an Aerodrome Risk Assessment Tool. Finally, because safety related occurrences are the direct consequence of accepting risks, it is presented an accident causation theory and the methodologies already in implementation on how to prevent this type of occurrences.

2.1 Aviation Safety Management System

Since the term ”safety” has been mentioned constantly until now, it is only appropriate to begin with its definition in terms of aviation. Safety, as defined in ICAO Annex 19 [3], is ”the state in which risks associated with aviation activities are reduced and controlled to an acceptable level”. Thus, when the expression ”completely safe” is used to characterise an activity, it is usually misunderstood as not having any risks associated to it, which is not entirely truthful. Safety consists of nothing more than the definition of a risk boundary (acceptable level) where anything above it is considered unsafe and, inversely, below it considered safe.

Safety Management Systems (SMS) and State Safety Programmes (SSP) are mandated by Member States and Service Providers in order to achieve an acceptable level of safety (ALoS). The main modules of the SMS consist in Safety Policy and Objectives, Safety Risk Management, Safety Assurance and Safety Promotion.

Safety Management itself is an organisational function with focus on applying principles, processes and measures to identify, assess and mitigate risks to an acceptable level preventing human injury, property and/or environment damage or any other adverse consequence that may be caused by making use of a service or product. It is this function’s responsibility to assist managers with the identification, correction or prediction of the system’s weaknesses before accidents occur. For a successful safety management, a systematic approach has to be defined, including the necessary organisational structure, accountabilities, policies and procedures. This approach can be summed in the following steps: (1) unambiguous safety policy; (2) hazard identification and risk assessment with resort to state-of-the-art methods; (3) safety reporting systems; (4) investigation of safety occurrences with an aim to identify systemic safety deficiencies; (5) assess safety performance through safety monitoring and oversight; (6) dedicated safety training for personnel; (7) safety lessons dissemination; (8) development of a safety culture with good practices and non-punitive safety investigations.

Regarding safety management in aviation operations, the main focus is the safety of flights and all other support services to this operation, like air navigation services and aerodrome operations management. Initially, this system was predominantly reactive, following the fixing after flying method, in which the main focus were accident investigations. The progress in technology allowed for a gradual replacement of this approach by a new system with focus on human error, trying to contain and mitigate all the procedures related to bad performance. However, even after the investment in human error mitigation resources, the safety issues continued to be related with unsatisfactory human performance so a relatively new approach was introduced in the mid 90's. This new approach consists of continuously analysing, in a proactive way, the routinely collected safety data. In fact, nowadays there is an even newer approach defined as a predictive approach that combined with the proactive and reactive approach are contributing to a higher safety level in the operation of aircraft and aviation in general. The predictive approach is making huge progress specially in the risk management department and will be addressed in that section (section 2.5).

It is easy to understand the reason why the traditional Reactive Safety Management perspective was the first to be used in aviation industry, as in many others. Its particular utility dealing with technological failures allied to the focus on compliance with minimum safety requirements made it very appealing but, as it turned out, that had also its main negative aspect. The limitations that come from the level of safety being exclusively dependent on reported occurrences, like the ability to only analyse failures that already occurred, the insufficient data, insight and latency of the investigation processes made the sole resort to this approach completely impracticable with today's aviation level of safety required. This is a common "problem" in extremely safe transport systems that was addressed in the paper "Challenges of improving safety in very safe transport systems" [6]. This paper is oriented to the study of the safety of railways but the challenges here addressed are perfectly applicable to aviation.

- Challenge 1 - "A low number of accidents per unit of time makes it difficult to estimate both the current level of accident risk and changes over time in the level of accident risk". In aviation this becomes quite noticeable when the accident and incident history of each aerodrome is analysed and one realises there is not much information to evaluate how safe the operation in each aerodrome is.

- Challenge 2 - "Partly as a result of the low number of accidents, incident reporting has to be introduced". This is what ICAO realised and then proceeded to develop the Accident/Incident Data Reporting (ADREP) system (section 2.8) that will prove to be the major foundation for the development of this Aerodrome Risk Assessment Tool.

- Challenge 3 - "Knowledge of the effectiveness of safety barriers combined with a good safety record may lead to excessive reliance on the safety barriers and behavioural adaptation to them". This is also an important subject that is constantly addressed in aviation, through the imposition of procedures and checklists in order to avoid human error caused by excessive comfort and consequent lack of awareness. However, this point is outside of the scope of this thesis.

On the other hand, in safety management, the proactive approach is mostly applied to the risk management component, continuously monitoring operational data, utilising data from past accidents to identify hazards before these become harmful and taking the necessary steps to reduce safety risks.

In fact, safety management has shown huge importance for aviation safety, sustainable business management and operational growth which led to the progressive implementation of these systems by aviation service providers.

The following sections provide a description of the components that constitute the SMS. Despite the sequence of the approach previously defined, it was decided to leave the component Safety Risk Management for last due to its major importance for the development of the Aerodrome Risk Assessment Tool and, consequently, a more in depth description of this component will be presented.

2.2 Safety Policy and Objectives

This is the first component of the SMS framework of a company and its focus is on the creation of an environment that enables an effective safety management and the management's commitment to safety, to its goals and to the supporting organisational structure. The Management commitment to safety is demonstrated through allocation of resources and management decisions and actions that should always be consistent with the safety policy and objectives of the company in order to cultivate a positive safety culture. The safety policy of a company should be developed and validated by senior management. Also, safety personnel and staff representatives, when appropriate, should be consulted to promote a sense of shared responsibility.

2.2.1 Safety Policy

The safety policy of a company should be actively supported by senior management and the accountable executive via means of communication and through the alignment of activities to the safety policy, ensuring that all personnel understand it and work in accordance with it.

ICAO states that, in order to reflect an organisation's commitment to safety, the safety policy should include commitment to: (a) continuously improve the level of safety performance; (b) promote and maintain a positive safety culture within the organisation; (c) comply with all applicable regulatory requirements; (d) provide the necessary resources to deliver a safe product or service; (e) ensure safety is a primary responsibility of all managers; and (f) ensure it is understood, implemented and maintained at all levels.

The safety policy of a company should also refer the safety reporting system in order to encourage the reporting of safety issues and ensure protection of safety data, safety information and also reporters, allowing the de-identification of reports to enable safety analyses without the implication of personnel or specific service providers. The appropriate de-identification of reports can improve the quality of the data collected.

Personnel should also be informed of the disciplinary policy applied in the case of safety events / issues that are reported. This policy should be used to determine if an error or rule breaking occurred and to establish whether any disciplinary action should be taken.

2.2.2 Safety Objectives

The safety objectives of a company should be concise and statements of the organisation's safety priorities while addressing its most significant safety risks. In order to monitor the achievement of these safety objectives it is required the definition of Safety Performance Indicators (SPIs) and Safety Performance Targets (SPTs) which vary with each company. Additionally, the safety policy and safety objectives should be periodically reviewed to ensure they keep up with the evolution of the company's operation.

2.3 Safety Assurance

Safety Assurance is the formal management component process of the Safety Management System that ensures confidence to the organisation that all systematic actions that constitute risk controls developed under the risk management process allow the achievement of the acceptable levels of safety. In other words, safety assurance continuously monitors the operation of the SMS, assuring it meets expectations and requirements. The implementation of safety assurance activities is mandatory in order to meet ICAO Standards and Recommended Practices (SARP).

Usually, there is a certain difficulty in distinguishing the different objectives between safety risk management and safety assurance. The aim of safety risk management is to identify and assess risks through the development of organisational safety risk controls. Once these are determined to be capable of reducing risk to ALoS and implemented, then it is safety assurance's role to ensure risk controls are being practised and objectives achieved. Furthermore, in case there are changes in operational environment, safety assurance must identify the need of new safety risk controls and develop and implement corrective actions as a response to the system's deficiencies. Figure 2.1 presents the safety assurance process and its interconnection to the safety risk management process.

Safety assurance, put in practice, consists of reviews, evaluations, inspections and, most importantly, internal and external audits, and it is recommended that these actions are an intrusive and enquiring exercise to ensure its effectiveness. Besides that, it is also considered a complement of compliance monitoring that focus on the monitoring of the organisation compliance with regulatory requirements. This complementary relationship allows for the integration of systems, constituting the Integrated Management System, and enables synergies that facilitate objective achievement.

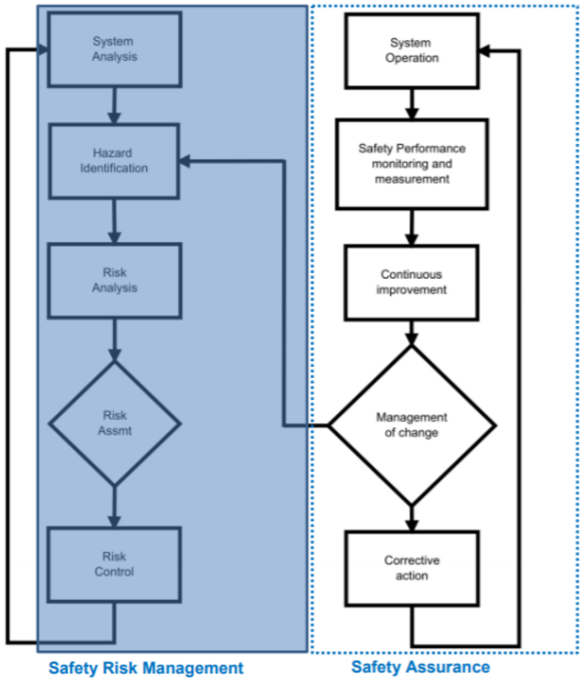


Figure 2.1: Safety assurance stages and interconnection to safety risk management from Portugália Airline's SMM.

2.3.1 Safety Performance Monitoring and Measurements

This is the process in charge of verifying the organisation's safety performance, comparing it to the overall defined safety policy and objectives. It includes the stages of Safety Performance, Safety Reporting, Safety Studies, Safety Surveys, Risk Reviews, SMS Audits and Internal Safety Investigations. Specific information about each of these stages can be found in ICAO Doc 9859 [2].

2.3.2 Management of Change (MoC)

This is the formal process to identify and manage operationally significant changes that should be developed by aviation service provider organisations. These changes are defined as the adoption of any work environment, condition, equipment or procedure that is new to a department. This documented process is destined to identify external and internal changes in the organisation, provision of services or in the operational environment, ensuring the reduction or elimination of the safety risks resulting from them. In the case of internal changes, before the implementation of any changes, all safety risks are considered. For external changes, only when operational environment is impacted, an evaluation of existing risk control takes place. Any change that may constitute a threat to safety shall be identified and managed through the processes of hazard identification, risk assessment and mitigation (safety risk management process). Additionally, the MoC process must take into account the past performance, the criticality and stability of the systems, equipment, activities and operational environments.

2.4 Safety Promotion

Safety promotion is another major component of the SMS and has the role of assisting in the achievement of effective control of safety risks during service delivery, through the combination of technical competence continuously enhanced through training and education, effective communications and information sharing, constituting the safety culture of the organisation. Safety promotion affects both individual and organisational behaviour and is the means that enables organisations to adopt a culture that goes beyond merely avoiding accidents or incidents and pursuits doing the right interventions at the right time. Furthermore, it is encouraged the dissemination of lessons learned and the “bottom up” communication, enabling senior management to receive open and constructive feedback from operational personnel that in many circumstances are in much closer contact with the existing safety deficiencies.

According to ICAO, safety training and education and safety communication are the two important processes supporting safety promotion.

2.4.1 Safety training and education

Safety training and education should be provided to all employees proportionally to their level of responsibility and impact on the safety of the service provided to ensure that they are trained and competent to perform their SMS duties. It consists of initial training and further recurrent training. This training itself should also be reviewed and updated periodically because its quality has direct influence on the actual performance of the employees in everyday work. For the success of SMS training, all employees must understand the safety philosophy, policies, procedures and practices of the organisation and their responsibilities within safety management framework. This training should consist of identifying training requirements, job-specific training, measuring the effectiveness of training, maintain training records and recurrent training.

Specific SMS training should include the programs of the Personnel Requirements, Accountable Manager, Safety Department, Managers, Employees and Safety Training.

2.4.2 Safety Communication

The success of the SMS depends on maintaining good formal means for safety communication that enables a continuous safety performance improvement, improves productivity and increases efficiency and profitability. Safety communication objectives include ensuring all staff full awareness of the SMS, conveying safety-critical information, explaining reasons behind particular procedures and communicate all relevant information.

The crucial component in safety communication is to transmit the experience acquired from past lessons learned that include all the relevant information contained in reports, audits, investigations and other data sources which generated safety recommendations and enable its implementation in daily practice.

Since communication failures are usually a major prompter for accidents and severe incidents, programs about communication and information dissemination are deeply encouraged. These means of safety communication can be internal or external. Internal means of safety communication include safety news, safety alerts and safety information.

Examples of external means of safety communications are meetings, workshops, websites, e-mails and magazines.

2.5 Safety Risk Management

After this overview of three of the major components of an organisation's Safety Management System, it is time to address what is certainly the most relevant component for this thesis, the Safety Risk Management. Included in this component is the whole process that constitutes the foundation for the creation of any risk assessment tool and, since this is the objective of this thesis, this component will be addressed with more detail than the previous ones.

First, in order to define risk management, it should be stated the meaning of risk and distinguish it from a hazard. Risk is defined in ICAO [2] as nothing but the probability or likelihood that the hazard's potential will result in actual harm. However, there is no general common definition for risk and it may slightly change between organisations, as well as the calculation of the risk value itself depending on the risk calculation model. Despite this, the majority states that the risk results from the combination of the likelihood and the severity of the occurrence of harmful events caused by a hazard.

As expected, these discrepancies in definitions are also present in the risk management process. Safety risk management is defined in the FAA Advisory Circular 120 [4] as a formal process within the Safety Management System composed of describing the system, identifying the hazards and assessing, analysing and controlling the risk embedded in the organisation processes used to provide the products or services. ICAO [2] defines risk management objectives as the identification, analysis and elimination and/or mitigation to an acceptable or tolerable level of those hazards, as well as the subsequent risks, that threaten the viability of an organisation. Since these are two major organisations in the aviation community, both definitions are acceptable and complement each other, sharing the same objective of preserving the general safety of operation of an organisation.

In the case of aviation operations, as in many others, the complete elimination of risk is unachievable and, besides that, not all mitigation measures are practical. Despite how low it can be, all aircraft operations have a certain risk associated and the "zero risk"/"completely safe" state would require grounding of all aircraft and stop aviation activities. As this is not an option, Risk Management is a conjunction of "a structured approach and systematic actions aimed to achieve the balance between the identified and assessed risk and practicable risk mitigation". Any changes that may impact the safety of services provided by the operator need to be assessed. Furthermore, an important remark is that the concept of Risk Management should not be seen as a requirement only for aircraft operators but also for all the entities that belong to the aviation industry as air navigation service providers, certified aerodrome operators, maintenance organisations and training organisations.

For the effectiveness of Risk Management, each risk control measure needs to be evaluated and an analysis of cost-benefit of every action implemented is required, even if the ”do nothing” strategy is adopted.

The Risk Management approach consists of three different elements: **Hazard Identification**; **Risk Assessment**; and **Risk Mitigation** (figure 2.2). Each of these elements will be addressed afterwards.

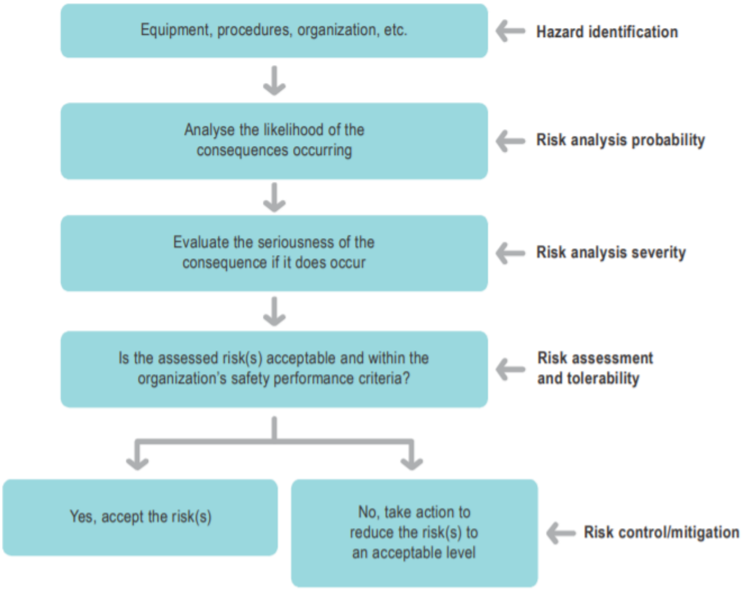


Figure 2.2: Risk Management process by ICAO [2].

Techniques included in Risk Management can be categorised as reactive, proactive or predictive. This was explained previously when introducing the SMS. Safety occurrence reporting and investigation are considered reactive since they address the risks identified in an accident or incident that already took place in the past. Early aviation safety could only resort to this technique to do risk management because they did not have enough data. However, with the increase of automation and complexity of flight operations, proactive approaches started to take action to continuously monitor operational data and identify potential risks utilising data from past accidents. Recently, a new technique designated Predictive Risk Management started to take place.

Predictive Risk Management

Predictive risk management is a technique that is relatively new in aviation and its use is being encouraged increasingly. The reason because it was not put into action in the past is that it requires a large quantity of normal operational data (not accident data) and data processing tools that only became available more recently. Today it enables us to identify hazards and their probability and severity, show the potential risks and identify the benefits of reducing them that previously could only be discovered after an accident had occurred.

However, for the success of this technique, a problem of human nature has to be faced. Regulators and safety investigation organisations are reactive by nature, so shifting instantly to being predictive is simply not possible and currently aviation industry is still in the transition phase. Despite having all the data needed to look at the events to identify hazards, the current safety system focuses on negative outcomes. If an event does not have a negative outcome, it is rarely investigated and that is the mindset that must be changed in order to fully implement this approach.

The fact that this approach is not completely imbibed in the organisation's safety management system, allied to the fact that the possible full transition for this approach will still take many years, dictates that, currently, the best approaches for the development of an aerodrome risk assessment tool would be a combination of the reactive and the proactive approaches, which, in fact, became the course of this project.

2.5.1 Hazard Identification

This is the initial element of the risk management process. Any condition, event or circumstance with potential to cause harm to an organisation can be considered a hazard. Harm may manifest in people in the form of injury, illness or death, manifest in equipment in the form of damage and/or loss of systems/property and manifest in the form of damage to the environment. Hazard identification is a crucial component of the SMS and, according to ICAO Doc 9859 [2], consists of the formal process of collecting, recording, analysing, acting on and generating feedback about existing hazards that may affect the safety of the company based on a combination of reactive, proactive and predictive methods of safety data collection. The task of identifying hazards related to their specific operations is a duty of all organisation's employees. This way, the embracing task of identifying every existing hazard becomes more facilitated.

Hazard identification sources

In order to identify a hazard, there are reactive, proactive and predictive methods that can have either internal or external sources. The foundation of the problem is trying to find elements that either isolated or combined with others can contribute to an incident or accident.

Source origin:

- **Internal hazard identification sources:** include, among others, employee's experience and operational perspective, mandatory and voluntary safety occurrence reports, safety occurrence indicator trend analysis, data from automated data collecting tools (FDM), results from internal safety surveys, inspections and audits;
- **external hazard identification sources:** include, among others, official state investigation results of accidents and serious incidents, technical publications from manufacturers, reliable websites, benchmarks and information exchange between operators, safety information bulletins, alerts and publications by industry and research organisations.

Source methods:

- **Reactive hazard identification methods:** these claim that incidents and accidents are clear indicators of the system's deficiencies so its focus is trend monitoring, employee reports analysis, searching for regulatory violations and investigating safety occurrences, trying to find out which accidents took place, the reasons behind the occurrences and which risk controls failed;

- **Proactive hazard identification methods:** these analyse the system's performance and functions, trying to identify hazards before they result in incidents or accidents. The objectives of these methods are to find out what accidents or incidents could happen, the prompting reasons for them and the recommended actions to prevent those occurrences. The most common proactive methods consist of safety surveys, operational safety audits, safety monitoring, safety assessments and also flight data analysis.

- **Predictive hazard identification methods:** consist of conducting predictive analysis aimed at discovering future hazards through statistical modelling and extrapolation, this way identifying and mitigating risks before they become evident. To put in other words, the aim is to eliminate, avoid or mitigate hazards from the future, trying to answer the question of what accidents can happen, what reasons are behind them and what actions should we take to avoid those risks.

Scope of Aviation Hazards

Hazards in aviation operations can have a very wide scope due to the many possible sources of failure and that is the reason why the identification of hazards is considered such a complex process. The ICAO Doc 9859 [2] has a list of the most common hazard sources in aviation but these depend on the organisation type and its specific operation. Some of these common hazards include Design factors, Procedures and operating practices, Communications, Personnel factors, Organisational factors, Work environment factors, Regulatory oversight factors and Defences.

Safety reporting system

Risks can only be assessed if hazards are efficiently communicated to the appropriate entities. The safety reporting system is the "tool" that allows the identification and proper communication of situations, actions and conditions that may have the potential to endanger the safety of operations and services. The importance of communication is the fact that, usually, the most suitable people to identify potential hazards in the company's operational areas are specifically the employees that work in those areas and deal with improper procedures and incorrect methods on a daily basis. More severe cases like procedures not followed for intentional reasons must be reported as soon as possible, thus, there are two types of reports: mandatory and voluntary. These reports consist of the full explanation of all related details to the Safety Department enabling the performance of a thorough analysis.

Mandatory Reporting System: It is a requirement of ICAO Annex 19 [3] that all states establish a mandatory reporting system to report, at least, incident and accident occurrences. However, organisations can decide to establish mandatory occurrence reports for other events they found relevant.

Voluntary Reporting System: This was created to complement the mandatory reporting system enabling anyone in an organisation to communicate their perspective of possible hazards and unsafe conditions besides the ones identified in the mandatory reporting system. This should be a confidential system with focus on improving the risk control process associated with any area of the operation and with no punishment intentions so that employees are not discouraged to communicate their standpoint. Past aviation and non-aviation severe incidents and accidents prove that, in many cases, hazards only resulted in harmful situations because operators already knew about the existence of the hazards but, for reasons that could jeopardise their job position, did not communicate to the appropriate authority. Usually, these reasons included lack of confidentiality and/or possible punishment. Thus, the Voluntary Reporting System was designed to be a confidential program that protects the identity of the reporter. The reporter's identity will only be known by the Safety office members that have the obligation of maintaining confidentiality and may contact the reporter if additional information is required. The use of the reported information outside the Safety Office must not contain any facts that enable the identification of the reporter. Furthermore, this system has no intent to punish the reporter and will only use the information to improve processes to eliminate or mitigate the identified hazards. However, it is important to mention that this non-punitive policy does not apply to illegal acts or intentional/blatant disregard of the regulations or established procedures.

Internal safety investigations

These consist of internal investigations of incidents, accidents or other occurrences and regulatory violations and aim to improve the effectiveness of risk controls in the organisation's operation. These investigations also take place when new hazards and risks are discovered or when recurrent safety risks are identified. The focus of the investigations is to collect and analyse occurrences, in order to determine the contributing factors and elaborate conclusions that allow the promotion of new safety recommendations. Most incidents that occur inside the organisations operation do not require intervention of State or regulatory authorities, or even its report, so it is easy to disregard the importance of such incidents in the identification of potentially harmful hazards. For this reason, internal safety investigations play a major role in hazard identification and, the same way as the voluntary reporting system, do not intend to punish operators neither chase guilt, to ensure the contribution and cooperation of those involved in the events, facilitating the detection of the causes. Safety departments have the authority to launch an investigation procedure whenever they find it advisable.

Operational data analysis

The thorough analysis and monitoring of the operational data, searching for indications of inherent hazards has a major role in the SRM process component of identification of hazards.

One important source of operational data are the Flight Data Recorders (FDR) and Quick Access Recorders (QAR). These devices enable the continuous analysis of the operational performance of aircraft and crews for quality assurance purposes, designated by Flight Data Monitoring (FDM). The main objective is to improve safety by identifying adverse trends. These trends can consist of unusual behaviour of flight crew members, weaknesses and anomalies in the aircraft. The methods used to identify these trends consist of detecting unusual exceedances and deviations from the flight manual limits or standard operating procedures (SOP). The FDM is capable of detecting adverse trends in any flight regime, facilitating the investigation of minor events. Thus, it is encouraged that crews stick to the Standard Operating Procedures, minimising non-standard behaviour and enhancing flight safety. The minor events that often result in adverse trends and that would surely go unreported, representing potential hazards to the aircraft's safety, show the importance of FDM. The FDM is performed by dedicated staff in the safety department and data is analysed every month. Because the purpose of FDM is to improve safety and not to search guilt, in cases when inadequate performance from a crew member is identified, this data is de-identified in order to protect the identity of the crew. Sufficient data should be collected in order to generate rate and trend information. Then, this information should be transmitted to the safety manager for a confidential discussion with the crew member with the aim to clarify the circumstances, obtain feedback and transmit recommendations. After the situation has been addressed, the data can be used in training or promotional initiatives with the condition that all data is properly de-identified. Once again, it is important to remember that the FDM program was designed to be non-punitive, confidential, anonymous and not to jeopardise a crew member's career.

Operational irregularities

The investigation of operational irregularities consists of identifying and investigating the occurrences of certain minor events, irregularities and other minor occurrences that take place continuously, often having no noticeable consequences, but eventually may lead to serious incidents or accidents, if disregarded. The analysis of risk matrices supports this fact because an event with minor severity can represent a major risk if a high probability of occurrence is associated to it. This is a subject that will be addressed in section 2.5.2. These events are referred to as accident precursors. The operator with main responsibility for this task is the Safety Line Officer that is the worker that is closer to the operation and can identify and transmit the system deficiencies to the Safety Department providing the operational link to safety. The monitoring of the operation should be based on quality audits and analysis of trends, ground operations delays reports, reliability reports, scheduling reports and external entity reports.

Hazard Classification

There are many ways of classifying hazards and the organisations should choose the classification system that is most suitable to their type of operation. However, when someone refers to hazard classification, it can be misinterpreted as the sub-process of the risk assessment element, that will be addressed later, that consists of the hazard's severity classification. The hazard classification in this section is completely independent of this previously mentioned type of classification and its only purpose is to organise the hazards by their nature or department.

Hazards in aviation can be classified in terms of their specific nature as the following examples:

- **Natural and environmental:** weather, earthquake, wind and sand, sea water, rocks, cliffs, ice structures, rough waters, volcano lava and dust, etc;
- **Economic:** competition, production pressure, cost pressure, etc;
- **Unsafe conditions:** use of unofficial documentation or documents not up to date, poor resources;
- **Unsafe acts:** errors, violations, negligence, sabotage, excessive/uncontrolled performance variations;
- **Physiological:** diseases, hypoxia, perceptual illusions, fatigue, sleep deprivation, jet lag, medication, alcohol, intoxication, digestion troubles, etc;
- **Technological:** design or maintenance related, hazardous material, pollution, explosions, etc;
- **Operational or mission specific:** obstacles, cables, demanding landing fields, low visibility conditions, demanding/overbearing customers (VIPs), etc.

An example of a classification of hazards in terms of their specific department is shown in table 2.1 present in the SMM of Portugália Airlines. Note that this is not an exhaustive list of all possible hazards.

Table 2.1: Portugália's example of hazard classification by department.

Flight Crew	Cabin Crew	Ground Ops	Maintenance	Cargo
Weather;	Loose galley carts;	Tow bar failures;	Time pressures to sustain on-time departures;	Odd sized pallets;
System malfunctions;	Late catering;	Overweight luggage;	Control of aircraft configurations;	Hazardous materials;
Congestion;	Excess carry-on luggage;	Jet blast;	Environmental factors (e.g. temperature, lighting and noise);	Late arriving aircraft.
False alarms; ATC communication; Smoke in the flight deck; Airport construction; Bird strike; Blown slide; Lightning strike; Portable Electronic Device interference; Wind shear.	Hostile passengers; Intoxicated passengers; Staffing; Blown slide; Galley equipment malfunction.	Propellers; Ice on ramp; Congestion; Noise; Lack of chocks; Passengers on apron.	Lack of parts; Weather.	

Previously, it was mentioned that this hazard classification could be misinterpreted for the hazard's severity classification. However, it can also be misinterpreted for the other important classification of hazards that is their probability of occurrence. This classification enables the assessment of the risk that a hazard can represent to an aviation operation or service. However, similarly to the severity classification, the analysis of the probability belongs to the risk classification component of the risk assessment in the safety risk management. This is the main difference that sets apart hazard classification from risk classification.

A proper process of identification of hazards is vital to deal with all potential hazards to the aviation operations and services. Since Hazard Identification provides the input to the other safety risk management components (Risk Assessment and Risk Mitigation) it has a major role in the effectiveness of the organisation's risk management process so it is required a thorough analysis of all possible outcomes and no aspect should be disregarded despite of how unlikely its occurrence may be.

2.5.2 Risk Assessment

Naturally, being that the objective of this thesis is the development of a risk assessment tool, this section about risk assessment must be as detailed as possible presenting the explanation of this element of the safety risk management and the recommendations of aviation authorities and organisations for the assessment of aviation's operations risks. As in many other aspects of the safety management system, each airline company, aviation authority and organisation have their specific risk assessment methods and recommendations defined and adapted to its type of operation. Thus, since this risk assessment tool is being purposely developed for Portugália Airlines, it was decided that the adopted risk assessment method to be addressed in this section would be based in the SMM of this company and also ICAO Doc 9859 [2].

Risk assessment can be defined as an analysis based on engineering and operational judgement with the aim to establish whether the perceived risk is acceptable and if eventual measures are needed to contain it within defined limits. All service providers should develop a safety risk assessment model and procedures allowing a consistent and systematic approach for the assessment of safety risks. This should also include a methodology to properly establish risk acceptance boundaries, i.e, to determine what safety risks are acceptable or unacceptable. This subject consists of the last step of the risk assessment analysis.

As stated before, risk assessment is the process that takes place after the hazard identification analysis. Each identified hazard has one or more associated consequences so, in this analysis, it is important to first identify all reasonable consequences/harms arising from each hazard. Once the potential harms and their possible outcomes have been identified it is feasible to assess the probability of the occurrence of these outcomes and their severity, so risk assessment is based in 3 analysis: hazard´s severity analysis, hazard´s probability of occurrence and acceptance of risk.

Service Providers are free to choose the prioritisation of their safety risk assessments. However, ICAO Doc 9859 recommends the following prioritisation process: (1) assess and control highest safety risks; (2) allocate resources to highest safety risks; (3) effectively maintain or improve safety; (4) achieve the stated and agreed safety objectives and SPTs; (5) satisfy the requirements of the State's regulations with regard to control of safety risks.

In addition, when performing risk assessment analysis, the effects of existing recovery controls and barriers that influence the consequences of the hazards should be considered, i.e, certification requirements, existence of abnormal and emergency procedures, secondary safety measures, technical measures/equipment, training, human and organisational factors and emergency preparedness.

All the safety information should be available to the safety risk assessment process to allow the service provider a data-driven decision-making process to determine what safety risk controls are needed. Comprehensibly, as in the case of other analysis, the performed actions and decisions should be documented so they can be tracked and monitored. This documentation should act as a historical source of the organisation's safety knowledge which can be used as reference for future safety decisions, safety information exchange, safety trend analyses and safety training and communication. Also, internal audits can take advantage of the documented information about safety risk controls and actions that were implemented to measure their effectiveness.

Furthermore, one service provider may find other more suitable approaches to their type of operation, so risk assessment methods can and should be reviewed and adapted to the needs of the operating environment of each service provider.

Hazard´s Severity Analysis

In order to make a credible assessment of a hazard's severity it is required a minute knowledge of the operational environment under analysis.

This type of assessment has the main focus on the impact of hazards on the safety of the aircraft, all its occupants and everyone that may be affected by it, such as environment, functions and reputation. For this reason, a large number of indicators take part in the severity assessment, as well as, a group of factors like the mitigation actions plan considered acceptable by the safety regulator. Thus, the determination of the severity of hazards is based on the credible short-term and long-term consequences, after the outcome of all the weaknesses, potential failures and safeguards has been taken into account.

Usually, a qualitative analysis is used in the hazard's severity determination. This type of analysis is focused on the chain of events and possible consequences that can follow from a hazard. However, if possible, it should be followed by a quantitative analysis based on relevant calculations. These calculations are aimed to predict the extent of damage that could result from an identified hazard.

Concretely, the determination of the severity of a hazard should be made considering its worst possible outcome. Although, less severe outcomes may be important and should also receive proper assessment, the level of severity of a hazard is defined by its worst outcome.

ICAO recommends five different categories to denote the levels of severity of hazards. Table 2.2 is provided with the description of each category and the respective qualitative value assigned.

Table 2.2: Hazard's Severity Criteria by ICAO Doc 9859.

Severity	Meaning	Value
Catastrophic	• Aircraft / equipment destroyed • Multiple deaths	A
Hazardous	• A large reduction in safety margins, physical distress or a workload such that operational personnel cannot be relied upon to perform their tasks accurately or completely • Serious injury • Major equipment damage	B
Major	• A significant reduction in safety margins, a reduction in the ability of operational personnel to cope with adverse operating conditions as a result of an increase in workload or as a result of conditions impairing their efficiency • Serious incident • Injury to persons	C
Minor	• Nuisance • Operating limitations • Use of emergency procedures • Minor incident	D
Negligible	• Few consequences	E

At this point, it is extremely important to disregard the probability of occurrence of such outcomes and focus on its severity, as this is an independent analysis that in conjunction with the severity analysis will define the risk that results from the hazard (to be addressed later in this section).

With the progress of risk assessment, an interactive process may help identifying new factors and barriers, which can be added to the procedures and included in the risk analysis. It is also important

Table 2.3: Probability of Occurrence table by ICAO [2] (Qualitative and Quantitative Definitions).

	Probability of Occurrence Definitions				
	Extremely Improbable	**Improbable**	**Remote**	**Occasional**	**Frequent**
Qualitative Definition	Should virtually never occur in the whole fleet life	Unlikely to occur when considering several systems of the same type, but nevertheless has to be considered as being possible.	Unlikely to occur during the total operational life of each system but may occur several times when considering several systems of the same type.	May occur once during total operational life of one system.	May occur once or several times during operational life.
Quantitative Definition	$<10^{-9}$ per flight hour	10^{-7} to 10^{-9} per flight hour	10^{-5} to 10^{-7} per flight hour	10^{-3} to 10^{-5} per flight hour	1 to 10^{-3} per flight hour

to understand that risk levels are dynamic as the nature of the operations may change over time so up-to-date data is essential for an effective risk assessment process.

Hazard's Probability of Occurrence

In its definition, hazard's probability of occurrence is the likelihood that a safety consequence or outcome will occur. Some outcomes can be considered foreseeable but are difficult to attribute a probability of occurrence. An outcome is considered foreseeable if any reasonable person can expect its occurrence always under the same circumstances. However, the determination of the probability of the meeting of these circumstances is not that straightforward. Therefore, service providers should exercise due diligence when identifying significant and reasonably foreseeable hazards related to their product or service.

Usually, the probability of hazard occurrence is determined with resort to standard classification schemes leading to a structured review. Often, these schemes result from extensive data available that allow making a numerical estimate. The major difficulty is that not every hazard probability can be directly quantified. Physical objects, such as an aircraft component, have usually an historical failure rate associated to it‘s maintenance plan so the estimation of the probability of hazard occurrence becomes more or less straightforward. The simple fact of searching for other equipment or components of the same type that had similar issues or finding the percentage of time of operation of the equipment can help to quantify the probability of a hazard occurrence. On the other hand, hazards associated with human error are a much bigger challenge. The fact that the only source of meaningful data is empirical, associated with a usual lack of registered occurrences makes this type of estimation much more subjective whereby a qualitative classification scheme associated to a quantitative definition becomes more suitable for this case. Thus, it becomes important to search for history of similar occurrences (if not an isolated case). If the hazard comes from bad procedures, finding the number of personnel following or subjected to it and the time of exposure become important factors to determine the probability of hazard occurrence.

Figure 2.3 shows an example chart by ICAO Doc 9859 of both qualitative and quantitative probability criteria and its level of detail and complexity should be adapted to the particular needs of each organisation. It includes five different categories to define the probability related to a hazard and the description of each category.

The presentation of a quantitative probability criteria is not mandatory and depends on the availability of appropriate safety data and the sophistication of the organisation.

Other tables like 2.4, besides the information contained in the previous one, present a value assigned to each category that enables the development of risk matrices that will be addressed afterwards.

Table 2.4: Probability of Occurrence table by ICAO [2] (Qualitative Definitions).

Likelihood	Meaning	Value
Frequent	Likely to occur many times (has occurred frequently)	5
Occasional	Likely to occur sometimes (has occurred infrequently)	4
Remote	Unlikely to occur, but possible (has occurred rarely)	3
Improbable	Very unlikely to occur (not known to have occurred)	2
Extremely improbable	Almost inconceivable that the event will occur	1

Risk Classification and Acceptance

Classifying a risk presumes taking into account both the severity of the hazard and the probability of its occurrence in order to later define its acceptance level. A useful approach to this two-dimensional problem is to use a Risk Classification Matrix. Qualitative or quantitative indicators can be assigned to this type of matrix although, in aviation industry, qualitative terms are more usual.

Risk Matrices A sample of a Risk Classification Matrix is depicted in figure 2.3, where the numbers inside the matrix represent the risk classification number and the 4 coloured areas represent the acceptance level of those risks. It should be emphasised that these coloured areas can change or additional colours can be introduced depending on the company's type of operation, i.e, the acceptance criteria can and should be different depending on the company's Acceptable Level of Safety (ALoS), which will be addressed later.

RISK PROBABILITY	RISK SEVERITY				
	NEGLIGIBLE (1)	MINOR (2)	MAJOR (3)	HAZARDOUS (4)	CATASTROPHIC (5)
EXTREMELY IMPROBABLE (1)	1	2	3	4	5
IMPROBABLE (2)	2	4	6	8	10
REMOTE (3)	3	6	9	12	15
OCCASIONAL (4)	4	8	12	16	20
FREQUENT (5)	5	10	15	20	25

Figure 2.3: Risk assessment matrix example.

In general, the following description applies to the risk matrices of the majority of airline companies.

- **Green:** represents "Acceptable/Tolerable Risks" (Acceptable Level), i.e, the risks that don´t require any intervention. Nonetheless, even though they belong to the acceptable range, the SMS main focus should always be to reduce risks to the lowest level/number practicable if it is economically feasible to do so.

- **Yellow:** represents the ”Acceptable with Recommendation Risks” (Caution Level). Hazards that constitute a risk in this area can be tolerated only if monitored to identify possible negative trends arising. Besides this, additional recommendations to the affected areas are required. Mitigation measures are not mandatory at this level but still are fairly encouraged.

- **Orange:** represents the ”Acceptable with Mitigation Risks” (Dangerous Level). Actual hazards that represent a risk in this area may be considered acceptable under certain conditions of mitigation, in order to have certain benefits. More specifically, these risks otherwise unacceptable could become tolerable if a defined procedure is implemented in that specific situation. These procedures consist of the implementation of defences and controls to reduce the risk level/number associated to the respective hazards. It is required continuous monitoring to evaluate the effectiveness of the procedures implemented and continuous review and adaptation is also recommended, as long as economically feasible.

- **Red:** represents the ”Unacceptable Risks” area (Unacceptable Level). Hazards with this risk level/number associated are not acceptable under the existing circumstances and require immediate intervention to eliminate the factors that are contributing to its high probability and/or severity. It is extremely important that hazards of this type in a company are immediately communicated to the Safety Manager in order to take immediate actions. If necessary, operations must be ceased instantly to perform priority risk mitigation in order to bring these risks' number/level at least to the "Acceptable with mitigation" area. Furthermore, Risk controls must be developed to maintain the risks associated to these hazards at a low level. Monitoring of the risk controls is also required to ensure their effectiveness and prevent the introduction of new hazards (Safety Assurance process).

At this point, it was mentioned how to characterise/classify the risk levels/numbers but it was not explained how risk levels differ from risk numbers, neither how these are obtained. The risk numbers (observed in the previous matrix), resulting from a specific hazard, are obtained from the multiplication of the severity level by the probability of occurrence level of that hazard, as shown in equation 2.1.

$$Risk\ Number\ (R_N) = Probability\ (P) \times Severity\ (S) \tag{2.1}$$

The Risk Level is another representation of risk and is obtained through the combination of the number correspondent to the probability level of the hazard and the letter correspondent to its severity level, e.g, a hazard classified as **”Improbable”** and **”Catastrophic”** has the Risk Level **2A** and the Risk Number equal to **10**.

There are other definitions for calculating the value of a risk. One famous type of risk that is constantly adopted is the Perceived Risk that emerged due to the fact that people tend to attribute more importance to the severity of a hazard rather than the probability of its occurrence. This fact is translated mathematically as an exponential factor (α) attributed to the severity level that increases with the greater importance given to the severity of a hazard, as shown in equation 2.2, where R represents the risk, P represents the Probability and S represents the Severity.

$$R = P \times S^{\alpha} \tag{2.2}$$

However, this last type of risk is not appropriate for this Risk Assessment Tool so it won´t be adopted in this project.

With the risk classification and acceptance subject explained, the question that comes to mind is how to define the limits of the acceptable. This decision requires a clearly defined criteria about tolerability that is known as Acceptable Level of Safety (ALoS).

Risk Tolerability / Acceptable Level of Safety (ALoS)

The concept of acceptable safety is often used in place of absolute safety because, in fact, it is impossible to achieve a complete state of safety and the closer one tries to get to it, the more expensive it gets. The meaning of acceptability consists in being willing to be subjected to a certain risk in order to achieve a goal.

In aviation industry, it is the safety regulatory authority´s responsibility to translate expectations and needs into a qualitative or quantitative target level of safety, expressed by safety performance targets and safety performance indicators. These regulatory authorities define the safety standards to be followed and inspect to check operators compliance so, usually, they are seen as a constrain to the regulated entity. However, it is mainly the responsibility of the operators to maintain the determined level of safety and regulators merely have to ensure operators compliance with their responsibilities. Thus, according to ICAO Annex 11 [19] "the acceptable level of safety expresses the safety goals of an oversight authority, an operator or a service provider. From the perspective of the relationship between oversight authorities and operators/service providers, it provides the minimum safety objective(s) acceptable to the oversight authority to be achieved by the operators/service providers while conducting their core business functions."

2.5.3 Risk Mitigation

After the Hazard Identification and Risk Assessment processes have been carried out, Risk Mitigation is the third and final step in the risk management process. It consists of establishing and implementing strategies and measures headed towards the prevention of hazards resulting in harm and the decrease of the risk to the acceptable level.

When performing the risk assessment analysis, it may be decided to design and implement risk mitigation measures that consist of new or adapted procedures, supervisory controls, organisational hardware, software aids, training adaptations, new or modified equipment and/or many other system changes. The priority of risk mitigation measures should be headed towards reducing the consequences of hazards with higher severity levels, decreasing their respective risk. The enforcement of these risk mitigation measures involves the deployment of the three traditional aviation safety defences: technology, training and regulations.

For these strategies to become successful, they usually follow a path surrounding three goals focused in reducing the severity of potential consequences, the probability of occurrence of harmful effects and the exposure to the risk. The attempt to reach all these goals is impracticable and expensive so deep understanding of the available system defences for each case is a must.

However, before any implementation, the Management of Change should perform an analysis to ensure the new risk mitigation measures do not carry any unintended consequences, primarily the introduction of new hazards, as previously explained in the Safety Assurance section.

Mitigation Measures

In order to mitigate a risk, it is necessary to start by understanding the factors that promote its occurrence and then define the best mitigation measure, or measures if more than one is required, to achieve the desired level of risk reduction. These measures aim at risk elimination, risk mitigation if elimination is out of chance or cooperation with risk if neither elimination or mitigation are feasible, always acting on the probability of occurrence and/or the severity of the consequences.

Usual approaches, according to ICAO, include revision of the system design, modification of current operational procedures, changes to staffing arrangements and training of personnel to deal with the hazard.

After the implementation of new measures, their effect should be continuously evaluated, with resort to Safety Performance Monitoring, to understand if the desired goals are being achieved.

Mitigation Strategies

The subject of defining strategies to attenuate risks is known for being very challenging because it is not an objective matter. Often experience and knowledge about operational environment are not enough to successfully reduce the risks so creativity and open mindsets are great values that help to overcome this problem.

As already mentioned before, although risks are manageable, they are often impractical or too expensive to be completely eliminated so the best solution is to reduce them to ”as low as reasonably practicable” which means following the strategies of **Control of Exposure**, **Exposure avoidance** and **Loss Reduction**.

- **Control of Exposure** - measures taken to isolate the potential consequences related to a hazard or to establish multiple defence layers (redundancy) as defined in the ”Swiss Cheese Theory” by Prof. James Reason (addressed in section 2.6).

- **Exposure avoidance** - the suspension of operations or activities due to the its risk being considered intolerable or unacceptable when compared to its benefits.

- **Loss Reduction** - Accepting some safety risk exposure with condition of the probability or severity associated to the hazard being decreased by measures that control its possible consequences.

A strategy to mitigate an identified risk can be composed of one or a combination of the approaches mentioned before. All the possible mitigation measures and approaches should be considered in order to find the best mitigation strategy and its effectiveness and consequences of implementation must be evaluated before any decision is taken, as already mentioned. Beside this, before any implementation of risk mitigation measures, each should be examined from the following perspectives:

- **Effectiveness** - The extent to which the alternatives reduce or eliminate the safety risks. Effectiveness can be determined in terms of the technical, training and regulatory defences that can reduce or eliminate safety risks.
- **Cost/benefit** - The extent to which the perceived benefits of the mitigation outweighs the costs.
- **Practicality** - The extent to which mitigation can be implemented and how appropriate it is in terms of the available technology, financial and administrative resources, legislation, political will, operational realities, etc.
- **Acceptability** - The extent to which the alternative is acceptable to those people that will be expected to apply it.
- **Enforceability** - The extent to which compliance with new rules, regulations or operating procedures can be monitored.
- **Durability** - The extent to which the mitigation will be sustainable and effective.
- **Residual safety risks** - The degree of safety risk that remains subsequent to the implementation of the initial mitigation and which may necessitate additional safety risk control measures.
- **Unintended consequences** - The introduction of new hazards and related safety risks associated with the implementation of any mitigation alternative.
- **Time** - Time required for the implementation of the safety risk mitigation alternative.

All mitigation or corrective measures should take into account the already existing safety defences and ensure there is no conflict between each other, leading to the inability to achieve the pretended level of safety. This usually results in a review of previous safety risk assessments that may be impacted by the new corrective measure, carried out by the Management of Change. As previously mentioned, after the implementation of the mitigation, its impact on safety performance should be monitored in the safety assurance process to evaluate and ensure the integrity, efficiency and effectiveness of the system defences under the new operational conditions.

Figure 2.4 is now presented to provide a summary of the Safety Risk Management process of ICAO explained throughout this section.

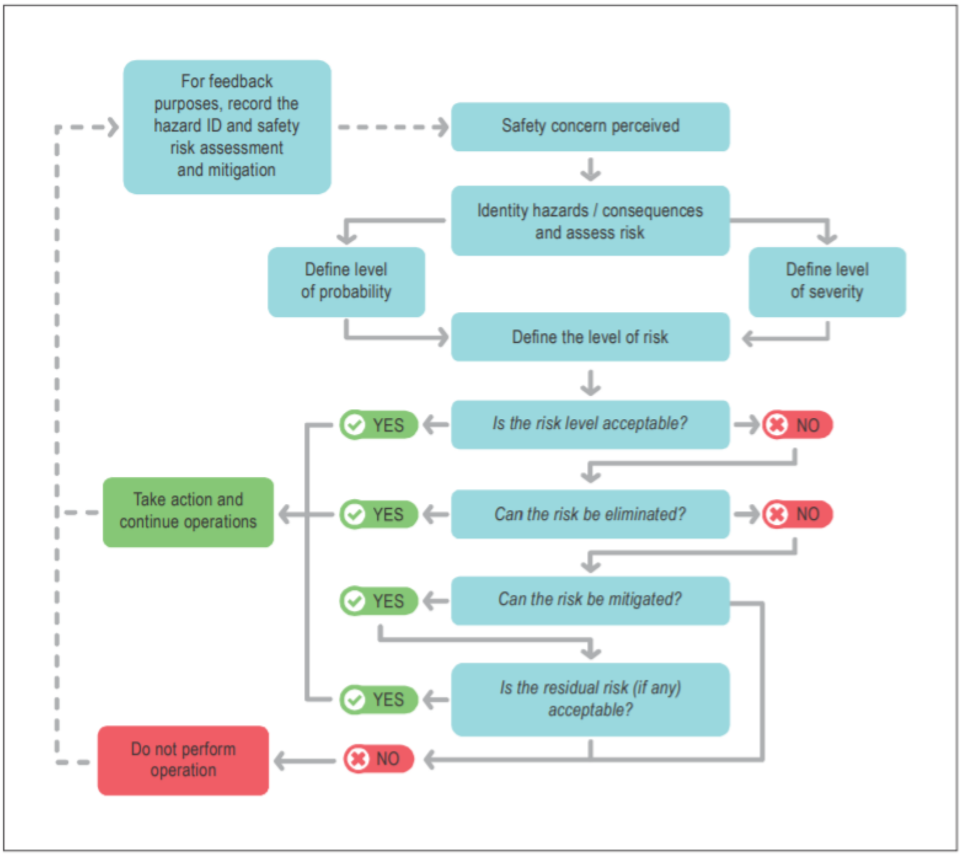


Figure 2.4: Safety risk management aid by ICAO.

2.6 Accident Causation Theory - "Swiss Cheese" Model by Prof. James Reason

In this section, emphasis is given to a popular theory for accident causation that focuses on the importance of increasing layers of defence in order to prevent safety related occurrences. The development of an Aerodrome Risk Assessment Tool consists of adding an additional defence layer against the risks of the airline operation, as it will be explained.

The "Swiss cheese" Model is an accident causation model, proposed by Professor James Reason (ICAO Doc 9859 [2]) that consists of a comparison of the human system defences to a series of randomly-holed Swiss Cheese slices arranged in an uni-axial stack like demonstrated in figure 2.5.

The application of this method to the aviation safety has gained widespread acceptance within the aviation safety community. Performing the translation of the model to aviation terms, the cheese slices consist of the multiple organisation's defences against failure at all levels and the holes represent the weaknesses in each system defence layer, randomly distributed in each slice. The goal is to prevent the alignment of the weaknesses (holes) in the system's different barriers (slices) leading to a breach that penetrates all the defensive barriers and may result in a catastrophic outcome.

Because complex aviation systems necessitate an extreme defence level, this model is truly suitable, supporting that the application of several defence layers (barriers) ensures that a single-point safety

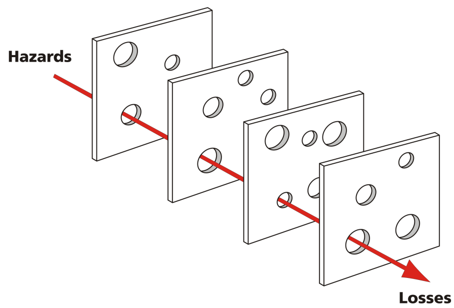


Figure 2.5: Swiss cheese model of accident causation.

failure is rarely consequential.

This model follows the hypothesis that the majority of the accidents can be resumed to one or more of four components of failure. These components consist of Organisational influences, Unsafe supervision, Preconditions for unsafe acts and Unsafe acts themselves.

When considering the breaches in safety defences (layers), the model defends that all accidents are the result of the combination of two types of triggering factors.

First, known as ”latent conditions”, these can be the delayed result of decisions made at the higher levels of the organisation. They are responsible for breaching the holes in the defence layers of the system representing the preconditions for unsafe acts. The consequences of the latent conditions can remain dormant for long periods until certain operation conditions trigger their damaging potential. The major concern with these conditions is that they can be created by decisions of people distant in space and time of the operations that actually become affected. This translates in a difficulty in finding the links in the eventual disaster chain. As matter of example, latent conditions can originate from safety culture, procedural design, conflicting organisational goals, defective organisational systems, management decisions and more.

It is important to mention that all the latent conditions created on a daily-basis of organisational decisions makers have good intentions. The potential damaging outcome that results from latent conditions is an unintentional adverse consequence that results from the everyday difficult activity of balancing organisational finite resources, conflicting priorities and costs reduction.

On the other hand, ”active failures” (human failures) are responsible for the final breaches in the system defence layers leading to a straight path that penetrates all defensive barriers with the possibility of resulting in disaster. These are considered all actions that are erroneous, rule-breakers or even the lack of action associated with the front-line personnel leading to immediate adverse consequences and possibly harmful outcomes. These are commonly referred to as the unsafe acts.

Essentially, the ”Swiss cheese” Model represents how the ever existing latent conditions can manifest their presence once triggered by unsafe human actions.

Although fairly simple, this model is commonly used by service providers as a guide that helps overcoming the urge to analyse the identified hazards and the individuals involved in the incidents and focus on the organisational circumstances which may have allowed the harmful occurrence. It is a common tool during safety risk management, safety surveillance, internal auditing, management of change and safety investigations helping to identify the effective organisational defences, the ones that were breached and the additional defences that could improve the safety of the system, preventing future accidents and/or incidents. Concretely, the system defences are breached from hazards to losses and the safety assessments should follow the opposite direction. However, because actual aviation harmful events have usually a much higher level of complexity, more sophisticated models are used in parallel to understand accident's chain of events.

2.7 Dynamic Risk Management Dashboards (DRMDs)

According to the article "Safety Management and the Concept of Dynamic Risk Management Dashboards" [11], the Dynamic Risk Management Dashboards emerged in recent years as a powerful risk management tool. Despite standard international aviation risk management methodologies being already in place, they were verified not being much effective in recent accidents, which appeared to have resulted from a combination of factors, instead of having one as a major cause. It was also verified that none of these factors alone could lead to the accident. Furthermore, traditional risk management tools like risk matrices and registers and also safety culture, reporting principles and collection of data were found to be less effective predicting this kind of accidents where a combination of factors makes it harder to early detect and avoid risks.

The ever-changing environment of the complex aviation industry requires a proactive and effective SMS, i.e, operators should not only proactively identify the initial risk of an operation but also recognise the current risk, introducing the required mitigation actions to prevent accidents.

The Dynamic Risk Management Dashboards (DRMD) were created to address this problem. It combines the efforts of different departments to identify hazards and to real-time assess risks, while examining the current state of aircraft, aircrews, aerodromes and air traffic routes. It can also be useful for risk assessments in other sectors of aviation industry. However, its main application is to enable operators to assess the overall risk state of an operation by cumulatively considering factors affecting critical system components which must perform within standards. These system components include airworthy aircraft, licensed and fit-to-fly aircrews, certified aerodromes and authorised traffic routes.

The DRMDs must have a pre-defined Risk Acceptance Criteria developed by each operator. This task involves knowing all the conditions that affect aerodromes, aircraft, aircrews and traffic routes and that together and successively lead to a high, medium or low risk state. Noticeably, the list of conditions is extensive and involves experts in different sectors, making this, as well as all risk management processes, a collaborative effort.

In the case of Risk Acceptance Criteria for Aerodromes, an assessment example developed between Flight OPS, Ground OPS, Safety and Security departments is shown in figure 2.6.

This type of assessment enables the evaluation of the overall risk state of an operating aerodrome (figure 2.7). Together with the many other assessments made to other aerodromes on a daily basis, the "DRMD for aerodromes" should be constantly updated with the current risk state of all aerodromes of interest, enabling operators to easily and immediately visualise which ones represent a higher risk.

AERODROME RISK ASSESSMENT: INDICATIVE *EXAMPLE*					
RISK FACTORS CRITERIA	RISK FACTOR POINT SCALE				EVALUATION MARKS
	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	
RWY dimencions (TORA-TODA-LDA)	>9000ft	7-8999ft	6-7000ft	<6000ft	2
Pavement Condition (RWY-TWY-APRONS	Excellent PCN>ACN evaluated by technical means	Medium PCN>ACN evaluated by experience	Good ACN=PCN	ACN>PCN or Not available data	1
NAVAIDS	Precision, ILS CAT -I-III	Precision, RNAV/GPS	Non precision APP	Visual APP only	1
RVR	>1000m	201-999m	101-200m	<100m	1
Lighting	Excellent	Good-Medium	Limited	None	1
Ground Handling fascilities	Owned by the Operator	Third parties	Limited	None	2
Airfield complexity – topography-terrain	Routine	Difficult	Challenging	Hazardous	1
Operating Environment – Language difficulties	None	Minor	Major	n/a	1
Weather Conditions-METAR	CAVOK	Moderate	Severe	Extreme	1
Arrival/Approach/Departure complexity	Routine	Difficult	Challenging	Hazardous	2
RCR-Friction	Good	Fair	Poor	Nil	2
Airport Security	Exceptional/ No recorded events	IAW international stds / 1-2 recorded events	IAW stds / high frequency security threats	IAW stds / high frequency security events	2
Perceived Threat	low	Medium	High	Extreme	2
Staying Lenght	Turn around	2-8 hrs	9-12 hrs	Overnight or more than 13 hrs	4
Recorded safety events in the vicinity	No accidents/serious incidents / no occurences	No accident but at least 1 serious incident/ few occurences	At least 1 accident-serious incident / >1-2 occurence per year	At least 1 accident-serious incident / >1-2 occurence per month	2
TOTAL AIRPORT RISK LEVEL	LOW =<20	MEDIUM 21-34	HIGH 35-49	EXTREMELY HIGH =>50	25

Figure 2.6: DRMD for Aerodrome Risk Assessment Example.

AERODROME RISK ASSESSMENT: INDICATIVE *EXAMPLE*					
LIST OF AERODROMES	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	Last update on
AERODROME 01					14/11/16
AERODROME 02			Due to pavement conditions		14/11/16
AERODROME 03					14/11/16
AERODROME 04					14/11/16
AERODROME 05					14/11/16
AERODROME 06		Due bird strikes and ground handling			14/11/16
AERODROME 07				Due FDM occurrences and weather conditions	14/11/16
AERODROME 08					14/11/16
AERODROME 09			Due to ATC / ATM re-organisations		14/11/16

Figure 2.7: Example of Aerodrome Risk Assessment Results using the Aerodrome DRMD.

Now in the case of aircraft, Maintenance and Quality departments should work together to develop the Risk Acceptance Criteria to enable the evaluation of the overall risk state of an aircraft. Like in the case of aerodromes, on daily basis, many other similar aircraft assessments should be performed that together result in the "DRMD for the fleet", compiling the current risk state of all the operator's aircraft on a specific date.

Likewise, for the case of aircrews, Flight OPS and Training departments should develop together the Risk Acceptance Criteria for a continuous assessment of the overall risk state of a licensed and fit-to-fly aircrew. Similar assessments made on a daily basis to other aircrews feed the results for the "DRMD for the aircrew", illustrating the current risk state of all organisation's aircrews on a specific date.

The same applies to the "DRMD for the air traffic routes" that consists of all the daily assessments of traffic routes, this time with the Risk Acceptance Criteria developed by the Flight OPS (in particular Dispatch) and Security departments. This type of DRMD shows the current risk state of all air traffic routes of interest to the operator.

Having all types of DRMDs, an operator can apply the **"Red2Red"** concept. This concept can and should be applied even if not all four types of DRMDs are available. It consists of avoiding dispatching a "red" aircrew to a "red" aircraft for flying to a "red" aerodrome through a "red" route. The "red" concept has the meaning that the aircrew, aircraft, aerodrome or route that it is characterising is still operational but far from its best operational state. This said, certainly, aligning different "red" components in the operation increases its risk level with the potential of resulting in a serious incident or accident.

All four types of DRMDs feed the master-dashboard that shows the comprehensive and cumulative current risk state of a particular Flight or Mission. This dashboard takes into account the current risk state of the aircraft and aircrew assigned to the flight, the chosen air traffic routes and both the departure and destination aerodromes. Thus, it represents a practical tool for decision making for the operator, streamlining the process to simply applying the Red2Red concept (see and avoid matching two or more high-risk level components). However, it is the management's responsibility to consider all available options and either accept, reject or attempt to further mitigate the risks based on tolerability criteria, then proceeding to authorise or reject a particular flight.

While common Hazard Logs focus on the risk of a hazard (individual risk), DRMDs considers the risk of an accident (cumulative risk). For this reason, DRMDs in combination with the Red2Red concept turns out to be a very powerful tool for aircraft operators. However, DRMDs should not replace the traditional risk management process but instead act as a supplement or even a redundancy. Moreover, since there is no standard risk acceptance criteria for aircraft operators besides manufacturing organisations, the DRMDs act as an opportunity for operators to develop their own risk acceptance criteria based on their type of missions but in accordance with the regulations, standards and minimum user requirements.

The DRMDs represent the most approximate implementation in aviation operation of the "Swiss cheese" model of Prof. James Reason. In analogy, the principal system components dashboards (aircrew, aircraft, aerodromes and air traffic routes) known as the different defence layers of the operation represent the slices and the higher risk procedures and conditions represent the holes in the slices (figure 2.8). Thus, avoiding the alignment of the holes in the cheese model is the same as applying the Red2Red concept in the DRMDs avoiding the alignment of "red" conditions (holes) that increase the overall risk level of the missions or flights.

The DRMDs have been continuously put to test within the safety department of a large military air transport organisation - NATO Strategic Airlift Capability (SAC), where they have been performing successively in their purpose of assisting operators decision makers to identify the cumulative risks of particular missions and effectively respond to unacceptable risks before authorising them. This performance has been continuously monitored and documented to verify the effectiveness of the application of DRMDs in aircraft operation.

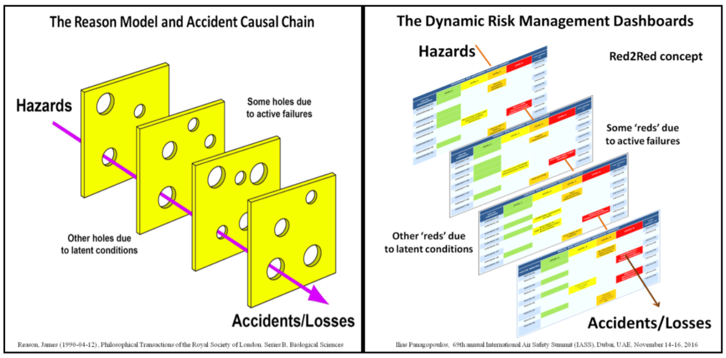


Figure 2.8: Comparison between Swiss Cheese Model and Red2Red Concept.

The experience gained with the implementation of DRMDs in SAC showed that this concept is capable of being effectively integrated over time in safety performance of flight operations, improving the efficiency and effectiveness of the decision-making skills necessary for continuously validating operational risks and issuing flight authorisations. It also provided the necessary methodology for the achievement of desired outcomes and effectiveness of flights and missions.

Surely, a new concept like DRMDs cannot be established in a matter of days and without the support of information technology tools. First, it should be applied to a set of flights and then, after its enhancement, be implemented to every other. Besides this, usually, the original risk acceptance criteria for each component dashboard is not the most suitable so it has to suffer a number of modifications and adaptations until it reaches the final structure which may take several months. Each organisation must find the best improvements in order to conjugate efficiency and safety performance, while minimising the overall operating costs and maintaining an effective SMS. Certainly, the implementation of a Management System method that is so integrated in agreement regulatory and organisational compliance requirements will result in a relevant operational risk reduction.

Risk acceptance criteria has no standard but, although each organisation is free to customise and develop this criteria aiming to the profile of its operations, it is encouraged that a certain harmonisation of this criteria between different organisations for similar operations, helping to establish a common language in the aviation industry and enabling more effective comparisons and benchmarking. However, as already mentioned the focus should be on knowing all the conditions that affect aerodromes, aircraft, aircrews and traffic routes and that together and successively lead to a high, medium or low risk state. In this task, help of experts in the different sectors is essential to generate a list of relevant criteria.

One major impediment in the successful implementation of DRMDs in all aviation operations is the limited organisational resources to collect, process and monitor the necessary data for DRMDs in daily activities, in particular without software support required to speed up the process. Another impediment is the periodicity of the DRMDs update. Even if all software support is available it may not be feasible to update and consult the dashboards for every single flight on a daily-basis. An alternative is to make use of this tool in a smaller sample of flights or to refer to longer period trends.

Finally, one fault that can be recognised in the DRMDs is the fact that these are a semi-linear approach that does not include weighting factors for each system components, neither for the risk factors.

Despite this, even in this current form, the DRMDs were able to practically assist the risk management processes of not only aviation organisations but also other industry sectors, which proves that the development of a risk assessment tool with proper weighting factors developed for each specific hazard would reveal itself to be an important aid to the safety department of any airline company. This is the aim of the development of this Aerodrome Risk Assessment Tool, that is not meant to fully replace the DRMDs but, instead, to act as an improvement/replacement of the ”DRMD of the aerodromes”. Only future work developing other risk assessment tools with an ARAT based structure but focused on other hazards related to the other DRMD types (fleet, aircrew and air traffic routes) would enable the complete improvement of all DRMD types.

2.8 ICAO ADREP

Since the objective of this thesis is the development of an Aerodrome Risk Assessment Tool it will be necessary, at some point, to perform an analysis to the past safety related occurrences in the various aerodromes around the world. This requires understanding the already established standards and definitions to categorise and describe safety related occurrences in aviation.

These standards and definitions are contained in a system that was established in 1976 but that has evolved to meet the changes in information, technology and the aviation industry. It is known as the Accident/Incident Data Reporting (ADREP) system and is operated and maintained by ICAO. This system receives, stores and provides States with occurrences data (accidents and incidents data) that will assist them in validating safety.

The information from the reports that are received from the states around the world is first checked and posteriorly stored. These reports constitute a data bank of world-wide occurrences to provide States with the services of bi-monthly summary of reports, annual ADREP statistics and replies to States' requests.

As previously mentioned, the ADREP reporting system is based on the use of a common reporting standard, also known as taxonomy, which operates using a software platform developed by ECCAIRS. This taxonomy is periodically updated in cooperation with the Contracting States and the current version is available in ICAO's website. The use of this taxonomy in national reporting is recommended to all States in order to achieve international harmonisation and thereby enable the exchange and aggregation of occurrence information.

This extensive taxonomy available in [12] is divided in various lists of attributes and values being the most prominent the following: Entities and attributes; Aircraft category; Aviation operations; Damage aircraft; Descriptive factors; Explanatory factors; Events; Event phases; Geographical areas; Injury level; Landing gear type; Mass group; Occurrence category; Occurrence classes; Organisations/Persons; and Propulsion type.

Not all of these lists will be relevant for the development of the Aerodrome Risk Assessment Tool so the ones that contain crucial information for this project are the Occurrence category [29], Damage aircraft [30], Event phases [31], Occurrence classes [32] and Injury level [33].

Chapter 3

Formulation of the Aerodrome Risk Assessment Tool

In the beginning of this chapter, it is performed an overview of the necessary tasks to develop the Aerodrome Risk Assessment Tool and the sections that follow this overview provide the detailed explanation of the procedures to achieve this goal.

An aerodrome risk assessment encompasses such an extensive variety of continuously updating safety subjects that, if there is no simplified method of performing this analysis, by the time the assessment is concluded, some safety components might already be outdated. For this reason, this new Aerodrome Safety Assessment Methodology was developed to standardise and speed up the assessment process, while also maintaining similarities to the method of operation of the DRMDs.

Since, in this case, this risk assessment tool is being developed for Portugália Airlines, the idea consists of developing a safety checklist that can be used by the Safety Department to evaluate the safety status of the current operation in an aerodrome already operated by the company, evaluate how safe it is to operate in an eventual new aerodrome and also assess the combined risk of operating from one aerodrome to another.

It was intended for the checklist to have safety related questions distributed through different Parts, each Part containing Sections that correspond to the different categories of concerns that should be considered while conducting a safety assessment of an aerodrome.

According to ICAO, the categories of items that should be considered while assessing the safety of operation of an aerodrome are the following: (a) aerodrome layout, including runway configurations; runway length; taxiway, taxilane and apron configurations; gates; jet bridges; visual aids; and the RFFS infrastructure and capabilities; (b) types of aircraft and their dimensions and performance characteristics, intended to operate at the aerodrome; (c) traffic density and distribution; (d) aerodrome ground services; (e) air-ground communications and time parameters for voice and data link communications; (f) type and capabilities of surveillance systems and the availability of systems providing controller support and alert functions; (g) flight instrument procedures and related aerodrome equipment; (h) complex operational procedures, such as collaborative decision-making (CDM); (i) aerodrome technical installations, such as advanced surface movement guidance and control systems (A-SMGCS) or other air navigation aids; (j) obstacles or hazardous activities at or in the vicinity of the aerodrome; (k) planned construction or maintenance works at or in the vicinity of the aerodrome; (l) any local or regional hazardous meteorological conditions (such as wind shear); (m) airspace complexity, ATS route structure and classification of the airspace, which may change the pattern of operations or the capacity of the same airspace.

However, it was decided that the Sections and Parts developed for the ARAT would be inspired in these ICAO categories but mostly modified and adapted to the requirements of Portugália Airline's Safety Department and type of operation.

Each Section is intended to have an attributed risk score that results from the answers of the user to the questions present in that Section. Consequently, the risk score of each Section should contribute to the risk score of the Part to which they belong and each Part score should influence the final global risk score that determines the acceptance (or not) of the safety status of the aerodrome. One way or another, this final risk score should result from the score of each and every Part so each Part has its own importance and, despite a safety aerodrome assessment having an acceptable global score, it can be considered unacceptable if the risk score of one Part is considered unacceptable. However, this consists of the Acceptance Criteria developed for the tool, that depends on the general acceptance criteria of Portugália Airlines and how the company feels safe accepting a determined level of risk exposure. This will be fully explained and detailed afterwards in section 3.13.

All this previous explanation details how the general look of the ARAT should be but an additional feature has to be implemented due to a specific requirement of Portugália Airlines. This feature consists of developing one Part, also divided in sections, but that is considerably different from the rest. This Part should be focused on one of the most critical types of occurrences in aviation, the Controlled Flight Into Terrain (CFIT) occurrence. Thus, as a requirement of the company, this Part should consist of an adaptation of a CFIT Checklist, developed by the Flight Safety Foundation (FSF). CFIT is one out of the many occurrence categories in aviation that will be addressed during the development of this tool and that are mentioned in the "Occurrence Category" list referred in section 2.8. The FSF checklist is already used by the safety department of Portugália Airlines to perform safety assessments and determine the risk level associated to the possibility of CFIT occurrences in each aerodrome operated by the company and the acceptance of this risk level. This checklist has already its own acceptance criteria developed and tested by the FSF but, in this case, it is necessary to adapt the criteria and the results of this checklist to include it in the ARAT in development, making it a part of this much more extensive safety assessment.

For each Part of this checklist (with the exception of the Part destined to the CFIT analysis), a list of suitable questions and respective answer options has to be developed in association with the safety department of Portugália Airlines and distributed through the appropriate Sections in these Parts. This will be explained with more detail afterwards in section 3.1.

Thereafter, these questions and respective answers have to be adapted through a series of standard type questions purposely developed. This standard consists of 4 types of questions, from questions with 2 to 5 answer options, in order to facilitate the user to better pinpoint the exact answer for each question (figure 3.1). An example to better understand the necessity of different types of questions is, when the user is answering to a question about the RFFS category available at an aerodrome, since the RFFS categories go from level 1 to 10, a 2 option answer would only present the 1 to 5 and 6 to 10 choices, not enabling the user to pinpoint the exact result, whereas a 5 option answer would be much more suitable for this case.

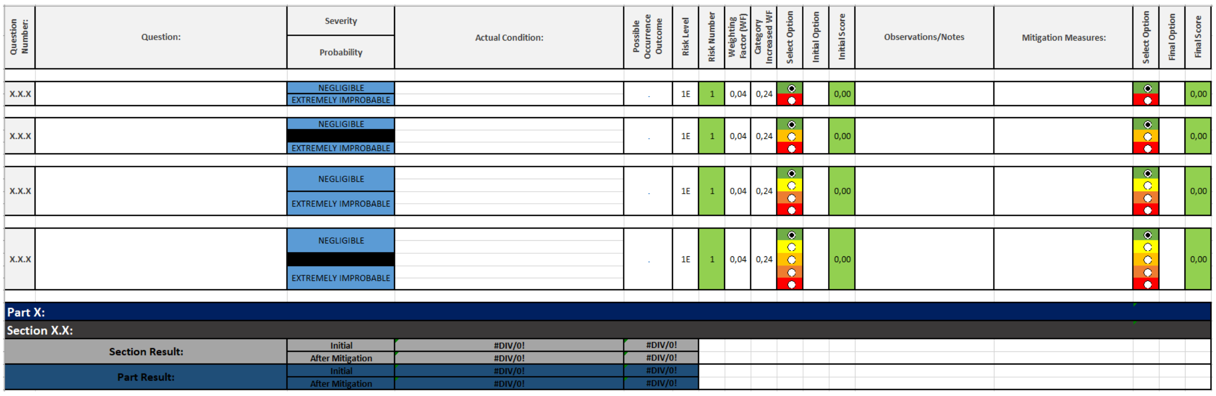


Figure 3.1: Standard model of questions, sections and parts for the checklist of the ARAT.

At this moment, it is noticeable, in figure 3.1, that the questions have a field destined to their weighting factor. As previously mentioned, question without weighting factors, like the case of DRMDs, have the same influence in the final score of the respective section, which is not the most effective way of performing a safety assessment since not all questions refer to subjects representing the same risk level. This way, it is necessary to develop these weighting factors.

In order to develop the weighting factors to attribute to each question, it is necessary to define which factors make a safety question more relevant than another.

Remembering the process of Safety Risk Management, it is possible to understand that the questions present in the checklist consists of the first step of this process: **Hazard Identification**. This way, the questions themselves represent each a different hazard. Regarding the answer options to these questions, these will represent the level of **Exposure** to the respective hazard, a subject that was not mentioned until now but will be addressed later in section 3.9. Now, it starts to become perceptible what part of the Safety Risk Management process the Weighting Factor might represent. The Weighting Factor results from the combination of the **Severity** level and the **Probability of Occurrence** level of the hazard represented in each question, i.e, the weighting factor is proportional to the risk of the hazard. The combination of the risk of the hazard and **Exposure** is what results in the risk score of each question, which afterwards is determined acceptable or not through the Acceptance Criteria. This summarises the translation of the checklist in the ARAT into a Safety Risk Management process.

The next important step is translating each question to the specific aviation hazard that it represents. There was a time in the aviation industry when it was deemed necessary to develop common taxonomies and definitions that were intended to improve the aviation community's capacity to focus on common safety issues. This way, a team of members of ECCAIRS Aviation was chartered to develop these "target" taxonomies and definitions of Occurrence Categories (among others) for adoption by organisations planning for, and implementing new safety systems (section 2.8). An important advantage of this occurrence categorisation design is that it permits the association of multiple categories to the same safety event/occurrence.

Resorting to this occurrence categorisation method, it is possible to effectively translate possible consequences related to the hazards that each question represents to one or multiple occurrence categories that can result from this hazard and, thereby, have an effective means to identify the levels of severity and probability of the occurrences related to each hazard through a statistical analysis of past occurrences.

3.1 Questions, Sections and Parts Formulation

An essential step of developing an Aerodrome Risk Assessment Tool is to find the relevant aspects of the overall characteristics and method of operation of an aerodrome that need to be checked for the compliance of the predefined safety standards of an aviation company.

Consequently, the questions present in this tool need to be targeted to address those aerodrome's characteristics and operation methods and the hazards that they might represent.

Besides being able to analyse the risks of the operation in the aerodromes currently operated by the company, this tool is also required to be able to analyse the risk of operation in any other aerodrome that can be added as a company´s destination in the future.

With these objectives in mind, the first step for starting the formulation of the necessary questions for the checklist was to analyse the current method for the aerodrome risk assessment process of Portugália Airlines. The normal procedure of the company, when analysing the safety of operation in either a current or a new aerodrome, is to answer the questions in the document ”Airport Validation” from the Flight Operations Department which is also reviewed and analysed by the Safety Department. The questions and respective hazards addressed in this document encompass the majority of the crucial aspects of the operations engineering in an aerodrome that need to be checked for compliance with the safety requirements, including aerodrome criteria, SIDs, LVO approval and availability of Navigation data. However, the only possible form of answer to these questions is checking if these are ”Ok” or ”Not Ok”, no intermediate options existing and no system of classification of the hazards represented by each of these questions. Thus, the final result of the assessment is a qualitative evaluation instead of a quantitative score. In addition to this document, the company complements the assessment with the document ”Management of Change New airport operation” in which a summary of the identified hazards is developed and risks of the introduction of a new destination or new procedures to the current destinations of Portugália Airlines operations and what mitigation actions are necessary to maintain an acceptable level of risk. The coverage of the hazards and risks addressed in this document is larger than the previous document, including concerns about the safety requirements in the Operations Engineering Department, Flight Operations Department, Ground Operations Department, Maintenance and Engineering Department, Security Department and Safety Department. However, as in the previous one, the final assessment result is a qualitative result instead of a more useful quantitative risk score.

Based on this current method of safety assessment of the company and the hazards addressed in the previously mentioned documents, the list of questions started to take shape and additionally the possible answer options were also developed together with the respective questions. Because all the hazards addressed in the ”Airport Validation” and ”Management of Change New airport operation” documents, more related with the Flight Operations and Operations Engineering Departments, were extremely important to be kept in this new Aerodrome Risk Assessment Tool, a portion of the questions developed specifically for the Operations Engineering Part of this tool were adapted from these documents. Nonetheless, there was also a far larger number of questions not addressed in these documents that were developed in close contact with members of the Operations Engineering Department of this company and included in the developed tool.

The need to address the major safety concerns of all departments led to a substantial number of total questions. This meant that there was a need to simplify the arrangement of the questions that accomplished through the creation of Sections and Parts. Some of the created Parts correspond to the different Departments of the company while other Parts were created to address specific hazards of greater importance (CFIT and Environmental Hazards).

The list of the created Parts for this checklist is the following: Part 1 - CFIT Risk Analysis; Part 2 - Operations Engineering Department; Part 3 - Flight Operations Department; Part 4 - Training Department; Part 5 - Security Department; Part 6 - Ground Operations Department; Part 7 - Maintenance and Engineering Department; Part 8 - Environmental Hazards; and Part 9 - Safety Department.

Each of the previously mentioned Parts was subdivided in sections according to the subjects of the hazards that the respective questions represent. Having an appropriate distribution of the Sections and Parts, the formulated questions could then be assigned to the proper Sections, improving the organisation and further interpretation of the results of the risk assessment. Due to the final list of the developed questions being very extensive it is presented an example table in appendix C.

3.2 Hazards Identification Process

With the necessary questions for the ARAT formulated and appropriately distributed and organised in Sections and Parts, the following task is to translate the concern addressed in each question to the hazard that each one represents. This procedure will facilitate the process, in the following section, of identification of the potential outcomes resulting from the non-compliance of the safety requirements for each question. In other words, at this point starts the common Risk Management process, that initiates with the Hazard Identification. However, in the development of this Aerodrome Risk Assessment Tool, the common definition of hazard was slightly modified, i.e, the hazard identification process was divided in three separate steps. These are the identification of the hazard, the potential outcome and the possible occurrences outcome, which usually would all be included in the same process. This method of identifying hazards will then enable the calculation of the weighting factor to attribute to each question, which will be further explained afterwards.

Hazards can be identified in three different methods: reactive, proactive or predictive. In this process of identification of the hazards represented by each question, the most used methods were the reactive and proactive. This meant that the process used was a combination of studying the concerns addressed in each question and identifying the dangerous aspects that, in the past, already led to safety related occurrences or that have substantial potentiality to jeopardise the safety of the operation. The predictive method was not taken into account in this process due to the tendency of considering the worst case scenarios, which affects the risk assessment in a ”pessimistic” way, increasing substantially the risk levels of all questions/hazards and jeopardising the distinction of the true higher risk hazards.

Nevertheless, hazard identification in the aviation industry continues to be considered a complex process due to the very wide scope of hazards in this industry and the many possible sources of failure. As already mentioned, ICAO tries to facilitate this process with a list of the most common sources of hazards distributed by the different departments of aviation (figure 2.1) or by the nature of the hazard but these always depend on the organisation and its specific operation. With the help of these lists of hazards of ICAO and also Portugália Airlines, the list of hazards represented in each question was developed as presented in appendix C.

3.3 Potential Outcome Identification Process

In the previous section were identified the hazards represented in each question. Thus, the following task was to identify the potential outcome that each hazard can generate. As the name suggests, the identification of the potential outcome consists of assessing the most probable consequences that can result from a hazard in the eventuality that it actually causes harm to the safety of the operation. The potential outcome consists of the description of the potential safety related occurrences, from damage to aircraft and infrastructures to injuries or fatalities, that can result from a hazard, and this description is what enables the following task of identifying the potential occurrence outcome, which is a similar description but properly identified with the ADREP taxonomy. This taxonomy, as it will be explained afterwards, acts as the bridge that connects the questions to their weighting factors.

This process of potential outcome identification required a similar kind of approach that was previously used for the identification of the hazards, resorting mostly to reactive and proactive methods. Once again, the predictive method, consisting in an extrapolation of the potential outcomes in the future, tends to overestimate the consequences of each hazard, substantially increasing the risk level of all the hazards and jeopardising the identification of the true higher risk hazards. Thus, it was not used for this potential outcome identification.

The list of questions with the respective hazards and potential outcomes identified is presented in the same table referred in previous section (appendix C).

3.4 Occurrence Category Determination Process

For all questions present in the checklist, a study had to be performed to identify which occurrences could become a result of the hazard represented in each question. Thus, as previously explained, the process for this study consisted of, for each question, identifying the hazard(s) that it represents, then identifying the potential outcome of that hazard and, finally, translating those outcomes to one or more of the occurrence categories previously mentioned. This process is done with help of the thorough description of the usage of each occurrence categorisation taxonomy present in the ECCAIRS / ICAO documents referenced in section 2.8. This taxonomy was purposely developed to categorise all safety related occurrences in aviation in a standard manner so that all aviation related companies are able to distinguish the various occurrence types in the same way, facilitating and simplifying safety occurrence analysis.

The process for attributing one or more occurrence categories to a certain question is to analyse the already identified potential outcome attributed to that question and search, in the usage description of each occurrence category, the one that better applies to that specific outcome. However, despite of the usage description of each occurrence usually being quite detailed, there are some circumstances where the potential outcome does not exactly match one of the occurrences descriptions. In these cases, there is a category designated as ”Other” (OTHR) to encompass these situations.

Besides this, in this process, it was noticed that some of the occurrence categories, in the previously mentioned list, would not be used in the development of this tool. Starting with one safety occurrence category included in this taxonomy designated as ”Unknown” (UNK), it is necessary to keep in mind that this occurrence taxonomy was developed to categorise the safety related occurrences in aviation after the occurrences took place, so the usage of this category makes sense in the situations where the aircraft is missing or there is lack of information to categorise the occurrence. However, since in the development of this Aerodrome Risk Assessment Tool, this taxonomy is being used to categorise known potential outcomes, already identified, there is no place for the usage of the ”Unknown” category.

One other category not being used is coded as GTOW, also known as, ”Glider TOWing related events”. The reason behind this is the fact that, because the main focus of this Aerodrome Risk Assessment Tool are the aerodromes that have the capability to sustain international flights, there is no place for the usage of the GTOW category since these types of aerodromes do not allow the operation of this type of aircraft. The same logic applies to the case of the ”LOLI” (LOss of LIfting conditions en-route) occurrence category. Despite its designation omitting this fact, this safety related occurrence category is only applicable to aircraft that rely on static lift to maintain or increase its flight altitude, namely sailplanes, gliders, hang gliders and paragliders, balloons and airships. Once again, since the focus of this tool are aerodromes with capability to sustain international flights, where the operation of this type of aircraft is not allowed, this occurrence category can not be taken into account.

Finally, there is the case of the runway incursion related occurrence categories. The list of occurrences developed by ICAO includes three different types of runway incursions: RI (Runway Incursion); RI-O (Runway Incursion - other) and RI-VA (Runway incursion - vehicle or aircraft). These different types of runway incursions where created to distinguish the nature of the runway intruder. However, when performed the statistical analysis of past occurrences, that is explained afterwards in the chapter 4, it was noticed that this distinction between the types of intruders does not exist because RI-O, as well as RI-VA, are not used in the ICAO databases. For this reason, it was decided to adopt the same procedure during this potential occurrence outcome identification process, only adopting the RI occurrence category to represent all types of runway incursions.

Once again, the tables in appendix C show the final product of this process, with the potential occurrence category attributed to each question and respective hazard.

Now, with each question having one or more occurrence categories attributed, it is possible to move on to attributing a severity and probability of occurrence level to each occurrence category. This way, the occurrence categorisation acts as a ”bridge” that connects each question and its related hazard to a severity and probability of occurrence level enabling the posterior development of the weighting factors that determine the relevance of each question for the final risk assessment result.

3.5 Severity and Probability of Occurrence Determination Process

There are several definitions for severity and probability of occurrence levels developed and adapted to perform safety assessments in all areas of industry. Even in the aviation industry there is no agreement of standard definition of these levels for all companies because they are meant to be adapted to the operation and safety requirements of each one. However, ICAO provides a criteria of severity and probability of occurrence levels that companies can adopt and refine to their benefit. This criteria of ICAO is the basis of the levels adopted for the development of this Aerodrome Risk Assessment Tool due to its general similarity to most of companies standards. The respective definitions for each level of severity and probability of occurrence were already described in table 2.2 and chart in figure 2.3, respectively. This table and chart will not be shown here again to avoid redundancy but it is **extremely important** to take them into consideration, as well as the tables in appendix C, while trying to understand the process explained in this section.

As explained in the previous section, for each question in the checklist of this Aerodrome Risk Assessment Tool, was attributed one or more potential occurrences whose usage description coincided with the potential outcomes previously identified. Each of these occurrence categories has an associated level of severity and probability. The determination of these levels was achieved through a reactive approach method that consisted of a statistical analysis to the safety related occurrences in all aerodrome members of ICAO. This data is present in one of the many ICAO databases that contains information about safety related occurrences and has the advantage of having a field identifying the correspondent occurrence category code(s) applicable to each situation. More information about this statistical analysis will be given in chapter 4.

Having each occurrence category and its specific severity and probability level, it is now possible to identify and attribute these levels to the questions in the checklist. As previously explained, some questions can have only one attributed potential occurrence while others may have two or more. In the case of the questions having only one potential occurrence attributed, the determination of the severity and probability levels of those questions is quite intuitive, corresponding simply to the same levels determined for the attributed potential occurrence. However, in the cases of questions having two or more potential occurrences attributed, the determination of the appropriate severity and probability levels to assign to that question is not as straight forward as in the previous case. One possibility is to analyse the most frequent severity and probability levels in the different potential occurrences attributed to each question and select those levels but this would become impossible in cases where these levels were different for all the occurrences (e.g a question with LOC-I and ADRM occurrences attributed). Another approach could be to assign an intermediate level between those of the potential occurrences attributed to each question. However, this approach would not be as simple in cases where the severity and probability levels were consecutive (the previous example also applies to this case). The third approach could be to choose either the lowest or highest severity and probability levels of the potential occurrences attributed to each question. Since this tool is designed to measure the risk and improve the compliance with safety requirements, it was expected that the best option was to decide to assign to each question the highest severity and probability levels of all the potential occurrences attributed to each one. Thus, the worst case scenario is being considered in this approach and, despite in some cases the attributed levels being slightly overestimated, as the old saying goes, ”it is better to be safe than sorry”.

Therefore, the determined severity and probability levels to assign to each question are presented in the same tables in appendix C.

A solution in order to minimise slight severity and probability level overestimations could be the modification of the adopted severity and probability intervals, creating a larger number of levels and decreasing the range of the intervals. However, despite this hypothesis being considered, it was deemed unnecessary after the implementation and verification of this approach, that will be addressed in chapter 5.

Although not always a simple task, the standard for severity and probability level determination used in this tool can also be modified by each individual company to better suit their operation. If the modification only involves the denomination of each level it becomes a simple task. However, in case of modification of ranges comprised in each level or modification of meaning/definition it would be necessary to perform a new Occurrence Statistical Analysis, as described in chapter 4, in order to properly attribute the weighting factor values to each question.

3.6 Risk Level and Risk Number Determination

After the determination of the level of severity and probability of occurrence for each question present in the checklist of this Aerodrome Risk Assessment Tool, a risk level and number were also attributed.

The risk level attributed to each question is composed by one letter and one number (e.g level 3E). The letter, comprised between A and E, corresponds to the level of severity attributed to the question in descending order of severity and the number, comprised between 1 and 5, corresponds to the probability of occurrence level, this time in ascending order of probability.

The risk number consists of the multiplication of the severity level by the probability of occurrence level (equation 3.1). However, in order to get this value, the severity levels are translated from the letters E to A to numbers from 1 to 5, similarly to the probability of occurrence levels. This way, the risk level is a number comprised between the lowest value 1 and the most critical value 25, as shown in figure 3.2.

$$Risk\ Number\ (R_N) = Severity\ (S) \times Probability\ (P) \tag{3.1}$$

				Severity				
				NEGLIGIBLE	MINOR	MAJOR	HAZARDOUS	CATASTROPHIC
				E	D	C	B	A
				1	2	3	4	5
Probability	EXTREMELY IMPROBABLE	1	1	1,00	2,00	3,00	4,00	5,00
	IMPROBABLE	2	2	2,00	4,00	6,00	8,00	10,00
	REMOTE	3	3	3,00	6,00	9,00	12,00	15,00
	OCCASIONAL	4	4	4,00	8,00	12,00	16,00	20,00
	FREQUENT	5	5	5,00	10,00	15,00	20,00	25,00

Figure 3.2: Risk matrix for the ARAT.

This is the method adopted by Portugália Airlines' safety department in order to perform Risk Classification. A set of four colours is also used to help identifying how critical is the risk level/number. In many situations, including the SMM of Portugália, this set of colours is considered an auxiliary to identify the acceptance of a risk. However, this is only true if one is considering the risk represented by a hazard. In the case of this ARAT, in order to define the acceptance of a risk represented in a question (risk score), it is also necessary to consider the exposure to the risk. As mentioned previously, the risk number and level are composed of the level of severity and probability of occurrence of a hazard and, in some situations, despite the risk level of a hazard being at the upper limit, the risk score of the question can still be acceptable if there is very low or none exposure to it.

Despite the used colours and denomination for the levels in figure 3.3 denoting risk acceptance these are only characterising the acceptance of the a hazard's risk (2D current system) and not the acceptance of the risk score of the question after considering the exposure (3D system in development).

2D Standard (Standard of Portugália)					
Acceptable	1,00	<	x	<	6,00
Acceptable with recommendation	6,01	<	x	<	12,00
Acceptable with mitigation	12,01	<	x	<	16,00
Unacceptable	16,01	<	x	<	25,00
Acceptance Criteria	Upper Boundaries (% of MAX Value)	Upper Boundaries	Max Value		
Acceptable	24	6	25,00		
Caution	48	12			
Dangerous	64	16			
Unacceptable	100	25			

Figure 3.3: 2D Risk Standard of Portugália.

The subject of risk acceptance will be addressed more in-depth afterwards, in section 3.13. The risk number attributed to each question will then be used to determine each weighting factor.

3.7 Weighting Factor

Once determined and attributed the risk levels to the questions present in this Aerodrome Risk Assessment Tool, it is now possible to calculate the weighting factor of each one, determining their influence on the risk score of the Section and Part that they are included in and also in the global risk score of the assessment.

For the calculation of the weighting factor attributed to a specific question, it was decided to take into account the risk number of the hazard represented in that question due to the fact that a hazard that represents a greater danger must have greater influence in the risk score of its section. This way, as expected, a hazard with a high risk number and low exposure can have the same influence on the risk score as a hazard with low risk number and higher exposure.

The weighting factor calculation, represented in equation 3.3, consists of the division of the risk number attributed to the question by the highest possible risk number (25) (equation 3.2). This way, for every question, this value is comprised between 0,04 (1/25) and 1 (25/25). The combination of this value and the exposure level (answer), selected by the user, results in the initial risk score that will be fully addressed afterwards in section 3.10.

$$Max\ Risk\ Number\ (25) = Max\ Severity\ Level\ (5) \times Max\ Probability\ Level\ (5) \tag{3.2}$$

$$Weighting\ Factor\ (WF) = \frac{Risk\ Number\ (R_N)}{Max\ Risk\ Number\ (25)} \tag{3.3}$$

3.8 Aerodrome Category Increased Weighting Factor (ACIWF)

Before companies establish a continuous operation to a specific aerodrome, it has to be classified as an aerodrome of category A, B or C. This category depends on the criteria established by the company evaluating the aerodrome so, in this case, only Portugália Airlines' criteria will be taken into account. According to Portugália, a Category A aerodrome satisfies the requirements of having an approved instrument approach procedure, at least one runway with no performance limited procedure for take-off and/or landing, published circling minima not higher than 1000 ft AAL and night operations capability. A Category B aerodrome does not satisfy the Category A requirements or requires extra considerations such as non-standard approach aids and/or approach patterns, unusual local weather conditions, unusual characteristics or performance limitations or any other relevant considerations including obstructions, physical layout, lighting etc. A Category C aerodrome requires additional considerations to Category B aerodromes.

With this in mind, it was decided to create the Aerodrome Category Increased Weighting Factor (ACIWF) besides the normal weighting factor attributed to all the questions, mentioned in the previous section. The Aerodrome Category Increased Weighting Factor (ACIWF) consists of the sum of the normal Weighting Factor (WF) with an Increment Factor (IF) based on the aerodrome category (equation 3.4). This increment factor will be determined through a statistical analysis in chapter 4.

$$Aerodrome\ Category\ Increased\ Weighting\ Factor\ (ACIWF) = Weighting\ Factor\ (WF) + Increment\ Factor\ (IF) \quad (3.4)$$

The key objective of this factor is to correct the influence of the higher number of category A aerodromes, in relation to B and C, in the determination of the probability of each occurrence type, i.e, because globally there is a bigger number of category A aerodromes, which in theory are safer, these tend to decrease the number of safety related occurrences, decreasing the probability of the occurrences. If this decreased probability is not taken into account for the aerodromes of categories B and C it would result in an assessment's final risk score that would be lower than the true one.

3.9 Exposure to Occurrences

In this Aerodrome Risk Assessment Tool, the method used for the risk score calculation differs from the usual 2D methods that only include the Severity and Probability of occurrence parameters. This 2D method (SP model) is used in this tool only for the calculation of the risk represented by a hazard (equation 3.5).

$$SP\ Model:\ Risk\ Number\ (R_N) = Severity\ (S) \times Probability\ (P) \quad (3.5)$$

However, for the calculation of the risk score of each question (risk after exposure is taken into account) the Severity, Exposure and Probability (SEP) Risk Assessment Model is used as inspiration. In fact, the SEP model (3D) consists of nothing more than an improvement of the SP model (2D) by adding another parameter/dimension (equation 3.6).

$$SEP\ Model:\ Risk\ Score\ (R_S) = Severity\ (S) \times Probability\ (P) \times Exposure\ (E) \quad (3.6)$$

The Severity and Probability of occurrence are the parameters which are predefined for each question present in the ARAT and contribute to the weighting factor that will determine the influence of each question in the final risk result, as mentioned in the previous section. On the other hand, Exposure is the parameter which is inserted by the user when answering the checklist's questions. As mentioned before, the types of questions go from having 2 answer options to 5 answer options. These options go from the best case, where there is a minimum exposure to that specific hazard, to the worst case, where there is maximum exposure.

This way, the model developed for the ARAT consists of the combination of the weighting factor (ACIWF in fact), given by the levels of severity and probability of the occurrence, and the exposure, given by the answer of the user, resulting in the risk score of the question (equation 3.7).

$$ARAT\ Model:\ Risk\ Score\ (R_S) = Weighting\ Factor\ (ACIWF) \times Exposure\ (E) \quad (3.7)$$

As in the cases of Severity and Probability, there are many standards of exposure in the aviation industry that depend on the companies. Exposure is also divided in levels and in the case of this checklist, 5 exposure levels where defined from ”very low” to ”very high” (from 1 to 5) as in table 3.1

Table 3.1: Exposure levels for the ARAT.

Exposure	Level
Very Low	1
Low	2
Medium	3
High	4
Very High	5

Since there are 5 exposure levels and the checklist has from 2 answer options to 5 answer options, scale adjustments had to be done to the answers with less than 5 options. For example, the case of a question having 2 answer options, it can only have the selected options 1 or 2, meaning that its an ”OK/Not OK” answer type, and it has to be scaled to the values from 1 to 5, meaning minimum exposure and maximum exposure to the hazard represented in that question.

In order to convert a value x in a scale x_i to x_f to a value y in a scale y_i to y_f, it is used the linear transformation formula as can be found, for example, in [34] and represented in equation 3.8.

$$\frac{x - x_i}{x_f - x_i} = \frac{y - y_i}{y_f - y_i} \tag{3.8}$$

Thus, the adjustments performed to all the types of answers are represented in the following equations (from 3.9 to 3.12), where x is the user selected answer option and y is the converted value to exposure level.

$$2\ Option\ Answer: \ \frac{x-1}{2-1} = \frac{y-1}{5-1} \iff y = 4x - 3 \tag{3.9}$$

$$3\ Option\ Answer: \ \frac{x-1}{3-1} = \frac{y-1}{5-1} \iff y = 2x - 1 \tag{3.10}$$

$$4\ Option\ Answer: \ \frac{x-1}{4-1} = \frac{y-1}{5-1} \iff y = \frac{4}{3}x - \frac{1}{3} \tag{3.11}$$

$$5\ Option\ Answer: \ \frac{x-1}{5-1} = \frac{y-1}{5-1} \iff y = x \tag{3.12}$$

3.10 Initial Risk Score

The initial risk score is the risk value determined for each question after the levels of severity, probability of occurrence and exposure have been attributed. This value’s calculation consists of the multiplication of the weighting factor (in this case, the Aerodrome Category Increased Weighting Factor) (value between 0,04 and 1) by the exposure level (value between 1 and 5), represented in equation 3.13.

$$Risk\ Score\ (R_S) = Weighting\ Factor\ (ACIWF) \times Exposure\ Level(E) \tag{3.13}$$

Thus, the matrices in figure 3.4 and a 3D representation in figure 3.5 demonstrate the possible risk scores that can be attributed to the questions.

Exposure	Very Low	1		Severity				
				NEGLIGIBLE	MINOR	MAJOR	HAZARDOUS	CATASTROPHIC
				E	D	C	B	A
				1	2	3	4	5
Probability	EXTREMELY IMPROBABLE	1	1	0,04	0,08	0,12	0,16	0,20
	IMPROBABLE	2	2	0,08	0,16	0,24	0,32	0,40
	REMOTE	3	3	0,12	0,24	0,36	0,48	0,60
	OCCASIONAL	4	4	0,16	0,32	0,48	0,64	0,80
	FREQUENT	5	5	0,20	0,40	0,60	0,80	1,00

Exposure	Low	2		Severity				
				NEGLIGIBLE	MINOR	MAJOR	HAZARDOUS	CATASTROPHIC
				E	D	C	B	A
				1	2	3	4	5
Probability	EXTREMELY IMPROBABLE	1	1	0,08	0,16	0,24	0,32	0,40
	IMPROBABLE	2	2	0,16	0,32	0,48	0,64	0,80
	REMOTE	3	3	0,24	0,48	0,72	0,96	1,20
	OCCASIONAL	4	4	0,32	0,64	0,96	1,28	1,60
	FREQUENT	5	5	0,40	0,80	1,20	1,60	2,00

Exposure	Medium	3		Severity				
				NEGLIGIBLE	MINOR	MAJOR	HAZARDOUS	CATASTROPHIC
				E	D	C	B	A
				1	2	3	4	5
Probability	EXTREMELY IMPROBABLE	1	1	0,12	0,24	0,36	0,48	0,60
	IMPROBABLE	2	2	0,24	0,48	0,72	0,96	1,20
	REMOTE	3	3	0,36	0,72	1,08	1,44	1,80
	OCCASIONAL	4	4	0,48	0,96	1,44	1,92	2,40
	FREQUENT	5	5	0,60	1,20	1,80	2,40	3,00

Exposure	High	4		Severity				
				NEGLIGIBLE	MINOR	MAJOR	HAZARDOUS	CATASTROPHIC
				E	D	C	B	A
				1	2	3	4	5
Probability	EXTREMELY IMPROBABLE	1	1	0,16	0,32	0,48	0,64	0,80
	IMPROBABLE	2	2	0,32	0,64	0,96	1,28	1,60
	REMOTE	3	3	0,48	0,96	1,44	1,92	2,40
	OCCASIONAL	4	4	0,64	1,28	1,92	2,56	3,20
	FREQUENT	5	5	0,80	1,60	2,40	3,20	4,00

Exposure	Very High	5		Severity				
				NEGLIGIBLE	MINOR	MAJOR	HAZARDOUS	CATASTROPHIC
				E	D	C	B	A
				1	2	3	4	5
Probability	EXTREMELY IMPROBABLE	1	1	0,20	0,40	0,60	0,80	1,00
	IMPROBABLE	2	2	0,40	0,80	1,20	1,60	2,00
	REMOTE	3	3	0,60	1,20	1,80	2,40	3,00
	OCCASIONAL	4	4	0,80	1,60	2,40	3,20	4,00
	FREQUENT	5	5	1,00	2,00	3,00	4,00	5,00

Figure 3.4: Risk scores in matrix view.

As well as the case of the hazard's risk number, these values are categorised with a set of four colours but, this time, this categorisation refers to the acceptance of each risk score, that will be discussed in section 3.13.

The sum of the initial risk score of each question in a section (equation 3.14) divided by the worst case scenario (all question's scores in that section having maximum risk level and exposure, equation 3.15) results in the initial risk score of a section, in percentage (equation 3.16). The "initial" denomination comes from the fact that this value results from the user selection of the initial options. The initial options correspond to the state of the aerodrome in the current conditions, without any intervention of the company to minimise the risk of operation. The same method is used to determine the initial risk score of each Part, this time considering the risk scores of all the questions in each Part.

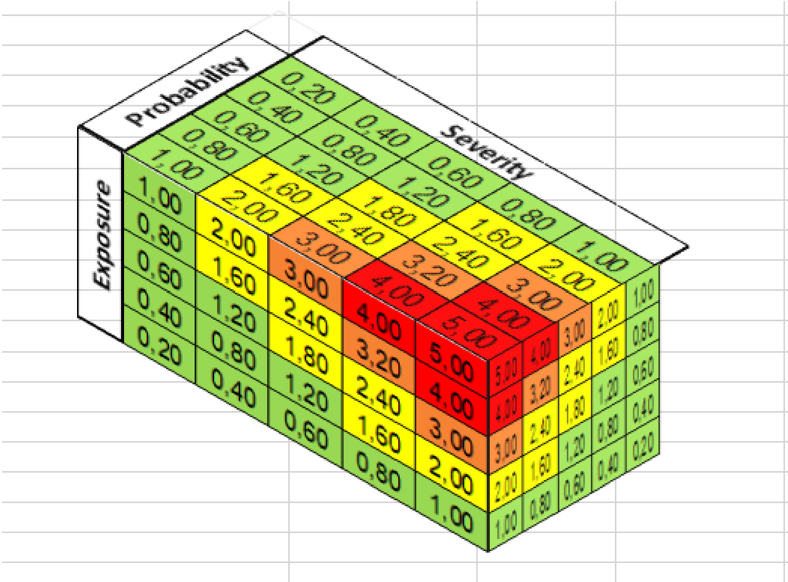


Figure 3.5: Risk scores in 3D view.

$$Risk\ Score\ Sum = \sum_{k=1}^{n} Risk\ Score\ of\ Question\ ”k” \tag{3.14}$$

$$Max\ Risk\ Score = \sum_{k=1}^{n} Max\ Risk\ Score\ of\ Question\ ”k” \tag{3.15}$$

$$Section/Part\ Risk\ Score\ (\%) = \frac{Risk\ Score\ Sum}{Max\ Risk\ Score} \times 100 \tag{3.16}$$

Finally, for the determination of the Initial Global Risk Score, it was adopted the value of the Part of the assessment with maximum risk score. This is due to the fact that, after an experiment of using the previous method for the Global Risk Score calculation, it was verified that the highest risk aspects of each assessment were ”diluted” due to the large number of questions present in the checklist, jeopardising the distinction between high and low risk aerodromes. Therefore, using the highest risk score method solves this problem, as well as being a safer approach. For every initial risk score, there is also an after mitigation risk score that will be addressed afterwards in section 3.12.

3.11 Observations and Notes

For every question present in this Aerodrome Risk Assessment Tool, there is a dedicated column for the user to insert observations, notes or even for the developer of the checklist to leave information that one might find useful to the user of the tool while responding to a specific question.

The data inserted in this dedicated column should not interfere at all with the risk score of the questions but only provide additional information about sources of information or explain the criteria used to select the answers to the questions.

An example of a useful situation of this column for the user is to provide links with the source of information that one used to select the answer to a question and/or provide the explanation and reasoning behind the answer selected. This, not only enables users to understand more easily the assessment performed by others but also to remind themselves of their reasoning while answering the questions.

This column may become useful for the developer of the questions in order to provide links to databases containing information that could be useful, helping the user to choose the most appropriate answer. In these cases, the observations column of those questions is already occupied by the hyperlinks provided by the developer, not enabling the user to insert additional information. However, in these cases, additional information should not be required as the one contained in the provided databases should be more than enough.

The particular case of Part 1 of the checklist is a specific case where the observations column of the question should not be modified and its only purpose is to alert the user for the presence of observation notes in the questions of the CFIT Checklist. This subject is explained with more detail afterwards, in section A.1.

3.12 Mitigation Measures and Risk Score After Mitigation

Besides the initial state assessment, this Aerodrome Risk Assessment Tool has also an assessment that corresponds to the analysis of the risk of aerodrome's operation after the implementation of certain mitigation measures targeted to decrease the exposure to the risks represented by the hazards in each question. Concretely, this means that the user performing the initial state assessment can also introduce, in the questions deemed necessary, one or more mitigation measures in order to control the risk represented in those specific questions, enabling the reduction of the exposure to that risk and, consequently, selecting a lower exposure option that will result in a lower after mitigation risk score.

The calculation of the after mitigation risk score follows the same process of the initial risk score, i.e, it is the result of the product between the exposure level, after applied the mitigation measures, and the weighting factor (Aerodrome Category Increased Weighting Factor) of that specific question.

Besides this, as in the initial risk score case, the sum of the after mitigation risk score of each question in each section divided by the worst case scenario results in the after mitigation risk score of the section, in percentage. The same applies to the calculation of the after mitigation risk score of each Part. Also, the calculation of the Global After Mitigation Risk Score follows the same previous method of the Global Initial Risk Score.

3.13 Acceptance Criteria

In order to evaluate the risk scores obtained after each assessment performed in this Aerodrome Risk Assessment Tool, an acceptance criteria had to be developed. However, this criteria can be a bit subjective, depending on the company that is performing the risk assessment and how much tolerance the company has to a certain risk level.

All aviation operations, as well as in other industries, have an associated risk level. Despite how insignificant this risk might be, it always exists with an associated severity and probability level, the so called risk level/number. The risk level/number itself can be subjected to an acceptance criteria, which is the case of the hazards risk in this tool. However, as previously explained, the risk score after answering the questions in this tool is measured with a third dimension, the exposure level to the risk number. Despite this fact, there is no change in the method of implementation of the acceptance criteria. The criteria for this risk assessment tool was develop in a way that it defines the acceptance in the same manner for the whole assessment, not only the risk score of each question, Section or Part, but also the acceptance of the risk level/number, represented by the hazard present in each question.

Because, since the beginning of its development, this Aerodrome Risk Assessment Tool was oriented to the safety requirements of Portugália Airlines, it only makes sense to develop the acceptance criteria according to the specifications of this company and its limit of tolerance to risk while operating in an aerodrome. Thus, the process for the development of the acceptance criteria started with an analysis to the SMM of Portugália Airlines, trying to understand this company's defined limits of tolerance to certain risks. In the Safety Risk Management section, was where the Risk tolerability of the company was found. In this case, these limits were specifically developed to define the acceptance of the risk levels in the common risk matrix used by the majority of aviation companies. As already explained in section 3.6, in this type of matrices, the levels of severity and probability of a hazard are represented in the rows and columns from levels 1 to 5, with the risk levels, represented in the matrix, corresponding to the product of the corresponding severity by the probability levels (figure 3.2). These risk levels comprised between 1 and 25 have four different colours associated which define their acceptance. This corresponds to the acceptance criteria developed by Portugália Airlines to categorise which risk levels are acceptable, acceptable with recommendation, acceptable with mitigation and unacceptable. The four acceptance levels and respective risk level intervals were already shown in figure 3.3.

At this point, it was considered that these acceptance intervals could be used to define the acceptance criteria of the risk scores in the Aerodrome Risk Assessment Tool, thus keeping a consistent risk tolerability criteria for all the safety related events in the company. This required to translate the risk level intervals to percentage intervals that could be implemented in the risk assessment tool. Thus, these percentage intervals were calculated and are also present in figure 3.3.

With this acceptance criteria defined it could then be implemented in the risk assessment tool. However, because this criteria rules the acceptance of all the risks identified in the tool, it was implemented in a separate sheet, enabling future modifications if deemed necessary by the company.

As previously mentioned, this same acceptance criteria based on the defined percentages is used to categorise the acceptance of the entire tool's risk scores such as risk numbers, question's risk scores, section's risk scores, part's risk scores and the global risk score of the assessment. The fact that the criteria is based on risk percentages and not on risk numbers facilitates its application to all situations due to the variety of risk ranges in this tool (risk numbers range from 1 to 25, question risk scores from 0 to 5 and risk scores of sections and parts from 0 to 100%).

Having been defined the acceptance criteria, it is now presented, in figures 3.6 and 3.7, the acceptance criteria developed for this tool to categorise all the possible risk scores and risk numbers presented in this Aerodrome Risk Assessment Tool. Note that this criteria is the one that also categorises the acceptance of the risk scores in figure 3.5.

General Acceptance Criteria		
Acceptable	<=	24,0%
Caution	<=	48,0%
Dangerous	<=	64,0%
Unacceptable	>	64,0%

Figure 3.6: General acceptance criteria of the ARAT.

3D Standard (Modified Standard)					
Acceptable	0,00	<	x	<	1,20
Acceptable with recommendation	1,21	<	x	<	2,40
Acceptable with mitigation	2,41	<	x	<	3,20
Unacceptable	3,21	<	x	<	5,00
Acceptance Criteria	Upper Boundaries (% of MAX Value)	Upper Boundaries	Max Value		
Acceptable	24	1,2	5,00		
Caution	48	2,4			
Dangerous	64	3,2			
Unacceptable	100	5			

Figure 3.7: 3D standard of the ARAT.

Chapter 4

Aerodrome Safety Occurrences Statistical Analysis

In order to define the severity level and probability of occurrence associated with each occurrence category, a statistical analysis was performed to the Safety Occurrences database from ICAO [35] containing safety related events from every aerodrome in all the 192 ICAO member sates through all continents, since the start of the year 2008 until December 1^{st}, 2019.

Taking into account this time interval previously mentioned, an initial analysis was performed as a first approach to the large extent of data present in this ICAO database in order to start defining the main parameters that would help the definition of the severity and probability levels to later attribute to the occurrence categories of the ICAO taxonomy, mentioned in section 2.8.

4.1 Initial Analysis

To start of, a first step in order to determine the probability of the occurrences was to perform an analysis with the aim of discovering the number of occurrences from each category during this time interval in order to sort the occurrence categories from the most frequent to the rarest ones (information in figure 4.1 in percentage). Although this is a crucial step to determine the probability of occurrence of each category, contrary to what one might think, knowing the frequency of occurrence of each category by itself does not allow to determine the probability of the occurrence. In fact, it allows to determine the order of the most probable occurrence to the least probable one which will coincide with the sorting of the frequency of occurrence but one will not be able to determine the probability level of each category. Further explanation to this fact is presented in section 4.2, addressed afterwards.

Once figured out the question of the frequency of occurrence, a second step was trying to understand what defines the severity level of an occurrence. Since the mentioned database provided the number of fatalities in each occurrence and being the fatality the most severe consequence of an occurrence in terms of human damage, an analysis was performed to identify the total number of fatalities from each occurrence category during the database time interval. However, the number of fatalities generated by

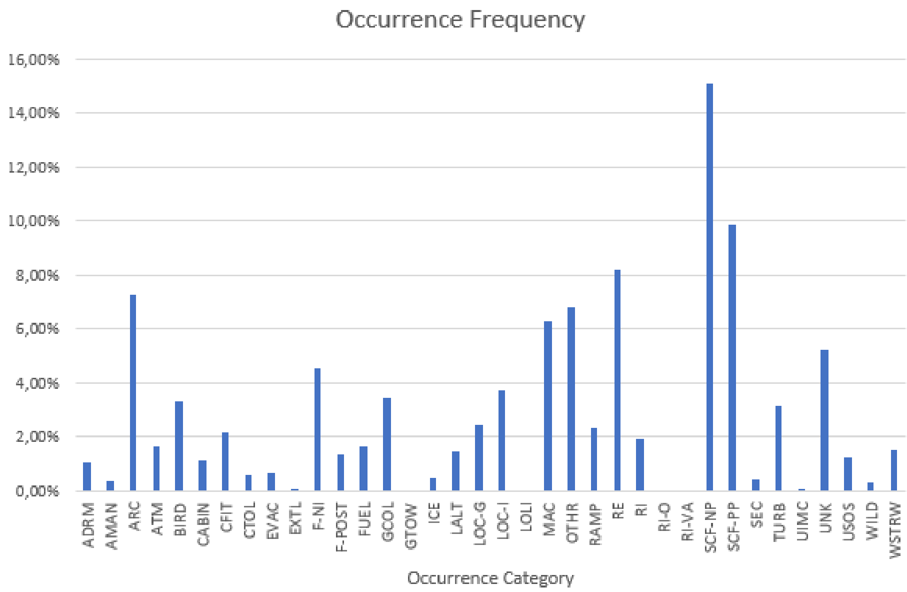


Figure 4.1: Frequency of each occurrence category based on ICAO database.

an occurrence category can be influenced by the frequency of the occurrence. For this reason, it was decided to study the parameter "Total Fatalities Number/Number of Occurrences" for each category, obtaining a weighted parameter that enabled the understanding of which occurrence category has been "the most fatal" during this almost 12 years time interval (figure 4.2).

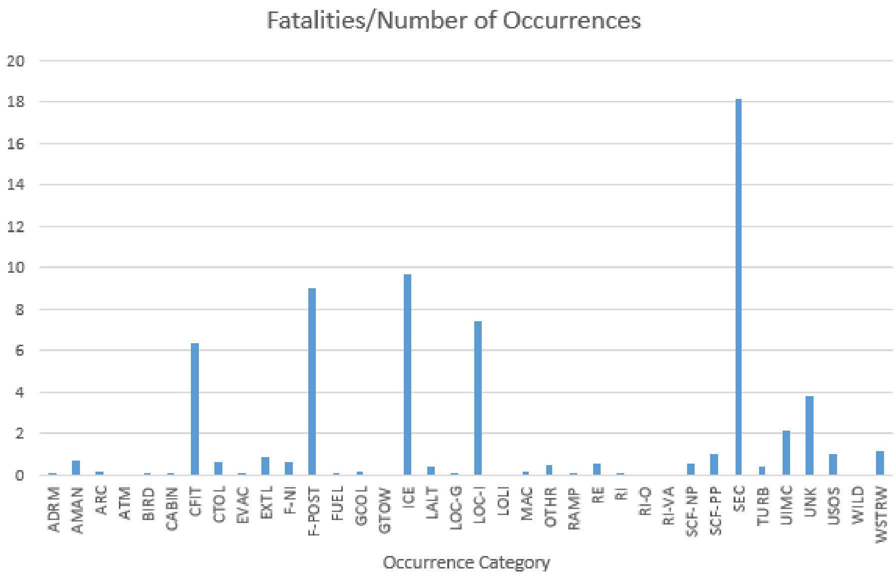


Figure 4.2: Number of fatalities per occurrence for each occurrence category based on ICAO database.

This analysed data consists of a crucial starting point in order to start understanding how past safety related events can help determining the severity and probability levels of each occurrence category, thereby achieving the risk level/number of the hazard(s) in each question addressed in the checklist.

4.2 Probability Analysis

While performing an initial analysis to the data contained in this safety related occurrences database from ICAO, the first approach was determining how many times each occurrence category was associated to a safety related occurrence in the time interval of this database. However, as mentioned, this data only enables the determination of the frequency of each occurrence category and not the actual probability of its occurrence (figure 4.1). Despite being related, the determination of the frequency of manifestation of an occurrence category is not enough to determine its probability. The similarity between the frequency of occurrence and the probability of occurrence is that both follow the same distribution, i.e, the most frequent occurrence category will also have the highest probability of occurrence and vice-versa. However, in this case, for the determination of the probability of occurrence, besides the frequency of occurrence, it is also necessary to consider either the total number of departures or flight hours. Thus, the probability level of each occurrence category is quantifiable in number of occurrences per departure (or per flight hour). Using the number of departures or flight hours, usually has no major change in the definition of the probability of each occurrence category. This is due to the fact that the total number of flight hours can be achieved through the multiplication of the total number of departures by the mean number of hours of a flight. Since the mean number of hours of a flight has order of magnitude 1, the value of total flight hours will, most likely have the same order of magnitude, meaning that the probability value in number of occurrences per flight hour will be similar, in order of magnitude, to the probability value in number of occurrences per departure.

ICAO developed a probability criteria with the aim to adapt to the safety requirements of the majority of airline companies that can be visualised in table 2.3.

This table provides 5 levels of probability of occurrence with the respective qualitative and quantitative descriptions of each one, going from ”Extremely Improbable” to ”Frequent”. Despite qualitative descriptions being useful, when provided a quantitative description of each level, it should have priority over the previous, avoiding misunderstandings in the attribution of the appropriate probability level to each occurrence category. This quantitative distinction of probability levels is provided, in this table, in number of occurrences per flight hour.

The number of occurrences consists in the number of times each occurrence category was associated to a safety related event and was already analysed in the initial analysis (in percentage), also known as a frequency analysis.

There are two methods of getting the probability value associated to each occurrence category. The simpler method is analysing the total number of occurrences of each occurrence category in the time interval of the database and dividing it by the total number of flight hours also in the same time interval, thus getting a mean probability of occurrence value. This method was tested but turned out to be not much accurate so the second method was implement. This one consists of getting the probability value of each occurrence category in each year of the time interval and study its evolution in order to extrapolate the probability value for the year 2020. This second method turned out to be much more accurate and appropriate for this type of tool.

However, in order to do this, it was necessary to calculate an estimate of the total number of flight hours of all aircraft registered by ICAO, for each year in the time period of the database in analysis. In order to get this number, the best approach was to analyse another ICAO database containing the total number of departures all around the planet for each year (Departures Analysis Database [36]). This database contained data since 2003 but, as the safety related events database only started in 2008, the data corresponding to the 5 initial years was not taken into account. The data in this database ended in the year 2019 so, in order to estimate the number of departures in 2020, it was applied, in Excel, an exponential trendline to the data of the type $y = ae^{bt}$, where y is the number of departures in period t (year 1, 2, 3, etc.), a is a constant and b is the constant that represents the rate of change of number of departures per time interval t. Figure 4.3 shows the distribution of this data, the trendline equation and the coefficient of determination R^2, which is close to 1 indicating a good fit of this equation to the given data.

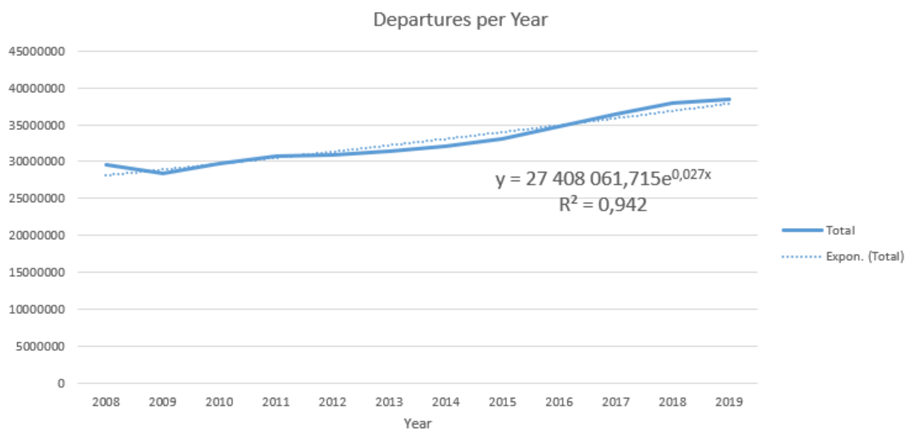


Figure 4.3: Number of total aircraft departures around the world per year.

With this equation it was possible to achieve an estimated total number of departures for 2020 of approximately 38 932 804. Despite a firm belief that this estimated value would be correct in normal circumstances, the true value for 2020 will be much lower due to the known COVID-19 pandemic that affected the global aviation, a fact that will be neglected in this analysis with hope that, in 2021, the pandemic retires and the global air traffic returns to normal.

With these values and with the previous explanation that the mean number of hours of a flight has order of magnitude 1 and so the value of total flight hours most likely has the same order of magnitude of the total departures value, it was assumed that these departure numbers would correspond to an estimate of the number of flight hours. This approximation is also acceptable because the intervals between probability levels in the ICAO Probability criteria are greater than 1 order of magnitude (table 2.3).

In order to explain the process for the determination of the probability for each occurrence category, the ADRM occurrence will be used as example. Firstly, it was registered the number of occurrences per year of the ADRM occurrence category (figure 4.4). Then, it was applied an exponential trendline to this data in order to extrapolate the estimated value for 2020, consisting of the same process to obtain an estimate of the number of departures in 2020, previously explained.

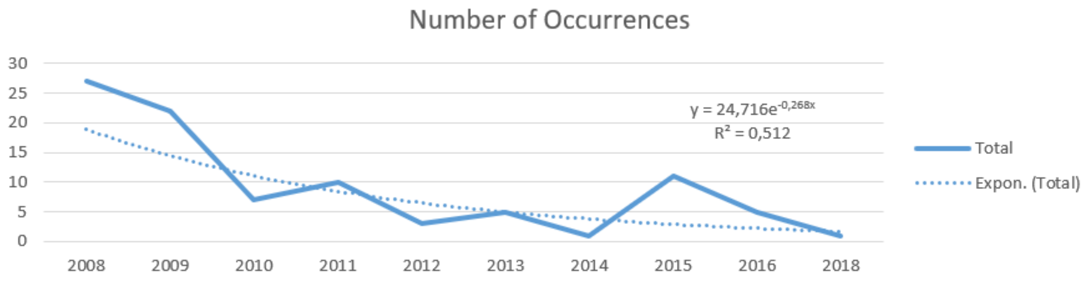


Figure 4.4: Evolution of ADRM occurrences per year based on ICAO database.

With this estimate of number of occurrences for 2020 ($\approx 0,76$) and the previous estimate of number of departures and flight hours for 2020 ($\approx 38\ 932\ 804$), the probability value was obtained through the division of the number of occurrences by the total number of flight hours ($\approx 1,95 \times 10^{-8}$).

Finally, resorting to the ICAO Probability definition table, the appropriate probability of occurrence level was attributed to this occurrence category, which in this case was "Improbable".

As previously mentioned, this same process was performed for every other occurrence category, which enabled the determination of the probability of occurrence values and levels in the last column of table C.2.

At this point, the analysis and determination of the probability level corresponding to each occurrence category should be finished. However, analysing the results obtained, it is noticeable that the probability levels seemed to be "poorly" distributed through the occurrence categories, i.e, the only levels attributed were "improbable" and "remote", being the majority of the occurrence categories classified as "improbable". Since the majority of the questions present in this Aerodrome Risk Assessment Tool have more than one potential occurrence outcome and the probability level attributed to each question corresponds to the highest of the potential occurrence outcomes of that question, the majority of the questions would have the "improbable" probability level associated. So, in order to try and fix this, another probability table was taken into consideration as a test.

With this problem in mind, it was noticed that the additional table that would be taken into account had to have smaller probability intervals between each probability level so the achieved levels for each occurrence category would be more diverse but still correct. After searching for various probability tables and criteria, it was found the FAA (Federal Aviation Administration) Probability definition (table 4.1).

Table 4.1: Federal Aviation Administration Probability Criteria.

Probability of Occurrence (FAA)	**P (per Departure)**
EXTREMELY IMPROBABLE	<4E-08
IMPROBABLE	>4E-08
REMOTE	>4E-07
OCCASIONAL	>4E-06
FREQUENT	>4E-04

This table fulfilled the previous requirements but presented the probability values in occurrences per departure, which is not a problem due to the fact that in order to estimate the total number of flight hours, it was required to get the total number of departures, as explained previously. In fact, using the number of departures over the number of flight hours should, in theory, show better results because the number of flight hours is an estimate and the number of departures is an official value from ICAO. At this point, with this new probability definition table it was expected that the probability levels obtained for each occurrence category should be substantially better than the previous ones.

The second to last column of table C.2 presents the FAA probability results obtained after the implementation of the previously mentioned changes.

This time, it was noticeable that more probability levels were achieved than before but the distribution of these levels through the occurrence categories was not that much better as it was previously anticipated due to the fact that the probability values were majorly low (perfectly normal due to aviation being considered an extremely safe means of transport). Since the difference between the results obtained with the two probability definitions were not as relevant as anticipated, it was decided to **maintain the ICAO probability criteria** and disregard the results obtained with the FAA probability criteria in order to keep the consistency and use the same organisation's definitions for severity and probability.

4.3 Severity Analysis

After performing the initial analysis described in section 4.1, there was already an idea of what occurrence types were the most severe in terms of damage to people's health. This idea was transmitted by the number of fatalities per occurrence caused by each occurrence category in the studied time interval. However, severity cannot be described only through the number of fatalities. Severity consists of the extent of harm that might reasonably be expected to occur as a consequence or outcome of an identified hazard and it is categorised in different classification levels that should take into account the extent of damage to people's health, including those on board of the aircraft and common citizens on the ground that may contact with detached aircraft parts and also the damage to the aircraft and/or infrastructures either belonging to an aerodrome or outside of it.

As already presented in chapter 2, ICAO proposed a Severity criteria with 5 classification levels, each with the description of its applicability and a letter from A to E assigned. Despite there is no agreement of an official severity criteria between all airline companies, this ICAO one was developed with the aim to better suit the majority of them, trying to become the reference severity criteria if one day that agreement is reached (figure 2.2).

The description of the severity classification levels takes into account the type of injury to persons and also the type of damage to the aircraft and infrastructures, as it is supposed to. However, these descriptions have to be conciliated with the information present in the database in analysis. In terms of information relative to the severity of each occurrence in this database, there is information about the occurrence class (accident, serious/major/significant incident, incident and no safety effect), the injury level (fatal, serious, minor and none) and the number of fatalities. Thus, the description of each severity classification level in the ICAO table 2.2 needs to be translated in terms of occurrence class and injury level.

In terms of occurrence class, analysing the description of the severity classifications in table 2.2 from ICAO, it is noticeable that no safety effects are considered as ”negligible” severity, incidents are considered ”minor” severity, serious/significant/major incidents are considered ”major” severity and accidents are considered either ”hazardous” or ”catastrophic” severity. These correspondences are shown in the first and second columns of table 4.2.

The distinction between hazardous and catastrophic depends on the extent of injuries or fatalities and damage to the aircraft and/or infrastructures. Since information about the extent of damage to the aircraft and/or infrastructures in the occurrences present in the database is not available, the only way to distinguish an occurrence classified as accident of being considered hazardous or catastrophic severity level is to analyse the injury level and number of fatalities of the occurrence.

In terms of injury type of the occurrence, analysing the description of the severity classifications in the ICAO table, it is noticeable that an occurrence with no injuries has ”negligible” severity, with minor injuries has ”minor” severity. However, the description of higher severity classification levels in the ICAO table becomes unclear about the severeness of injuries and misses some cases. An example is an occurrence with one fatality. In this case it cannot be included in the hazardous level because it only mentions ”serious injuries” and also can not be included in the catastrophic level because it only mentions ”multiple deaths”. Thus, it was decided that the higher severity levels would be considered as the following: an occurrence with serious injuries would be considered ”Major” severity; a fatal occurrence would be considered as having ”Hazardous” severity; and a fatal occurrence with multiple deaths would be considered ”Catastrophic”. In order to identify the occurrences that have the capability to result in multiple deaths, the parameter ”$\frac{Fatalities}{Number\ of\ Occurrences}$” was created. Thus, if this parameter’s value is greater than 1, that occurrence type is automatically considered ”Catastrophic”. The previously described correspondences can be visualised in the first and third columns of table 4.2.

Table 4.2: Translation of ICAO severity criteria to occurrence class and injury type.

Severity	Occurrence Class	Injury Type
Catastrophic	Accident	$\frac{Fatalities}{Number\ of\ Occurrences} > 1$ (multiple deaths)
Hazardous		Fatal
Major	Serious Incident	Serious
Minor	Incident (Major/Significant included)	Minor
Negligible	No safety effect	None

Taking into account the entire table 4.2, it is possible to verify that, with exception of the accident occurrence classification, all occurrences classifications and injury types correspond to only one severity classification of the ICAO table. In the case of the occurrences with accident classification, the distinction between hazardous and catastrophic severity will be performed through the injury type of the occurrence. However, this will be better explained afterwards in this section.

4.3.1 Severity Classification (Occurrence Class POV)

According to ICAO and ECCAIRS, an occurrence can have 4 determined types of classes: accident, serious incident, incident (major and significant incidents included) and occurrence without safety effect as explained in the ICAO ADREP references in section 2.8. The identification of the appropriate class for each occurrence category of ICAO ADREP enables to achieve the correct severity classification for each one. However, the major concern is how to identify which class is the most appropriate to attribute to each occurrence category.

The major difference between the probability analysis and the severity analysis is the fact that the probability analysis is quantitative and the severity analysis is qualitative. However, the same principle of the trendline used in the probability analysis can also be used in the severity analysis to identify which class is most appropriate to attribute to each occurrence category. Thus, for each occurrence category, it was analysed how many times they were associated to each type of occurrence class per year in the time interval of the database. Then, the trendlines were inserted as shown in figure 4.5, that represents an example with the ADRM occurrence category.

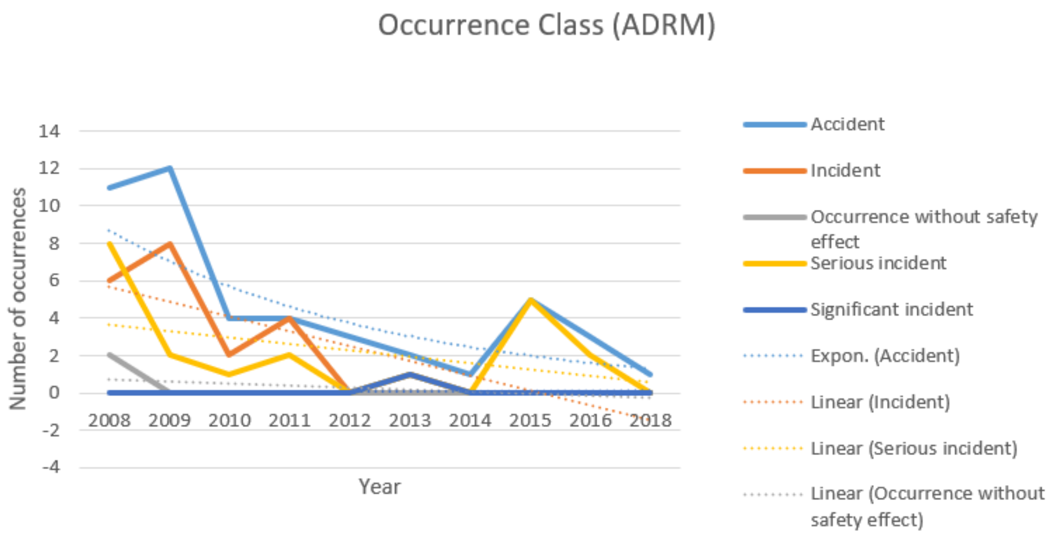


Figure 4.5: Evolution of ADRM occurrence associated classes per year based on ICAO database.

The major "problem" when trying to apply a trendline in this analysis is the lack of data. As known, an exponential trendline cannot be applied to a data distribution if it has null values, so a mix of exponential and linear trendlines had to be used, always resorting to exponential trendlines when possible. Despite this, the analysis was still valid and the evolution of each trendline was studied. This time, since this is not a quantitative analysis, the trendline equations were not considered because a visual estimation would be enough to identify which class each occurrence category will most frequently be associated to in the year 2020. As an example, in figure 4.5, it is noticeable that, if the trend remains, in 2020 the ADRM occurrence category will be associated to the "accident" class more times than any other class. This means that the "accident" class is the most appropriate class to attribute to this occurrence category.

The same process was performed to every other occurrence category of the ICAO ADREP an the obtained results were compiled in the second column of table C.2.

4.3.2 Severity Classification (Injury Type POV)

According to ICAO and ECCAIRS, an occurrence can have 4 determined injury types associated: fatal, serious, minor and none, as explained in the ICAO ADREP references in section 2.8. As in the previous case, the identification of the appropriate injury type for each occurrence category of ICAO ADREP enables to achieve the correct severity classification for each one.

The same process performed for the Occurrence Class POV was applied to the Injury Type POV and, as an example, it is provided figure 4.6 that represents how many times each injury type was associated to the ADRM occurrence category per year in the database time interval.

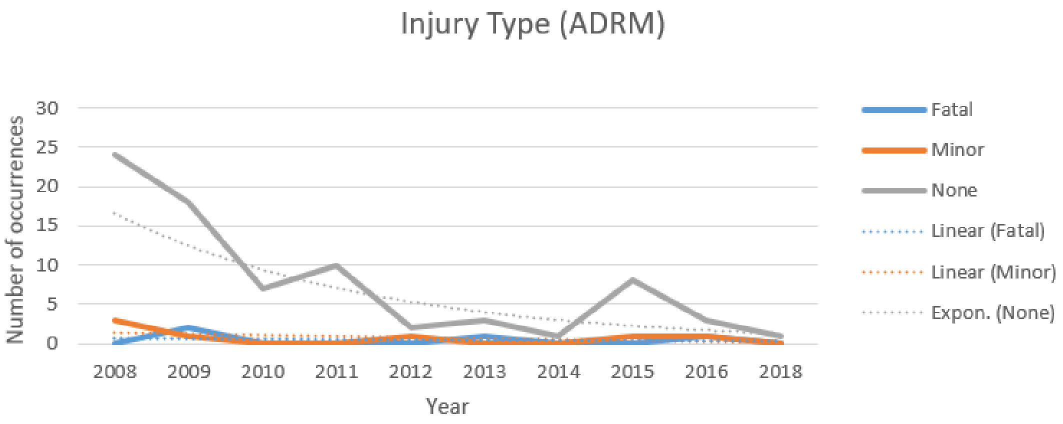


Figure 4.6: Evolution of ADRM occurrence associated injury types per year based on ICAO database.

With the help of the trendlines it was estimated that the most frequent injury type associated to the ADRM occurrence category in 2020 will be ”none”, being this the most appropriate injury type to attribute to this occurrence category.

As in the class POV, the same process was performed to every other occurrence category of the ICAO ADREP an the obtained results were compiled in the third column of table C.2.

4.3.3 Severity Classification (Multiple Fatalities POV)

Previously, it was explained that the ”catastrophic” severity level in the ICAO severity criteria was related to safety related occurrences that resulted in multiple deaths. Thus, the parameter ”$\frac{Fatalities}{Number\ of\ Occurrences}$”, mentioned in the initial analysis, becomes useful in order to check the usual mean number of fatalities that results from each occurrence category. It was decided that the value of this parameter has priority over the main injury level of the occurrence category, so if this value is higher than 1, the severity level of the occurrence category is automatically considered catastrophic. The reason behind this will be explained afterwards in section 4.3.4.

The fourth column of table C.2 shows the value of this parameter for each occurrence category where it is noticeable that SEC (Security related events) has the highest value, as expected due to a usual high number of fatalities each time unlawful interventions in an aircraft are ”successful”.

4.3.4 Severity Classification (Final)

Having analysed the severity of each occurrence category in the point of view of occurrence class, injury type and multiple fatalities, it was then possible to compile all the information in table C.2 and then identify the appropriate ICAO severity classification of each occurrence category. The severity classification attributed to each category corresponds to the highest severity from both occurrence class and injury type. This way, the worst case scenario is always taken into account as a form of prevention. Besides this, there is the parameter of ”$\frac{Fatalities}{Number\ of\ Occurrences}$” that if higher than 1, the ”catastrophic” severity level is automatically selected, having priority over both main occurrence classification and injury level. In normal situations, if an occurrence category has associated a value higher than 1 for this parameter, it usually has the ”fatal” injury level associated. However, in some cases such as ICE, SCF-PP, SEC, USOS and WSTRW this does not happen, meaning that despite, usually, these types of occurrences not leading to fatalities, when they do, the number of fatalities is very high which is a huge concern and so they should as well have associated the ”catastrophic” severity level.

As a final note, it should be mentioned that the accuracy of the results obtained by this statistical analysis depends on a good quality database. Although this ICAO database is one of the most complete databases available and one of the few having an occurrence category field, it is far from perfect because many occurrences lack information in this field which is vital for this analysis, compromising the accuracy of the severity and probability levels attributed to each ADREP occurrence category.

Chapter 5

Aerodrome Risk Assessment Results and Validation

The focus of this chapter is testing the developed Aerodrome Risk Assessment Tool (ARAT) and studying the obtained risk results, while, additionally, comparing them to previous risk results obtained by the company. Thus, first of all, the analysed aerodromes are presented, as well as the requirements for their selection. Then, in section 5.1 it is presented the company's previous method to perform aerodrome risk assessments and respective results. Section 5.2 presents an introduction to the additionally developed ARAS tool that is used to compile and compare the ARAT results. Section 5.3 is focused on the presentation and analysis of the risk results obtained with the newly developed ARAT and, finally, section 5.4 focuses on the comparison of the results obtained with both methods and the possible optimisation aspects.

The ARAT was tested with a total of eight aerodromes operated by Portugália Airlines. The key objective was to select a considerable variety of aerodromes from those which tend to have associated a lower risk of operation to the ones that have a higher one, also taking into account the necessity of choosing aerodromes from different countries to cover aspects such as the country's safety and security beyond the aerodrome's border. Besides this, there was the intention of selecting aerodromes with different characteristics that would explore the different Parts of the tool, i.e, aerodromes that stand out from the remaining due to either a more complex approach, specific training required, high intensity traffic, common hazardous meteorological conditions, topography hazards, concerning historical data, etc. On the other hand, in order to have a reference of the usual risk result of the operation in aerodromes who are known to be "safer", some aerodromes that do not possess the previous characteristics were also selected. This way, the final decision was to select the two most critical aerodromes operated by the company, LPMA (Madeira, Portugal) and EGLC (London City, UK), classified as Category C, three less critical aerodromes, LIRQ (Florence, Italy), LPPT (Lisbon, Portugal) and LEMD (Madrid, Spain) classified as Category B and other three relatively safer aerodromes LPPR (Porto, Portugal) and LFPG (Paris, France) and GMMX (Marrakech, Morocco), classified as Category A.

Ultimately, the risk results obtained with the ARAT will be subjected to validation by the Safety Manager of Portugália Airlines that will certify the usage of the tool as common practice when validating the risk of the company's operation in current or new aerodromes.

5.1 Company's Previous Method Description and Results

Previously to the development of this Aerodrome Risk Assessment Tool, Portugália's Safety Department performed assessments to the risk of operation in each specific aerodrome through a different method. For the Safety Department, this process consisted, for each aerodrome, of filling the FSF CFIT Checklist that addresses concerns related with the risk of CFIT occurrences and searching for past safety related occurrences and common issues in the aerodrome. Every other department should also perform a similar analysis to identify the aerodrome's common issues related with their scope of the operation. All this information should be compiled in the MoC Operation document, summarising all risks identified in the operation and the proposed mitigation measures. A conclusion in this document would summarise the most critical risks and the appropriate mitigation measures while also providing an estimated (qualitative analysis) risk level/number for the before and after mitigation conditions and the respective acceptance levels.

The table in figure 5.3 presents the compilation of the initial condition risk results obtained with this method previously used by the company where the after mitigation results are not taken into account because the objective is to compare the risk results obtained with both methods in the same initial condition.

5.2 Aerodrome Risk Assessment Summary (ARAS)

The ARAT was developed to perform the risk assessment of the operation of each aerodrome at a time, i.e, each aerodrome risk assessment corresponds to a different ARAT file. However, it is equally important to compile and compare the risk assessment results of the different aerodromes in order to draw conclusions for which the Aerodrome Risk Assessment Summary (ARAS) was developed. As the ARAT, the ARAS is able to compile the initial and after mitigation Global and Part risk scores and the respective acceptance level. The Section risk scores were not included in order to simplify the understanding of the results of each assessment but if the user finds it necessary to know more information about a specific aerodrome assessment, one can access the ARAT file of that aerodrome from inside the ARAS through the hyperlinks made available.

Due to the extreme importance of the ARAS in the summary of results and conclusions achievement process, its operation method and additional functionalities are fully described in section B.11.

5.3 ARAT Results

In this section are analysed the obtained results from the assessments performed with the developed Aerodrome Risk Assessment Tool for each previously mentioned aerodromes, compiled numerically in the table in figure 5.2 and also graphically in the radar chart in figure 5.1 with resort to the previously mentioned ARAS tool. The three different colours, in which the Parts risk scores are presented, in figure 5.2, represent the highest risk scores obtained for each aerodrome category, consisting of a post processing to facilitate result interpretation. The ARAT was developed to present both initial and after mitigation risk scores but, in this case, the initial and after mitigation results are the same because no mitigation measures were introduced in these analyses due to the fact that the key objective of this chapter is only to analyse if the obtained risk scores are valid or not. Thus, to avoid redundancy of data, only the initial risk scores are presented.

In order to answer all the questions present in the assessment tool, it was required to access specific documents containing information about the aerodromes characteristics and about experiences from previous operations. Thus, the main used documents were the Jeppesen Charts and Aeronautical Information Publications (AIP) where relevant details and charts are published and also the Aerodrome Operation Briefing (AOB) of each aerodrome that contains a summary of the most relevant aspects of the operation acquired through the experience in each aerodrome. Besides this, also the document N236 of the Maintenance and Engineering Department was used to check the existence or not of contracted MRO in each aerodrome. In order to answer the questions in section 3 of Part 5 - Security Department, it was used the security information from the Country Reports available in the Garda database [37]. It should also be mentioned that, Section 2 of Part 5 - Security Department contains an Aerodrome Security Risk Report whose questions should be answered according to the information from TAP Air Portugal. This information was not available at the time so, for all aerodromes, it was selected the lowest risk option in all the questions of this Section (5.2) in order to remove its influence in the final risk score.

5.3.1 Cristiano Ronaldo Airport - Madeira, Portugal (LPMA)

Madeira airport is classified as a Category C aerodrome in Portugália's Operations Manual. The reason behind this is the fact that the aerodrome is located near water with terrain rising rapidly immediately to the NW of the runway and final approach paths which frequently creates wind variation, turbulence and windshear close to the aerodrome. This high ground and obstacles result in a curved approach path to runway 05 and an offset final approach to runway 23. All these aspects, allied to the non existence of Instrument Landing System, contribute to a necessity of compliance with strict departure, approach and go-around procedures which requires additional specific training and simulator experience from the crew in order to operate in this aerodrome. Thereby, all these peculiarities of this aerodrome should translate in a risk assessment with higher risk scores than the other aerodrome's assessments, specifically in the following Parts: Part 1 - CFIT Risk Analysis; Part 2 - Operations Engineering Department; Part 4 - Crew Training Department; and Part 8 - Environmental Hazards.

In Part 1 - CFIT Risk Analysis, it is verified that this aerodrome presents the highest risk score alongside the aerodrome EGLC. Aerodromes can stand out in this department mainly due to surrounding mountainous terrain, obstacles close to the approach path and/or lack of precision landing systems and LPMA aerodrome checks all these negative aspects so this high risk score was expected. In Part 2 -

Operations Engineering Department this aerodrome presented the highest risk score of all assessments which is an adequate result due to the aerodrome's infrastructures, location near water and surrounding mountainous terrain. In Part 3 - Flight Operations Department, despite the increased performance requirements for approach, this aerodrome presented a lower risk score than expected mainly due to the low traffic intensity and good infrastructures that it presents. Part 4 - Crew Training Department is clearly the weakest point of this aerodrome and every other that is classified as Category C due to the additional requirements of specific training and simulator for the crews that operate in these aerodromes. In Part 8 - Environmental Hazards this aerodrome naturally presented the highest risk score of all, as expected, due to the common wind variations, turbulence and windshear that occur close to the runway. Besides this, Part 6 - Ground Operations Department, Part 7 - Maintenance and Engineering Department and Part 9 - Safety Department also presented high risk scores due to aspects that are not commonly taken into account. In the case of Part 7 this high risk score occurs due to the lack of maintenance support and facilities in this aerodrome, which can lead to AOG and the necessity of dispatching a maintenance team, tools and parts from Lisbon. For the case of Parts 6 and 9, in reality, despite the risk score being the highest value obtained, this is not a high risk because it is still a value inside the acceptable range and many other aerodromes obtained an equivalent score. Regarding Part 9, the reason for this score is due to the aerodrome having registered few minimal safety related occurrences (one in this case) in the last two decades of its operation.

5.3.2 London City Airport - London, United Kingdom (EGLC)

London City Airport is the other aerodrome out of the two classified as Category C in Portugália's Operations Manual. This time, the reason behind this classification is mainly the obstacles (buildings), which despite the most critical close-in obstacles not falling within the take-off flight path area, affect the final approach flight path which requires a steep approach path angle of 5.5º, for both runways. This steep approach requires that the operations should only be permitted when the runway is dry, damp or wet, i.e, if the runway is contaminated by standing water, ice, dry snow and/or slush to a water equivalent depth exceeding 3 mm, the operations should be prohibited. The presence of buildings in close proximity to the approach path has another consequence of common building induced turbulence and/or windshear. All these specific aerodrome characteristics allied to a medium length and width runway imply that only specific aircraft are certified to operate in this aerodrome due to aircraft performance restrictions.

Given the previous information, similarly to the LPMA, this aerodrome's characteristics should translate in a risk assessment with higher risk scores than the other aerodrome's assessments, specifically in the following Parts: Part 1 - CFIT Risk Analysis; Part 2 - Operations Engineering Department; Part 3 - Flight Operations Department; Part 4 - Crew Training Department; and Part 8 - Environmental Hazards. In Part 1 - CFIT Risk Analysis, as previously mentioned, it is verified that this aerodrome presents the highest risk score alongside the aerodrome LPMA. Despite this aerodrome not presenting surrounding mountainous terrain neither lack of precision landing systems, it presents obstacles close to the approach path and a steep approach path. Additionally there is the factor that the primary language of pilots and controllers are not the same which increases the CFIT risk, according to the FSF. Thus, this high risk score is coherent with the expectations. Regarding Part 2 - Operations Engineering Department this aerodrome presented the second highest risk score which is an adequate result due to the aerodrome's runway and taxiway dimensions, infrastructures, location inside a city and near water and surrounding buildings. In Part 3 - Flight Operations Department, this aerodrome presented the highest risk score of all assessments which is coherent with the steep approach, medium/high traffic, aircraft performance limitations and elevated missed approach and departure climb gradients that it presents. As previously mentioned for the LPMA case, Part 4 - Crew Training Department is clearly the weakest point of all Category C aerodromes due to the additional requirements of specific training and simulator for the crews that operate in these aerodromes, thus the same applies to the London City Airport, representing the highest risk score of the entire assessment. Regarding Part 8 - Environmental Hazards, as expected, this aerodrome presents a high risk score but far from the highest value obtained for LPMA aerodrome. This is due to the turbulence and windshear induced by the buildings only during windy days, thus not being a phenomena as common as in LPMA. For Part 5 - Security Department it was obtained a risk score slightly higher than expected but that is perfectly justifiable due to the Aerodrome's Country Security Report values from Garda database which indicates that security risks are higher in the United Kingdom when compared to Portugal. The risk score obtained for Part 7 - Maintenance and Engineering Department was not as high as the LPMA one but was also inside the "caution" interval. This is due to the fact that, although there is a maintenance organisation in the aerodrome with all equipment necessary for a complex maintenance procedure, there is no contract, at the moment, between Portugália and an MRO and so it is necessary to dispatch a team from Lisbon if needed. Regarding the risk scores obtained for Part 6 - Ground Operations Department and Part 9 - Safety Department, the same explanation presented for the LPMA aerodrome can be applied to this aerodrome.

5.3.3 Humberto Delgado Airport - Lisbon, Portugal (LPPT)

Lisbon Airport is classified as a Category B aerodrome in Portugália's Operation Manual. This is an aerodrome located inside a city without major obstacles that can be considered close to the approach path. The terrain is almost level in close proximity to the aerodrome but starts to rise to NW up to 1723 ft AMSL. The major concerns of this aerodrome are the Winter fog that may occur during the night and early morning and persist until midday or later, the turbulence on final approach and touchdown zone during windy days and medium/high traffic intensity, not only caused by this aerodrome but also three military facilities (Montijo, Sintra and Alverca) and one civil airport (Tires) within 15NM.

Given this information and regarding the risk assessment results, this aerodrome's characteristics should make stand out the risk scores of the following Parts: Part 3 - Flight Operations Department; and Part 8 - Environmental Hazards. Regarding Part 8 - Environmental Hazards, this was, in fact, the highest risk score in the assessment of this aerodrome due to the reported seasonal fog during the night and early morning but it was still in the acceptable range. The risk score obtained for Part 3 - Flight Operations Department was the third highest score but still far into the acceptable range.

This is coherent with the expectations of a category B aerodrome with medium/high traffic intensity. Unexpectedly, the second highest risk score was obtained for Part 9 - Safety Department, which can be explained, similarly to the previous aerodromes, by the record of few minimal safety related occurrences (also one in this case) in the last two decades of its operation. Regarding the risk scores obtained for all the other Parts, these were all in the acceptable range and approximately intermediate values between the scores obtained by category A and C aerodromes, as expected.

5.3.4 Amerigo Vespucci Airport - Florence, Italy (LIRQ)

Florence Airport is classified as a Category B aerodrome in Portugália's Operation Manual. Despite this, it is known that this aerodrome's characteristics take its classification almost to the border between B and C Categories. This is mainly due to ground elevation and obstacles up to 2549 ft on NORTH and EAST within 3NM from the ARP (aerodrome reference point), also resulting in terrain induced windshear during the windy months of December and January. Because of this surrounding terrain runway 23 must not be used for landing proposes due to a very short LDA of 977 m. The previous points allied to a medium runway length make an approach to this aerodrome very demanding in terms of aircraft and crew performance. Additionally, the elevated surrounding terrain also requires an increased climb gradient for departures and missed approaches.

Regarding this aerodrome's risk assessment results, the previous information indicates that the risk scores obtained for the following Parts should be higher than usual for an aerodrome of category B: Part 1 - CFIT Risk Analysis; Part 2 - Operations Engineering Department; Part 3 - Flight Operations Department; Part 4 - Crew Training Department; and Part 8 - Environmental Hazards. In Part 1 - CFIT Risk Analysis, it was verified that this aerodrome presents the highest risk score of the analysed Category B aerodromes alongside LEMD, but also lower than the Category C ones. This result is coherent with the expectations because despite presenting surrounding mountainous terrain, this aerodrome still has precision landing systems. Regarding Part 2 - Operations Engineering Department, the surrounding mountainous terrain, the runway and taxiways dimensions and the elevated reference temperature of this aerodrome resulted in the highest risk score of the analysed Category B aerodromes, in fact, close to the results obtained for the analysed Category C aerodromes, which is an adequate result. In Part 3 - Flight Operations Department, similarly to the LPMA assessment, despite the increased performance requirements for this aerodrome's approach, it presented a lower risk score than expected mainly due to the low traffic intensity. Part 4 - Crew Training Department is by far the weakest point of this aerodrome due to its similarities with Category C in terms of the additional requirements of specific training and simulator for the crews. Thus, the risk score obtained for this Part was the highest of the entire assessment, as expected. Regarding Part 8 - Environmental Hazards, as expected, the turbulence and windshear induced by the surrounding mountainous terrain of this aerodrome resulted in the second highest risk score of all the aerodromes analysed, even surpassing EGLC, a category C aerodrome. This being the main reason for this aerodrome being in the border between B and C Category aerodromes. However, the risk score obtained for Part 7 - Maintenance and Engineering Department was, in fact, one of the lowest of all analysed aerodromes due to the existence of a contract with an MRO in that aerodrome. Additionally, the risk scores obtained for Part 5 - Security Department, Part 6 - Ground Operations Department and Part 9 - Safety Department were all inside the acceptable range and an intermediate between the results obtained for Category A and C aerodromes, as expected.

5.3.5 Adolfo Suárez Airport - Madrid, Spain (LEMD)

Madrid Airport is classified as a Category B aerodrome in Portugália's Operation Manual. This aerodrome is known for a very high traffic intensity which requires using all the 8 available runways, 4 at each time depending on the wind (South and North configurations). This translates into an extremely busy airspace, requiring strict execution of the established departure and approach procedures. Besides this, the aerodrome has a high elevation with high reference temperature, common fog during winter and some possible turbulence and windshear induced by the orography during windy days near the final approach. The terrain around the aerodrome only starts to rise 25NM to the North.

This information indicates that the risk assessment of this aerodrome should have relatively high risk scores in the following Parts: Part 1 - CFIT Risk Analysis; Part 2 - Operations Engineering Department; Part 3 - Flight Operations Department; and Part 8 - Environmental Hazards. Regarding the risk score obtained for Part 1 - CFIT Risk Analysis, it was unexpected that this aerodrome obtained the same value as LIRQ, when in fact it should be lower. After investigating this, it was verified that the reason behind this value is the fact that the FSF Checklist does not take into account the distance of the mountainous terrain to the aerodrome, only identifying if the aerodrome is located ”in or near mountainous terrain”, which leads to subjectivity. If distance was taken into account, surely the CFIT risk for this aerodrome should be lower than LIRQ aerodrome. In Part 2 - Operations Engineering Department, it was obtained an intermediate risk score between the other two analysed Category B aerodromes (LPPT and LIRQ), closer to the risk score obtained for LIRQ aerodrome, which is an appropriate result because of this aerodrome's high elevation, high reference temperature and surrounding mountainous terrain. The risk score obtained for Part 3 - Flight Operations Department was the highest of this aerodrome's assessment and, in fact, higher than the LPMA aerodrome (Category C), almost reaching the risk value of EGLC aerodrome (also Category C). This is mainly due to the high traffic intensity of this aerodrome, the simultaneous runway operation and strict departure, approach and missed approach procedures. As expected, Part 8 - Environmental Hazards presented the lowest risk score of all analysed Category B aerodromes due to the fact that the fog occasional occurrences usually take place only during the Winter and turbulence and windshear are not as common as in aerodromes closer to mountainous terrain, like the case of LIRQ. Regarding the risk scores obtained for the remaining Parts, as expected, these were approximately intermediate values between Categories A and C, with a notoriously low risk score in Part 7 - Maintenance and Engineering Department due to the existence of a contract with an MRO in that aerodrome.

5.3.6 Francisco Sá Carneiro Airport - Porto, Portugal (LPPR)

Porto Airport is classified as a Category A aerodrome in Portugália's Operations Manual. As expected from Category A, this aerodrome does not present any extra considerations or requirements to normal operation procedures, providing an approved instrument approach procedure, one runway with no performance limited procedure for take-off and landing, no surrounding mountainous terrain and night operations capability. The only slight concerns about this aerodrome are the necessity of aircraft back-tracking if unable to vacate in taxiway F, the high intensity traffic, wake turbulence awareness, the high missed approach climb gradient and the sudden fogs, most particularly in high humidity and low wind conditions. Thus, it is expected that the only Parts of the risk assessment of this aerodrome presenting an increased risk score, compared to a "normal" Category A aerodrome, are Part 3 - Flight Operations Department and Part 8 - Environmental Hazards. Regarding the risk score of Part 8 - Environmental Hazards, despite it still being in the acceptable range, it is noticeably higher than the LFPG aerodrome (also category A), analysed afterwards in this chapter, and close to the values obtained by some category B aerodromes (LEMD), which is expected due to the previously mentioned sudden fogs. However, the risk score obtained for Part 3 - Flight Operations Department was not as increased as expected due to the fact that, despite this aerodrome having high traffic intensity, it only has one runway available at a time minimising the exposure to this hazard. For the remaining Parts, the risk scores obtained were, in general, close the lowest values obtained in all the assessments, which is appropriate for a Category A aerodrome.

5.3.7 Charles de Gaulle Airport - Paris, France (LFPG)

Charles de Gaulle Airport is classified as a Category A aerodrome in Portugália's Operation Manual so it satisfies the same requirements as the previously analysed aerodrome (LPPR). However, this aerodrome has a much higher traffic intensity which requires full use of the 8 available runways, 4 at a time. Additionally, in close proximity are located Orly and Le Bourget aerodromes, which also increases traffic in the airspace near this aerodrome. For these reasons, the departure and approach procedures must be strictly followed.

Given the previous information, it is expected that despite this being a category A aerodrome, its risk assessment should manifest high risk scores in Part 3 - Flight Operations Department. In fact, despite still being in the acceptable range, it was verified that the risk score obtained for this Part was substantially higher when compared to the other category A aerodromes analysed, surpassing the risk scores of two category B aerodromes (LPPT and LIRQ) and reaching close to LPMA's score (Category C). This evidences the influence of high traffic intensity in the risk of flight operations. Besides this, for Part 7 - Maintenance and Engineering Department it was obtained a higher than expected risk score which is still inside the acceptable range. Similarly to previously analysed aerodromes, this was only due to the non existence of a contract with an MRO in that aerodrome and the necessity to dispatch a team from Lisbon if needed. Regarding the risk scores obtained for the remaining Parts, similarly to LPPR aerodrome, the risk scores obtained were, in general, close to or even the lowest values obtained from all the assessments, which is expected from Category A aerodromes.

5.3.8 Menara International Airport - Marrakech, Morocco (GMMX)

Marrakech Airport is the third analysed Category A aerodrome according to Portugália's Operations Manual so it satisfies the same requirements as the other analysed category A aerodromes (LPPR and LFPG). Unlike the previously analysed aerodromes, this one does not present many specific concerns, aside from the predominant winds from NE from April to August (the windiest months) and westerly winds during the Winter season. Besides this, another fact that should be taken into account is the location of the aerodrome, not because of the surrounding terrain but because it is located in Africa which was a continent known in the past for poor infrastructures, systems and lack of security in comparison with West European and North American aerodromes. Nowadays, this difference is reduced and this is noticeable in the results of the risk assessment performed for this aerodrome. In Part 5 - Security Department, it was obtained a risk score that, despite being the highest of the analysed Category A aerodromes and even higher than one Category B aerodrome, it is still far inside the acceptable range which proves the previous point. Regarding Part 8 - Environmental Hazards, naturally the risk score obtained was the highest value of the entire assessment due to the common winds at this aerodrome. Part 7 - Maintenance and Engineering also obtained a risk score higher than expected for a Category A aerodrome due to the same reason as the other analysed aerodromes that is the non existence of a contract with an MRO and the necessity of dispatching a team from Lisbon if needed. Regarding the risk scores obtained for the remaining Parts, as expected from a Category A aerodrome, these were all close to or even the lowest values of all assessments.

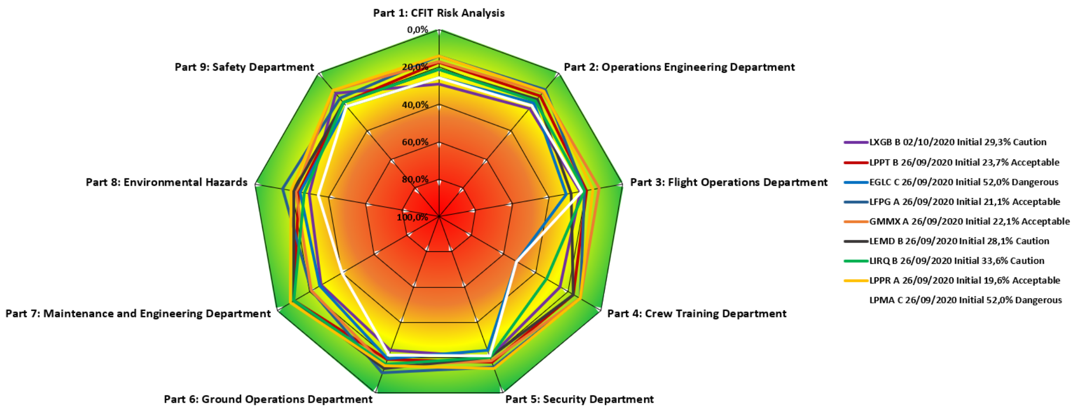


Figure 5.1: Radar chart of the results of the assessments performed with the ARAT.

5.4 Results Comparison and Conclusion

Along section 5.3 it was explained all the obtained results of each aerodrome risk assessment, always mentioning which of the risk scores were expected and unexpected and the reasons that justify each expectation. Overall, it can be concluded that the developed Aerodrome Risk Assessment Tool provided

Aerodrome (ICAO Code)	Category	Result	Global Risk Score	Acceptance	Part 1: CFIT Risk Analysis	Part 2: Operations Engineering Department	Part 3: Flight Operations Department	Part 4: Crew Training Department	Part 5: Security Department	Part 6: Ground Operations Department	Part 7: Maintenance and Engineering Department	Part 8: Environmental Hazards	Part 9: Safety Department
LFPG	A	Initial	21,10%	Acceptable	14,10%	11,60%	21,00%	12,80%	14,50%	11,20%	21,10%	14,90%	17,30%
GMMX	A	Initial	22,10%	Acceptable	17,10%	13,20%	12,70%	12,80%	18,20%	15,50%	21,10%	22,10%	12,00%
LPPR	A	Initial	19,60%	Acceptable	14,10%	12,40%	16,20%	12,80%	13,80%	15,50%	8,30%	19,60%	12,00%
LPPT	B	Initial	23,70%	Acceptable	17,60%	15,60%	19,70%	16,80%	17,30%	18,80%	10,30%	23,70%	20,20%
LEMD	B	Initial	28,10%	Caution	21,40%	18,20%	28,10%	16,80%	20,00%	13,60%	10,30%	21,00%	20,20%
LIRQ	B	Initial	33,60%	Caution	21,40%	19,40%	20,70%	33,60%	20,00%	16,20%	10,30%	26,60%	20,20%
EGLC	C	Initial	52,00%	Dangerous	25,70%	21,00%	30,90%	52,00%	24,00%	19,10%	26,10%	24,60%	23,10%
LPMA	C	Initial	52,00%	Dangerous	25,70%	22,70%	22,40%	52,00%	20,70%	21,40%	40,00%	34,20%	23,10%

Figure 5.2: Results of the assessments performed with the ARAT.

Aerodrome (ICAO Code)	Category	Risk (Initial Condition)	Risk Number	Acceptance
GMMX	A	Remote (3) x Major (3)	9	Acceptable with recommendation
LPPR	A	Remote (3) x Major (3)	9	Acceptable with recommendation
LFPG	A	Occasional (4) x Major (3)	12	Acceptable with mitigation
LEMD	B	Occasional (4) x Major (3)	12	Acceptable with mitigation
LIRQ	B	Remote (3) x Hazardous (4)	12	Acceptable with mitigation
LPPT	B	Occasional (4) x Minor (2)	8	Acceptable with recommendation
LPMA	C	Occasional(4) x Major(3)	12	Acceptable with mitigation
EGLC	C	Remote (3) x Hazardous (4)	12	Acceptable with mitigation

Figure 5.3: Risk results obtained with the company's previous method.

appropriate and trustworthy risk scores for each aerodrome while integrating successfully the safety standards of the company, which was confirmed by two Captains and all the Safety Department members involved in the project.

Comparing the obtained results of the ARAT with the previous method of the company (table in figure 5.3), it is noticeable that the previous method was a very simplified analysis, which lacked the specification of the risk associated to the operation of each department (as it is performed with the ARAT) only presenting a global risk value. Besides this, the risk number obtained with the previous method resulted from a qualitative analysis which is highly dependent on the subjectivity of the person making the assessment. This fact can be supported by noticing that the obtained results of this method are not coherent in some occasions, e.g, comparing the risk result of the aerodromes LFPG and LPPT in the table in figure 5.3, it is noticeable that LFPG (Risk Number 12) has a higher value than LPPT (Risk Number 8). However, LPPT is a Category B aerodrome while LFPG is a Category A. It is certain that not always a Category B aerodrome should have an associated risk of operation higher than a Category A but, in this case, the risk score of LFPG is so high that it reaches risk numbers of Category C aerodromes, which certainly is not an adequate value. In fact, with the previous method, it is noticeable in the table in figure 5.3 that all the other analysed Category B aerodromes present the same risk of operation as both Category C aerodromes which are also not trustworthy risk values.

Taking into account the previous points, it can be concluded that besides giving more complete and coherent risk results, the ARAT also takes away the majority of the subjectivity introduced by the user performing the assessment (major source of incoherence) and also has the potential to standardise and speed up the aerodrome risk assessment process of this company.

Chapter 6

Conclusions

6.1 Achievements

It can be affirmed that the key objective of this thesis of developing an Aerodrome Risk Assessment Tool (ARAT) for Portugália Airlines was successfully achieved, substantially simplifying the task of evaluating aerodrome's operation risks.

As promised, this tool addresses the major aerodrome safety concerns of all departments of the company, presenting an approachable design with helpful instructions that are able to guide the common user that only intends to perform an assessment but has no knowledge of the overall method of operation of the tool.

Additionally, the tool evidences a successful integration of the company's safety standards and acceptance criteria, as well as, good integration of ICAO's risk management process and criteria, which is a big achievement given that this is one of the most important organisations in aviation. Besides this, it was verified the successful implementation of ICAO's ADREP in the development of a risk assessment tool.

It was also achieved with success the development of a mathematical model behind every classification attributed, majorly eliminating the subjectivity present in the previous risk assessments of Portugália and enabling the achievement of trustworthy risk scores for the evaluated aerodromes. In addition, these obtained risk scores for each aerodrome can be studied as they evolve with time and compared between one another.

Finally, this tool can be majorly editable to keep up with the evolution of the company's safety requirements (appropriate instructions provided) and can act as a foundation for the development of the remaining DRMDs mentioned in chapter 2.

6.2 Future Work

Despite all the work achievements previously mentioned, as every other project, there are also certain aspects that can be improved and this one is no different. The following paragraphs address the main features that were identified as being worthy to be introduced in a future version of the ARAT or that are already introduced but can be improved.

Firstly, the severity and probability classifications for each question in the ARAT depend on a statistical analysis that was performed manually. A huge improvement for this tool could be the development of an automated process to perform this analysis and, in addition, the automation of the database with monthly updated information. This would make the severity and probability classifications dynamic, i.e, dependent on the monthly safety related occurrences updates.

Additionally, in order to make the severity and probability classifications completely dynamic it would also be necessary to develop an automated process that could automatically identify the hazards in each question and link them to the possible occurrence outcomes and respective ADREP codes. This is the most delicate aspect of the entire tool and the development of an automated process would require a thorough study of the links between questions, hazards and their respective possible consequences.

In terms of the data support of this project, an important improvement would be getting access to a more complete and detailed database, thus improving the accuracy of the obtained severity and probability classifications.

Another way to improve the accuracy of the obtained severity and probability classifications could be the development or adoption of new severity and probability classification definitions/criteria besides the ICAO one. The use of a different criteria with more classification levels would enable to better pinpoint the exact severity and probability classifications for each question, allowing more accurate risk scores.

Finally, in Chapter 2, it was mentioned that this Aerodrome Risk Assessment Tool would be only one of the four risk assessment tools that should be developed in order to complete all types of DRMDs (DRMD for the fleet, DRMD for the aircrew, DRMD for aerodromes and DRMD for the air traffic routes). Only by having all the risk assessment tools would it be possible to use the Red2Red concept and avoid dispatching a ”red” aircrew to a ”red” aircraft for flying to a ”red” aerodrome through a ”red” route, which is the translation of the Swiss Cheese model to the airline operations. Thus, the main future work for this project is the development of the remaining types of DRMDs based on the ARAT method, completing all the ”barriers” that can avoid future significant safety related occurrences.

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Appendix A

Additional Statistical Analyses

A.1 Controlled Flight Into Terrain (CFIT) Analysis

The CFIT checklist can be considered a sub-checklist inside this Aerodrome Risk Assessment Tool. When the user interacts with this tool, he/she is first presented with the main checklist that consists of the major project that has been developed in this thesis, containing questions related with all existing safety occurrence types. However, the Safety Department of Portugália expressed some specific concern about studying the CFIT occurrence possibility and, after performing the Aerodrome Occurrences Statistical Analysis in section 4, this type of occurrence revealed to be major concern due to its high ”Fatality/Number of Occurrences” rate, along side the SEC, LOC-I, ICE and F-POST occurrence types, as presented in figure A.1.

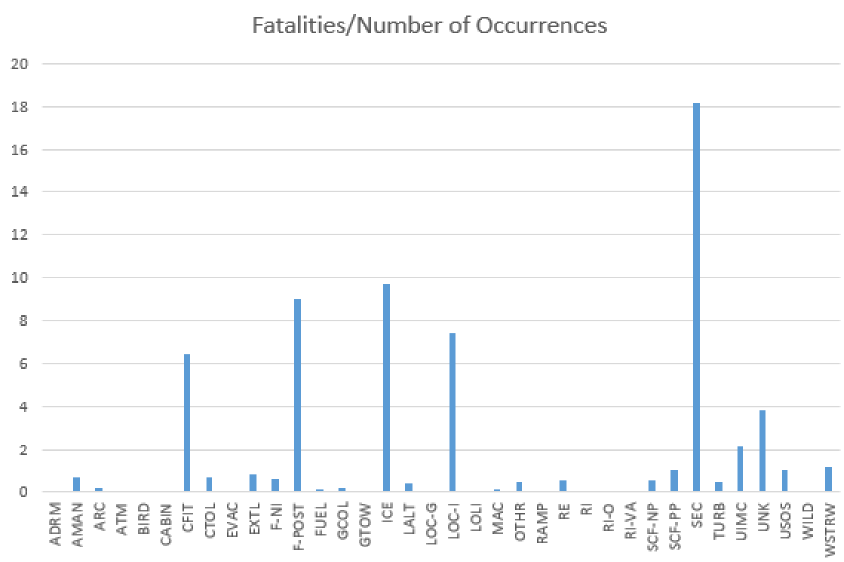


Figure A.1: Number of Fatalities per number of occurrence based on ICAO database.

The high relevance of the CFIT occurrence led to the development of a specific Part in this Aerodrome Risk Assessment Tool (Part 1) consisting of another checklist only related with the CFIT occurrence category. This checklist is a modified version of the one developed by the Flight Safety Foundation that is already used by the safety department of Portugália Airlines to perform safety assessments that are only related with the risk associated with the possibility of CFIT occurrences in each aerodrome operated by the company and the acceptance of this risk. As previously mentioned, this checklist has already its own acceptance criteria developed and tested by the FSF but, in this case, it was adapted to the criteria and the risk score calculations of this Aerodrome Risk Assessment Tool, making it part of a much more extensive safety assessment.

A.1.1 Sections and Questions

The Part 1 ”CFIT Risk Analysis” in the main checklist presents three sections that correspond to the three parts that the CFIT checklist is divided into. All the sections in Part 1 of the main checklist present topics that resemble normal questions, as in the other parts of this checklist. However, despite these topics being displayed as questions, they do not have answer options. Instead, these represent the different sections of the CFIT checklist and the respective results obtained in each one, also having a button, where the answer option is usually located, that redirects the user to the respective section of the CFIT checklist, where he/she is able to answer all the questions of that section.

This CFIT checklist is divided into three parts (corresponding to the three Sections in the Part 1 - CFIT Risk Analysis of the main checklist), each part with its own sections (corresponding to the topics in the main checklist, mentioned previously). In each part, numerical values are assigned to a variety of factors that the user will use to score his own situation and to calculate a numerical total. Due to all the topics/questions being related to the CFIT occurrence category, all have the same severity and probability of occurrence level.

The subjects addressed in each CFIT checklist part are described as the following:

- **Part I:** CFIT Risk Assessment - the level of CFIT risk is calculated for each flight, sector or leg, consisting of a negative number. Two sections make up this first part. Section 1 is focused on the Destination CFIT Risk factors, addressing aerodrome and approach control capabilities, expected approach, lighting, controller/pilot language skills and departure procedures. Section 2 consists of the Risk Multiplier factors, addressing the company's type of operation, departure and arrival aerodrome locations, visibility conditions and crew. The sum of these factors will be multiplied by the total Destination CFIT Risk factors to obtain the total CFIT Risk Factors. Once again, this will be a negative number that should be compensated by the second Part of the CFIT checklist.

- **Part II:** CFIT Risk-reduction Factors - in this part are addressed the factors that can reduce the risks calculated in Part I. Four sections consisting of factors related to the Company Culture, Flight Standards, Hazard Awareness and Training and Aircraft Equipment, respectively, make up Part II. After selected and added all the factors correspondent to the situation, the total of CFIT Risk Reduction factors is obtained, this time, a positive number.

- **Part III:** Final CFIT Risk result - the totals of the four sections in Part II are combined into a single value (a positive number) and compared/added with the total (a negative number) in Part I: CFIT

Risk Assessment to determine the final CFIT Risk Score, which will result in either a positive or negative number. This Part addresses the global CFIT Risk result of the aerodrome and its acceptance. However, not only this final score, but also the individual results of each section should be analysed.

A.1.2 Acceptance Criteria of the CFIT Checklist

The CFIT checklist developed by the FSF has already an acceptance criteria developed and tested. In this checklist, the main criteria that defines if the result of the CFIT analysis is acceptable or not is the CFIT Risk score that is calculated in Part III and is the result of the sum of the total CFIT Risk factors score (negative) from Part I and the total CFIT Risk Reduction factors (positive) from Part II. The criteria is simple, if the score value calculated in Part III is positive, the CFIT risk is considered acceptable because the risk reduction factors compensate the risks. On the other hand, if this value is negative, the CFIT risk is considered unacceptable.

However, besides this, the FSF checklist has other type of acceptance criteria destined to evaluate the scores obtained in each section of the Part II CFIT Risk Reduction Factors. This acceptance criteria is based on the score points obtained in each section that are divided in different intervals of acceptability depending on the section as demonstrated in the table A.1. A low score in one of these sections does not deem the CFIT Risk assessment unacceptable but a thorough review to the company's operation is demanded.

Table A.1: Section scores acceptance criteria of Part II of FSF Checklist.

Part II	**Section 1**	**Section 2**	**Section 3**	**Section 4**
Tops in CFIT standards	115-130	300-335	285-315	175-195
Good but not the best	105-115	270-300	250-285	155-175
Improvement needed	80-105	200-270	190-250	115-155
High CFIT Risk	0-80	0-200	0-190	0-115

However, for Part I that addresses the CFIT Risk through destination factors and other multiplier factors, there is no acceptance criteria developed. This comes from the fact that Part III is already focused on whether these risks are compensated or not by the risk reduction factors. Despite this, for the implementation of the results of Part I in the main checklist of the Aerodrome Risk Assessment Tool, an extension of the acceptance criteria developed by the FSF for the sections of Part II was created to evaluate the scores obtained in Part I. This way, the user could get a perspective of how high is the risk value of the current situation he/she is assessing.

First of all, this required the establishment of the worst case situation (highest risk value) possible for both sections of Part I. For Section 1 - Destination CFIT risk factors, the worst case scenario corresponds to the case where there is no ATC service, the aerodrome is located in or near mountainous terrain, a visual night "black-hole" approach, limited lighting system, controllers and pilots speak different primary languages with poor spoken English or ICAO phraseology and no published departure procedures. This case corresponds to -180 points. For Section 2 the worst case corresponds to an international type of operation, in Africa, at night with IMC, with a single-pilot flight crew, corresponding to a multiplier factor of 14,8. Now, having the values of the worst case scenarios, the acceptance intervals can be defined. These acceptance interval have to follow the same logic of the acceptance intervals already defined by the FSF in Part II, so after an analysis to these intervals, it was discovered that they all follow the same percentage separation as shown in the third column of table A.2. However, these intervals in Part II have positive points where the higher the score, the better the CFIT standards. In Part I, the logic is inverted, the higher the absolute value of the score, the highest CFIT risk (Maximum points = Worst Case). In order to apply the same percentage intervals logic to Part I, these intervals have also to be inverted as shown in the second column of table A.2.

Table A.2: Acceptance Criteria for the CFIT checklist.

Condition	Part I (% of maximum points)	Part II (% of maximum points)
Tops in CFIT standards	0 to 10	90 to 100
Good but not the best	10 to 20	80 to 90
Improvement needed	20 to 40	60 to 80
High CFIT Risk	40 to 100	0 to 60

This way, the acceptance intervals have the same dimension in percentage and present the same logic as the method developed by the FSF. Thus, the score acceptance intervals of each section of Part I should result, approximately, from the multiplication of these percentages by the worst/maximum score of each section of Part I, as it is done in Part II (table A.3).

Table A.3: Section scores acceptance criteria of Part I of FSF Checklist.

Condition	Part I	
	Section 1	Section 2
Very High CFIT Risk	70-180	5.9-14.8
High CFIT Risk	35-70	3.0-5.9
Medium CFIT Risk	20-35	1.5-3.0
Low CFIT Risk	0-20	0-1.5

A.1.3 Conversion of Results

The remaining task is to convert the results of the sections in the CFIT Checklist to a question's risk score type in the main checklist of the Aerodrome Risk Assessment Tool. Since both the answers to the questions in the main checklist and the CFIT Checklist correspond to the exposure to a specific hazard, it was only necessary to convert the Points Classification of the CFIT Checklist to the exposure level classification of the main checklist.

As previously mentioned, after a thorough analysis to the operation method of the CFIT Checklist, it was noticeable that this checklist had an acceptance criteria in the sections of Part II that was based on a percentage of the best case scenario, already presented in section A.1.2.

In addition, Part III had also its acceptance criteria which was acceptable if a final positive result was achieved and unacceptable if not. The acceptance criteria of Part I was the one developed in table A.3.

It then became noticeable that these acceptance levels could be used to translate each section result in the CFIT Checklist to question's "answers" or "exposure levels" in the main checklist as shown in table A.4. This way, the sections from Parts I and II of the CFIT checklist acted as questions with 4 answer options in the main checklist and Part III as a question of 2 answer options.

Table A.4: Translation of the CFIT checklist results to the main checklist.

Part I		**Part II**		**Part III**	
Condition	**Answer/ Option**	**Condition**	**Answer/ Option**	**Condition**	**Answer/ Option**
Very High CFIT Risk	4	**Tops in CFIT standards**	1	**Acceptable**	1
High CFIT Risk	3	**Good but not the best**	2	**Unacceptable**	2
Medium CFIT Risk	2	**Improvement needed**	3		
Low CFIT Risk	1	**High CFIT Risk**	4		

A.1.4 Mitigation Measures and Observations/Notes

The same way the main checklist allows the user to introduce observations and mitigation measures in order to decrease the risk exposure, the CFIT Checklist also presents that capability. For every question there is a specific location to insert the mitigation measure and/or observation and choose a different exposure level, and an initial score and after mitigation score are always calculated. Both these scores are converted to the main checklist results in the same manner as described previously.

The way the mitigation measures and observations are inserted in CFIT Risk part of the main checklist is slightly different from the other parts. Since the "questions" present in this Part 1 are not real questions but the results of the respective sections in the FSF Checklist, when a mitigation measure or observation has to be implemented, it must be described in the specific question location in the CFIT Checklist. After inserting this measure, the main checklist question that represents that specific section of CFIT Checklist presents a message that alerts the user to the existence of a mitigation measure or observation in that section and directs to the CFIT Checklist in order to view it.

A.1.5 Modification of Risk Multiplier Factors of the CFIT Checklist

The Part I of the FSF Checklist has Section 1 where the applicable Destination CFIT Risk factors are picked and Section 2 where the Risk Multiplier factors are chosen. While Section 1 focuses on the destination factors, Section 2 focuses on the company type of operation, the location of the aerodrome, the weather and the crew. However, there was a concern related with the original risk multiplier factors attributed to the location of the aerodrome. The original distribution of the regions and their respective factors is the one presented in table A.5

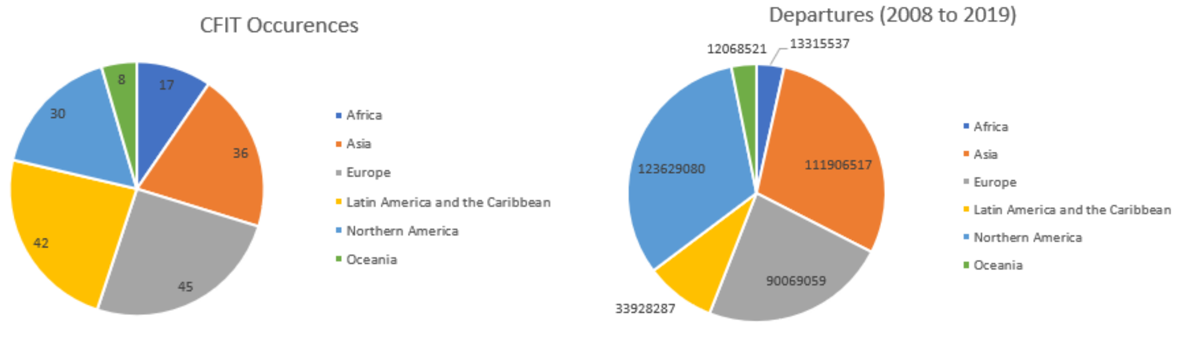
Table A.5: Original FSF CFIT checklist risk multiplier factors by location.

Location	Risk Multiplier Factor
Australia/New Zealand	1.0
United States/Canada	1.0
Western Europe	1.3
Middle East	1.1
Southeast Asia	3.0
Euro-Asia (Eastern Europe and Commonwealth of Independent States)	3.0
South America/Caribbean	5.0
Africa	8.0

These factors did not seem to correspond to the current situation, some felt quite overestimated, specially the one referring to Africa. In order to confirm this, a statistical analysis had to be performed to the databases containing information about CFIT occurrences in the past years.

This statistical analysis was performed to the same database used for the determination of the severity and probability of occurrence level of all ADREP occurrence categories. It is a Safety Occurrences database from ICAO containing safety related events from every aerodrome in all the 192 ICAO member sates through all continents, since the start of the year 2008 until the December 1^{st}, 2019.

Firstly, the analysis was focused on selecting only the CFIT occurrences and sorting them by continents. This way, it was noticeable that, from the start of 2008 to almost the end of 2019, the continent with the highest number of CFIT occurrences was Europe (figure A.2 a).



(a) CFIT occurrences per continent in ICAO database. (b) Departures per continent in ICAO database.

Figure A.2: CFIT occurrences statistical data.

However, this does not mean that this continent is the most propitious to having CFIT related safety occurrences. The number of flights over that continent has also to be taken into consideration because, it is normal that a continent in which aircraft operate more frequently presents a higher number of safety occurrences. Thus, another database from ICAO containing, this time, only information about the total number of departures from each country [36], in each year since 2003 had to be analysed, with help from another database [38] in order to sort the information by continents (ICAO Member States Database).

In order to make the analysis consistent, only the number of departures since the beginning of 2008 to the end of 2019 were considered. Because the number of departures was sorted by countries, the information had to be manipulated in order to sort it by continents. After this was done, the distribution of the total number of departures from each continent in the mentioned time interval was presented in figure A.2 b.

Having the total number of CFIT occurrences and departures from each continent in this time interval, it is possible to get the factor "CFIT occurrences/Departures" for each continent that tells, in fact, which of all the continents has been the most propitious to having CFIT related safety occurrences. The table A.6 and figure A.3 show the obtained results.

With this data, it is noticeable that, in fact, as the FSF checklist considered, Africa is the most propitious continent to have CFIT related safety occurrences. However, the risk factor attributed to Africa was much higher than the one attributed to Latin America and Caribbean (8 vs 5), when in fact, these values are much closer. In order to create a new risk multiplier factors, all the factors "CFIT occurrences/Departures" for each continent where divided by the lowest of these factors. This way, the continent with the lowest factor "CFIT occurrences/Departures", being considered the safest one, has the risk multiplier factor value of 1 which, obviously, does not increase the initial Destination CFIT Risk factors. The rest of the new calculated risk multipliers factors for each continent can be viewed in the table A.6. This summarises the result of all the previous databases analysis and consist of the only modification made to the original FSF Checklist parameters.

Table A.6: Summary of the analysis to the influence of location in CFIT occurrences.

Continent	CFIT Occurrences	Departures (millions)	CFIT/Departure	Risk Multiplier Factor
Africa	17	13,32	1,28	5,3
Asia	36	111,91	0,32	1,3
Europe	45	90,07	0,50	2,1
Latin America and the Caribbean	42	33,93	1,24	5,1
Northern America	30	123,63	0,24	1,0
Oceania	8	12,07	0,66	2,7

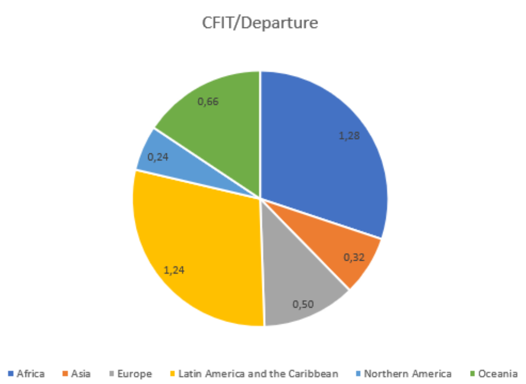


Figure A.3: CFIT/Departure ratio per continent.

A.2 Analysis of Weighting Factor Increment relative to Aerodrome Category

As mentioned in section 3.8, it was necessary to develop increment factors to add to the normal weighting factor of each question in order to compensate for difference in the probability of the occurrence categories that should exist between aerodromes of category A, B and C.

In order to determine the appropriate value for the increment factors, a statistical analysis of the past safety related occurrences in each aerodrome operated by Portugália was performed. For this analysis it was decided to study only the aerodromes operated by this company because the aerodrome categorisation A, B and C always depend on the criteria established by each company. Besides this, the database used for this analysis is not the same ICAO database that was previously used for the severity and probability level determination, but instead the Aviation Safety Network (ASN) database due to the fact that this was the only accessible database that identified the aerodromes where the safety related occurrences took place (if it happened near an aerodrome).

The key objective of this study was to analyse, in a specific time interval, the total number of safety related occurrences and the total number of departures in each category of aerodromes operated by the company, in order to obtain the parameter $\frac{Number\ of\ Occurrences}{Number\ of\ Departures}$ for each of the three categories. Analysing this parameter instead of just focusing on the number of occurrences enables the elimination of the influence of the aerodrome traffic intensity in the obtained results.

Thereby, it would then be possible to verify if, in fact, aerodromes of category C have the highest value and aerodromes of category A have the lowest one, indicating that the probability of each ADREP occurrence category should be increased with the aerodrome category.

This said, after analysing this database, only taking into account the same time interval as the previous analysis (2008 to 2019), the following values were achieved (table A.7).

Table A.7: Analysis of the relation between aerodrome category and the number of occurrences.

Aerodrome Category	Number of Aerodromes	Number of Occurrences	Number of Departures	$\frac{Number\ of\ Occurrences}{Number\ of\ Departures}$
A	40	88	29514041	2,98E-06
B	44	19	17362544	1,09E-06
C	2	4	571911	6,99E-06

It is noticeable, in table A.7, that the aerodrome category C has the highest value of the parameter $\frac{Number\ of\ Occurrences}{Number\ of\ Departures}$, indicating that, in fact, independently from the aerodrome's traffic, there is an increased number of safety related occurrences in this type of aerodrome, which is an evidence of the more demanding operation requirements. The fact that this parameter has a value that is over double of the one for category A aerodromes justifies the affirmation that the probability of the ADREP occurrences in these types of aerodromes should also be doubled. Observing the ICAO probability criteria table 2.3, it is noticeable that doubling the probability value, at most takes the probability to the following level, which is not always the case. However, in order to cover all the possibilities, it was decided that **for category C aerodromes, the probability values of all occurrences should be increased one level**.

To assure this, in terms of risk number it was added a value of 5, which corresponds to **increasing the weighting factor** of all the questions in the checklist by **0,2** (equivalent to $\frac{5}{25}$; remember that the max risk number is 25).

However, the values obtained for the parameter $\frac{Number\ of\ Occurrences}{Number\ of\ Departures}$ in the cases of aerodromes of category A and B were not the expected. Since category B aerodromes do not satisfy Category A requirements due to their unusual characteristics and extra considerations, it was expected that, independently from the aerodromes traffic, category B aerodromes would have an increased number of occurrences. However, the Category A aerodromes got double the $\frac{Number\ of\ Occurrences}{Number\ of\ Departures}$ than Category B aerodromes. One valid justification for this is the fact that the sample of analysed aerodromes can be considered small because, as previously mentioned, only aerodromes operated by Portugália Airlines were considered. Additionally, other justification may rely on the extra care or innate defence of the crews when operating in Category B aerodromes due to the special briefing, overriding the smaller risk difference between A and B aerodromes when compared with Category C aerodromes. Thus, it was decided to disregard the obtained values and consider Category B aerodromes as an intermediate between Category A and C which is in fact what they are and so, if for Category C aerodromes was decided to use an increment factor of 0,2, for **Category B aerodromes** was established an **WF increment factor of 0,1**. These attributed values, in table A.8, were then put to test, in chapter 5, in order to check if the obtained risk scores of the aerodrome assessments were coherent and appropriate.

Table A.8: Aerodrome Category Increment Factors

Aerodrome Category	**Increment Factor**
A	0
B	0,1
C	0,2

Appendix B

ARAT Functionalities

In this chapter is presented a brief explanation of the main features and functionalities of the developed Aerodrome Risk Assessment Tool.

B.1 Overview

Firstly, it is presented, in figureB.1, a small sample overview of the ARAT checklist interface that the user has to answer when performing the risk assessment of an aerodrome.

Figure B.1: Sample overview of the ARAT checklist interface.

Additionally, it is presented in figure B.2 a small sample overview of the CFIT checklist interface inside Part 1 of the ARAT.

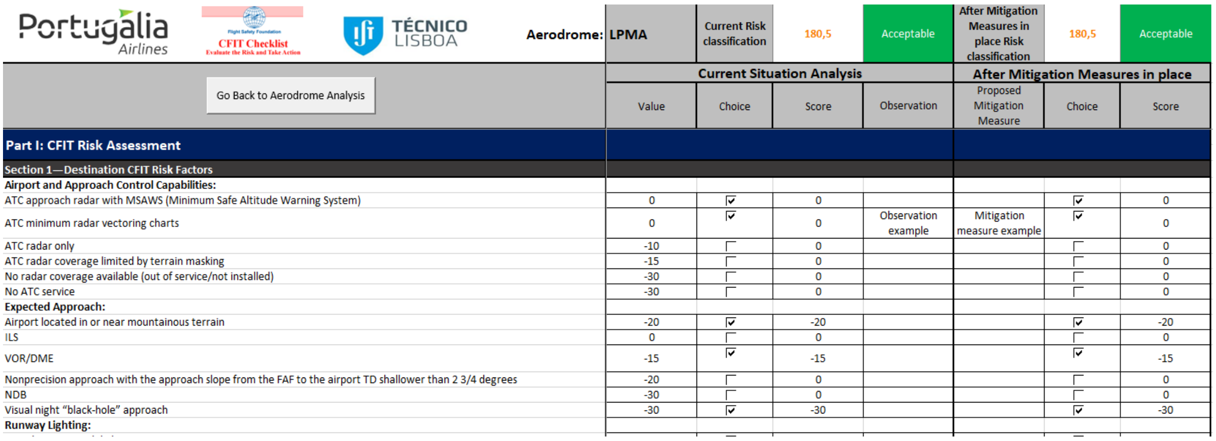


Figure B.2: Sample overview of the CFIT checklist interface.

B.2 Header

The main checklist presents an header with locations destined to the aerodrome ICAO code, aerodrome category and the date of the assessment, which should be provided by the user. As a matter of example, it is shown, in figure B.3, the header of the risk assessment of LPMA (Madeira Airport).

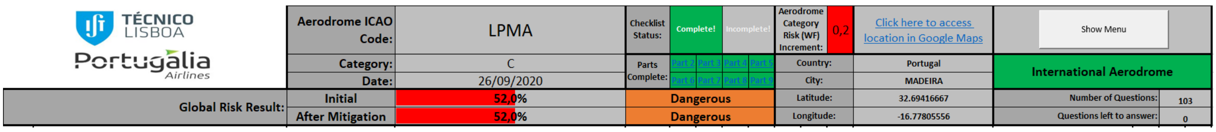


Figure B.3: Example of the header of the LPMA (Madeira Airport) risk assessment.

Besides this, in the header are also presented the global initial and after mitigation risk scores and their acceptance. As the questions of the checklist are being answered, a count of the total number of questions present in the checklist is shown, as well as the number of questions still left to answer. While there are questions still left to answer, a red message is shown in the header location destined to present the Checklist Status mentioning that the checklist is incomplete to alert the user that one may have forgotten to answer a question. In this case, it is useful to look at the number of questions still left to answer or look at the header location destined to the Parts Status, which shows the user which parts are already fully answered and which are not. Besides this, every part or section has a symbol on the right side which is red while no question of that part or section is answered, yellow when at least one question was already answered and green when all the questions in that part or section were already answered. Answering all the questions is a crucial condition to get an accurate assessment because, otherwise, questions left to answer will be considered as presenting zero risk, compromising the global risk score and the assessment itself. When finally all questions have been answered, the header presents a green message mentioning that the checklist is complete. At this point, the risk results and respective acceptance are not available yet.

B.3 Location

This feature is also present in the header but, because it does more than provide information about the checklist status and risk scores, it deserves a separate description. This feature's aim is to help the user who is not familiar with the aerodrome under assessment, to understand its location and surroundings in an easier way. Thus, when the user starts a new assessment, after inserting the respective aerodrome ICAO code, the section of the header destined to this feature presents the country, city, latitude and longitude of the aerodrome location (figure B.4).

Aerodrome Category Risk (WF) Increment:	0,2	Click here to access location in Google Maps
Country:		Portugal
City:		MADEIRA
Latitude:		32.69416667
Longitude:		-16.77805556

Figure B.4: Location section of the header of the LPMA (Madeira Airport) risk assessment.

Besides this, there is also an hyperlink that redirects the user to a google maps page with the precise location of the aerodrome and where the user can study the terrain and infrastructures surrounding the aerodrome. However, there is one minor criticism to point to this feature which is not so important but should be mentioned. This consists of the fact that the provided aerodrome coordinates in the header are used to find the aerodrome location in Google Maps and these coordinates come from an ICAO database [39] containing information about all the ICAO aerodromes. The problem is that these coordinates do not coincide precisely with the Google Maps coordinates of the aerodromes, consisting this difference in around 300m. One might think that this difference is irrelevant when an aerodrome runway length , usually, is far greater than this value but the "problem" is that this difference is enough for Google Maps not identifying automatically that location as the aerodrome itself. This requires that, when in the Google Maps page, the user selects the name of the aerodrome in the map for it to assume that as the aerodrome location and then provide useful information about the aerodrome in the left tab of the page. As mentioned, this is not a major problem but it is worth to be mentioned. In order to solve this, all aerodrome locations in the database of ICAO would have to be updated to the Google Maps coordinates, which is not justifiable.

B.4 Menu

In order to access the global risk scores, the user has to make use of the "Show Menu" button also featured in the header (figure B.3). This menu has all the main editing functions of the checklist, as well as, the buttons that enable the calculation of the global risk results, the respective insertion in the historic of assessments, the presentation of the risk distribution through parts in a radar chart, the access to the aerodrome safety history and also the button that presents the sheet with the summary of the risks and respective mitigation measures in the current assessment (figure B.5).

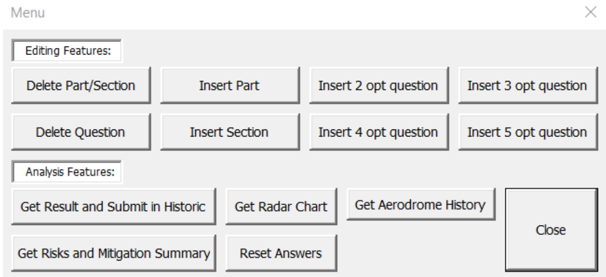


Figure B.5: Menu of the ARAT.

This menu button featured in the header of the Aerodrome Risk Assessment Tool/Checklist, as previously mentioned, contains the main functions of the checklist related with the assessment itself (obtainment of risk scores, summaries, historic and resetting of answers) and also editing functionalities such as deleting and inserting Parts, Sections and questions. Although, at the moment, the modification of the checklist by any user should not be required, these functions are still integrated to enable future updates that eventually will become a necessity as aviation safety standards evolve. Further explanation on these checklist editing functions will be addressed afterwards in section B.10.

B.5 Historic

After the checklist is complete, the user can use the button in the menu that calculates the global risk result with resort to the scores of each question and saves all the risk scores of the parts and sections of the assessment in the historic of previous assessments. This historic enables the user to analyse the progress over time of the risk assessments of that specific aerodrome. The data saved in this historic sheet for each assessment corresponds to the aerodrome ICAO code, the aerodrome category, the date of the assessment, the initial and after mitigation global risk results, the acceptance of such result and the initial and after mitigation risk result of each part and section of the checklist.

B.6 Radar Chart

The data previously mentioned is then used to create a more intuitive visualisation of the results, enabling an easier comparison between different assessments. This is achieved with resort to a Radar Chart. As a matter of example, it is shown the radar chart of the LPMA (Madeira Airport) assessment in figure B.6.

In this chart, the radial axis represents the risk result of each section while the tangential axis represents all the different Parts of the assessment. The global risk score of each assessment is not portrayed in this chart because the intention is to compare the risk score of each specific Part and evaluate the weakest/riskier aspects in each assessment, i.e, the aspects of the safety defences of an aerodrome that are more fragile. However, contrary to normal radar charts, the radial axis had to be inverted in order to facilitate comparisons between different assessments, with outer lines representing less risk and consequently the inner lines representing the more riskier safety aspects. The necessity to invert

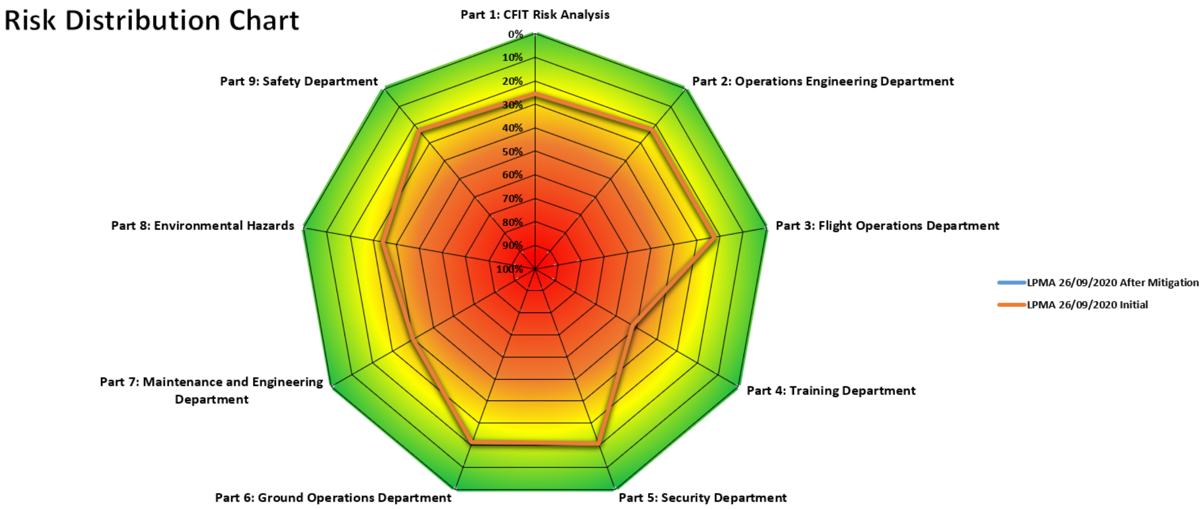


Figure B.6: Radar chart of the LPMA (Madeira Airport) assessment.

the radial axis comes from the fact that the aviation industry is very safe and so, risk results tend to be low and differ slightly from one assessment to the other. This way, having a normal radial axis with risk increasing from the center would become very confusing with the majority of the lines/points near the center of the radar chart.

B.7 Aerodrome Safety History

This feature can also be accessed through the menu button in the header and consists of a brief summary of the safety related events that took place in the aerodrome under assessment until the present day.

Figure B.7: Aerodrome safety history of LPMA (Madeira Airport).

The information that feeds this summary comes from an incident and accident database of Aviation

Safety Network (ASN) [40] contained in another sheet of the file and its data can be manually updated. However, the accuracy of this summary depends on the quality of the data in the database. The reason that the ICAO Safety Occurrences database [35] previously analysed could not be used for this task is the fact that this database does not identify the aerodrome in which the occurrences took place (if these occurred near an aerodrome).

This summary of safety related events in an aerodrome presents the information in graphics and mentions flight phase of the occurrences, the occurrence classifications, the type of damage to the aircraft and the casualties, as shown in figure B.7 with the example of LPMA airport.

B.8 Risks and Mitigation Measures Summary

Another function in the menu that the user can take advantage of is the summary of risks and mitigation measures. In figure B.8 it is shown an example with the LPMA (Madeira Airport) assessment. When the user selects this option, all the questions in which a mitigation measure was imposed are properly identified in a summary table. For each question in this table, it is identified the Part and Section which it corresponds to, the risk identified (initial option/condition selected), the observations or notes and the mitigation measure imposed. This way, the identification of the major fragilities in the safety defences of the aerodrome under assessment is facilitated, expediting the whole process.

Risks and Proposed Mitigation Measures:					
Part	Section	Question	Risks Identified	Observations/Notes	Mitigation Measures
Part 1: CFIT Risk Analysis	Section 1.1: CFIT Risk Assessment	Destination CFIT Risk Factors	Check risk in CFIT Risk Analysis	Check observations in CFIT Risk Analysis	Check mitigation measures in CFIT Risk Analysis
Part 2: Operations Engineering Department	Section 2.1: Aerodrome Geographical Data	Aerodrome Reference Temperature	25ºC < Temperature ≤ 30ºC	Observation example	Mitigation measure example
Part 2: Operations Engineering Department	Section 2.10: Radio Navigation and Landing Aids	Runway undershoot / overshoot issues	Aerodrome near water/ Bad lighting/ High probability of visual illusions/ Short runway	Observation example	Mitigation measure example
Part 4: Training Department	Section 4.1: Crew Training	Training in the simulator	Required	Observation example	Mitigation measure example
Part 5: Security Department	Section 5.3: Aerodrome's Country Security Report	Terrorism, Crime and/or War Risk	Moderate	Check Portugal Security Report in Garda Database	Mitigation measure example
Part 6: Ground Operations Department	Section 6.1: Runway, FOD, Fuel and Jetblast Considerations	Parking area protection	Parking areas unprotected / Risk of damage from flying FOD/ Risk of jetblast	Observation example	Mitigation measure example
Part 8: Environmental Hazards	Section 8.2: Local or Regional Hazardous Meteorological Conditions	Windshear, Downdrafts, Updrafts and/or Turbulence Encounters	Common	Observation example	Mitigation measure example

Figure B.8: Risks and mitigation measures example summary of LPMA (Madeira Airport) assessment.

B.9 User Guide and Instructions

Due to the fact that the developed Aerodrome Risk Assessment Tool has a wide variety of functionalities, as previously described, it can become somewhat confusing for the user experiencing it for the first time. Thus, a sheet denominated as ”Instructions” was created which, as the name suggests, includes all the instructions that the user might find useful to perform a successful analysis without wasting much time trying to understand the operation of the tool.

For the user which is only interested in performing an Aerodrome Risk Assessment, the only useful sheets of the tool are the checklist sheets, ”Aerodrome Analysis” and ”CFIT Risk Assessment”, which are the ones containing the questions that need to be answered in order to perform the assessment, and also the ”Historic”, ”Summary”, ”Radar Chart” and ”Aerodrome History” sheets in which it is possible to review previous assessment’s results, consult the summary of risks and mitigation measures of the current assessment, access a graphical comparison between the initial results and after mitigation results of each part of an assessment and access the history of safety related occurrences of that aerodrome, respectively. All the other sheets are only required for auxiliary calculations, functions and organisation.

In order to start a new Aerodrome Risk Assessment, the user should start by accessing the ”Aerodrome Analysis” sheet and inserting the ICAO code of aerodrome under assessment and the respective date in the indicated locations of the header. After this, the user should start answering all the questions, only interacting with the columns with the following designation: ”Select option”, ”Observations/Notes” and ”Mitigation measures”. Part 1 of this checklist is somewhat different than the remaining parts because each question redirects the user to the ”CFIT Risk Assessment” sheet in order to answer it. However, this checklist follows the same answering principles of the previous one and, when complete, the user should press the button ”Go Back To Aerodrome Analysis” to go back to the main checklist and continue answering normally all the remaining parts.

Completed the checklist, the user can make use of the previously described functionalities by pressing the ”Show Menu” button and selecting one of the following options: ”Get Result and Submit in Historic”; ”Get Risks and Mitigation Summary”; ”Get Radar Chart”; and ”Get Aerodrome History”. It is recommended, in order to get a complete assessment, to use all these functionalities which were explained in section B.

Completed all the previous steps and concluded the analysis, the user can either leave the questions answered and save the file in this form or select the ”Reset answers” option in the menu to get a blank checklist for the next time performing a risk assessment to that aerodrome. However, this option is not reversible so when selected, the previous answers will be irreversibly deleted. This does not include the data in the ”Summary”, ”Historic” and ”Radar Chart” sheets which will be still accessible and need to be ”manually” deleted if desired.

B.10 User Editing Instructions

Previously, in section B was mentioned that, although not required at the moment, some functionalities were implemented in this Aerodrome Risk Assessment Tool to enable future updates that eventually will become a necessity as aviation safety standards evolve.

These functionalities include the possibility of deleting questions, Sections and Parts that may become outdated in the future and, as complement, the possibility to insert new questions with 2 to 5 answer options, new Sections and new Parts. All the new inserted Parts and Sections results will be accounted in the historic of results, in the radar chart and also in the summary of risks and mitigation measures.

The procedures for executing these modifications are explained in the ”Instructions” sheet enabling the user to modify the checklist without having to previously perform a thorough study of its operation.

Deleting either a question, Section or Part consists of the same procedure with the only difference of pressing different buttons which are appropriately labelled. The user only has to select all the cells that constitute the question, Section or Part and select the button ”Delete Question” or ”Delete Part/Section”, as appropriate.

To insert a new Section/Part, the user has to previously select the cell containing the name of the Section/Part where he/she wants the new Part to be inserted after and then press the ”Insert Section” or ”Insert Part” button, as appropriate.

In order to insert a new question, the procedure is similar, having the user to select the cell containing the name of the Section where he/she wants the new question to be inserted and then press the button to insert a new question, with the possibility of selecting questions with 2 to 5 answer options, as previously mentioned. However, despite inserting a new question being a fairly easy process, selecting the question's severity and probability levels is much more difficult. The selection of these levels involves performing a study similar to the one performed to the current questions in the checklist, that was explained in chapter 3.

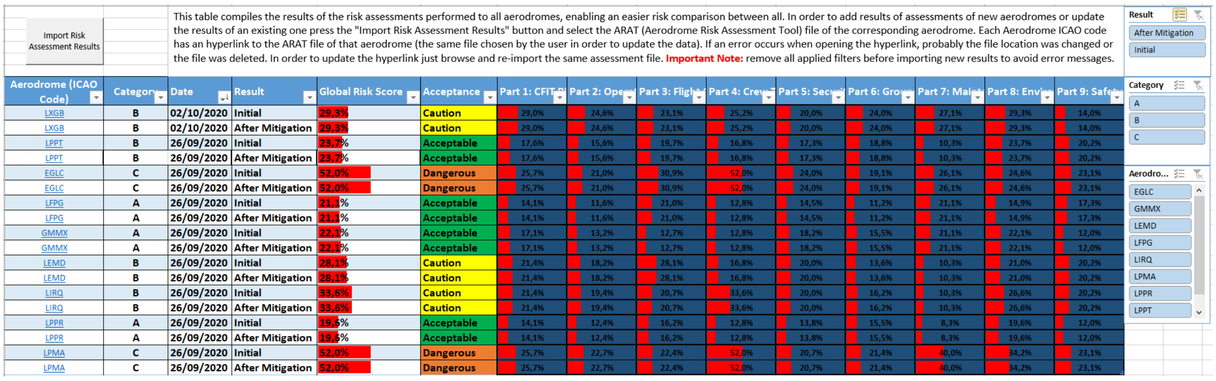
Besides these editing features, there is also one ”hidden” editing feature of the checklist present in the ”Acceptance Criteria” sheet. In this sheet, a table containing the acceptance criteria of the entire Aerodrome Risk Assessment Tool is present. The modification of the values in this table changes the entire acceptance criteria used to characterise the acceptance of the risk scores of all the questions, Sections, Parts and also the global risk score. Thus, the modification of these values is certainly not recommended without a thorough study of the company's safety objectives and safety margins.

B.11 Aerodrome Risk Assessment Summary (ARAS)

In addition to the Aerodrome Risk Assessment Tool, it was developed the Aerodrome Risk Assessment Summary. The Aerodrome Risk Assessment Tool already has a sheet destined to the summary of the risk results of all the assessments of a specific aerodrome. However, each aerodrome should have its ARAT file, thus, there was the necessity of developing a tool that gathered the most relevant data of the risk summaries of each aerodrome and presented it in a simplified form. This is the aim of the Aerodrome Risk Assessment Summary.

This tool compiles the initial and after mitigation global risk scores, and respective acceptance, and also the initial and after mitigation risk scores of each Part, as shown in figure B.9. It was decided not to include the Section results in order to simplify the understanding of the results of each assessment. Thus, if the user finds necessary to know more information about a specific aerodrome assessment, one should access the ARAT file of that aerodrome.

All the data contained in the ARAS file needs to be provided by the user, i.e, the file does not fill or update automatically each time the ARAT file of each aerodrome is changed. Despite at first this lack of automation sounding like a disadvantage, it was purposeful, with the aim of giving the user the responsibility of deciding when to update the results of each ARAT file in the ARAS. The purpose behind this decision is the fact that each ARAT file will be answered/filled in by multiple departments and probably not all in the same day. In this case, if the updates where automatic, incomplete and incorrect



Import Risk Assessment Results

This table compiles the results of the risk assessments performed to all aerodromes, enabling an easier risk comparison between all. In order to add results of assessments of new aerodromes or update the results of an existing one press the "Import Risk Assessment Results" button and select the ARAT (Aerodrome Risk Assessment Tool) file of the corresponding aerodrome. Each Aerodrome ICAO code has an hyperlink to the ARAT file of that aerodrome (the same file chosen by the user in order to update the data). If an error occurs when opening the hyperlink, probably the file location was changed or the file was deleted. In order to update the hyperlink just browse and re-import the same assessment file. **Important Note:** remove all applied filters before importing new results to avoid error messages.

Aerodrome (ICAO Code)	Category	Date	Result	Global Risk Score	Acceptance	Part 1: CFIT	Part 2: Oper	Part 3: Fligh	Part 4: Crew	Part 5: Secu	Part 6: Grou	Part 7: Mai	Part 8: Envi	Part 9: Safe
LXGB	B	02/10/2020	Initial	29,3%	Caution	29,0%	24,6%	23,1%	25,2%	20,0%	24,0%	27,1%	29,3%	14,0%
LXGB	B	02/10/2020	After Mitigation	29,3%	Caution	29,0%	24,6%	23,1%	25,2%	20,0%	24,0%	27,1%	29,3%	14,0%
LPPT	B	26/09/2020	Initial	23,7%	Acceptable	17,6%	15,6%	19,7%	16,8%	17,3%	18,8%	10,3%	23,7%	20,2%
LPPT	B	26/09/2020	After Mitigation	23,7%	Acceptable	17,6%	15,6%	19,7%	16,8%	17,3%	18,8%	10,3%	23,7%	20,2%
EGLC	C	26/09/2020	Initial	52,0%	Dangerous	25,7%	21,0%	30,9%	52,0%	24,0%	19,1%	26,1%	24,6%	23,1%
EGLC	C	26/09/2020	After Mitigation	52,0%	Dangerous	25,7%	21,0%	30,9%	52,0%	24,0%	19,1%	26,1%	24,6%	23,1%
LFPG	A	26/09/2020	Initial	21,1%	Acceptable	14,1%	11,6%	21,0%	12,8%	14,5%	11,2%	21,1%	14,9%	17,3%
LFPG	A	26/09/2020	After Mitigation	21,1%	Acceptable	14,1%	11,6%	21,0%	12,8%	14,5%	11,2%	21,1%	14,9%	17,3%
GMMX	A	26/09/2020	Initial	22,1%	Acceptable	17,1%	13,2%	12,7%	12,8%	18,2%	15,5%	21,1%	22,1%	12,0%
GMMX	A	26/09/2020	After Mitigation	22,1%	Acceptable	17,1%	13,2%	12,7%	12,8%	18,2%	15,5%	21,1%	22,1%	12,0%
LEMD	B	26/09/2020	Initial	28,1%	Caution	21,4%	18,2%	28,1%	16,8%	20,0%	13,6%	10,3%	21,0%	20,2%
LEMD	B	26/09/2020	After Mitigation	28,1%	Caution	21,4%	18,2%	28,1%	16,8%	20,0%	13,6%	10,3%	21,0%	20,2%
LIRQ	B	26/09/2020	Initial	33,6%	Caution	21,4%	19,4%	20,7%	33,6%	20,0%	16,2%	10,3%	26,6%	20,2%
LIRQ	B	26/09/2020	After Mitigation	33,6%	Caution	21,4%	19,4%	20,7%	33,6%	20,0%	16,2%	10,3%	26,6%	20,2%
LPPR	A	26/09/2020	Initial	19,6%	Acceptable	14,1%	12,4%	16,2%	12,8%	13,8%	15,5%	8,3%	19,6%	12,0%
LPPR	A	26/09/2020	After Mitigation	19,6%	Acceptable	14,1%	12,4%	16,2%	12,8%	13,8%	15,5%	8,3%	19,6%	12,0%
LPMA	C	26/09/2020	Initial	52,0%	Dangerous	25,7%	22,7%	22,4%	52,0%	20,7%	21,4%	40,0%	34,2%	23,1%
LPMA	C	26/09/2020	After Mitigation	52,0%	Dangerous	25,7%	22,7%	22,4%	52,0%	20,7%	21,4%	40,0%	34,2%	23,1%

Figure B.9: ARAS assessments summary table.

assessment results could be uploaded to this summary file. Therefore, in order to avoid this problem, one user, probably from the safety department will have the responsibility and control to decide when an assessment is finished and when the results are ready to be uploaded to the ARAS file. In order to insert these new assessment results in the ARAS file, there is an ”Import Risk Assessment Results” button above the table that the user should press and then select the respective ARAT file containing the results of the aerodrome that he/she wants to update. After this process, if the data contained in the selected ARAT file was already present in the ARAS file, a message will pop up mentioning that. On the other hand, if the data contained in the selected ARAT file is new, a message will pop up mentioning that the aerodrome risk assessments were successfully updated.

Accessing to the ARAT files corresponding to each aerodrome assessment was facilitated through the insertion of an hyperlink in the name of each aerodrome in the summary table in this file. Therefore, when the user wants to access the ARAT file of an aerodrome, one only needs to press the name of that aerodrome in the table. When trying to access this file, if an error occurs, it means that either the ARAT file of that aerodrome was deleted or the name of the file or its location was changed. In order to correct this problem, the user only has to import the data of those ARAT files again to the summary file. If the data contained in this ARAT file was not changed, this will result in a message mentioning that the data was already present in the ARAS file but the hyperlink will be updated and perfectly functional.

Similarly to the ARAT files, in this ARAS file was developed a Radar Chart, as the one in figure B.6, to graphically present the risk distribution by the Parts for each aerodrome risk assessment. The difference in this case is that, instead of comparing only the risk distribution between assessments of the same aerodrome in different dates as in the case of the ARAT files, it also enables the comparison of the risk distribution of assessments of different aerodromes, facilitating the identification of the aerodromes that present the highest risk for each Part of the assessment. This Radar Chart is in all aspects similar to the ones in the ARAT files, also presenting an increasing risk in the center direction with colour graduation to represent the acceptance level.

As an additional feature, inserted in the assessments summary table and also in the radar chart is a slicer that enables the user to view both initial or after mitigation risk scores or only one type of scores at a time.

The ARAS file contains another tool designated ”Combined Risk”. This tool was implemented in a separate sheet and enables the user to study the combination of the risks of operating between two aerodromes (figure B.10).

		Select Option:	Global Risk (after mitigatio	Acceptanc	Part 1: CFI	Part 2: Op	Part 3: Flig	Part 4: Cre	Part 5: Sec	Part 6: Gro	Part 7: Ma	Part 8: Env	Part 9: Saf
Individual Risk	Departure Aerodrome	LPMA	52,0%	Dangerous	25,7%	22,7%	22,4%	52,0%	20,7%	21,4%	40,0%	34,2%	23,1%
	Arrival Aerodrome	LFPG	21,1%	Acceptable	14,1%	11,6%	21,0%	12,6%	14,5%	11,2%	21,1%	14,9%	17,3%
Combined Risk		From LPMA to LFPG	52,0%	Dangerous	25,7%	22,7%	22,4%	52,0%	20,7%	21,4%	40,0%	34,2%	23,1%

Figure B.10: Combined risk feature example.

In order to use this function, the user should select the departure and arrival aerodromes and press the ”Get Combined Risk” button. The tool will then get the risk scores of each Part from each aerodrome assessment and select the highest risk values from each aerodrome, attributing it to the combined risk value. In this manner, the combined risk feature selects the worst aspects of each aerodrome and presents the user the highest risk possible of an operation between the two aerodromes. In the case that there is more than one assessment (different dates) for each aerodrome, the selected aerodrome assessment for the combined risk calculation will correspond to the most recent one, as long as the order of the assessments in the assessments summary table is kept by decreasing date value as standard. The task performed by this feature is not complex and could be manually performed by studying the values in the Assessments Summary table. However, this feature enables a simpler and faster analysis from the safety department members.

Instructions on how to use this ARAS file are provided in the first sheet above the assessments summary table so that any user can easily understand the functions and take the most advantage out this tool.

Appendix C

ARAT Development Tables

In this appendix are presented the tables C.1 and C.2.

Table C.1 presents an excerpt of the 110 questions developed for the checklist of the ARAT and the summary of the process for the determination of the severity and probability levels to attribute to each one, described in sections 3.1 to 3.5, which then enables the determination of each weighting factor, as explained in sections 3.6 and 3.7. Due the extensive number of developed questions and the imposed space restrictions not all questions can be presented in this document. In order to visualise all the remaining questions it is suggested to get access to the ARAT tool and look for the ”Questions” sheet.

Table C.2 presents the summary of the statistical analysis performed to the ICAO Safety Occurrences Database which enabled the determination of the severity and probability levels to attribute to each ADREP Occurrence Category, thus acting as the ”bridge” between the questions (and respective hazards) and their weighting factor, as explained in section 3.5.

Table C.1: Compilation of the R&D for the ARAT Checklist (Table 1)

Question Number	Part	Section	Question	HAZARD	Potential Outcome	Possible Occurrence Outcomes	Highest Severity Possible Occurrence(s)	Highest Probability Possible Occurrence(s)	Severity Classification	Probability Classification
1.1.1	CFIT Risk Analysis	CFIT Risk Assessment	Destination CFIT Risk Factors	Loss of Situational Awareness during departure/approach;	Collision with terrain or obstacles;	CFIT;	CFIT;	CFIT;	**CATASTROPHIC**	**IMPROBABLE**
1.1.2	CFIT Risk Analysis	CFIT Risk Assessment	Risk Multiplier	Loss of Situational Awareness during departure/approach;	Collision with terrain or obstacles;	CFIT;	CFIT;	CFIT;	**CATASTROPHIC**	**IMPROBABLE**
1.2.1	CFIT Risk Analysis	CFIT Risk-Reduction Factors	Company Culture	Loss of Situational Awareness during departure/approach;	Collision with terrain or obstacles;	CFIT;	CFIT;	CFIT;	**CATASTROPHIC**	**IMPROBABLE**
1.2.2	CFIT Risk Analysis	CFIT Risk-Reduction Factors	Flight Standards	Loss of Situational Awareness during departure/approach;	Collision with terrain or obstacles;	CFIT;	CFIT;	CFIT;	**CATASTROPHIC**	**IMPROBABLE**
1.2.3	CFIT Risk Analysis	CFIT Risk-Reduction Factors	Hazard Awareness and Training	Loss of Situational Awareness during departure/approach;	Collision with terrain or obstacles;	CFIT;	CFIT;	CFIT;	**CATASTROPHIC**	**IMPROBABLE**
1.2.4	CFIT Risk Analysis	CFIT Risk-Reduction Factors	Aircraft Equipment	Loss of Situational Awareness during departure/approach;	Collision with terrain or obstacles;	CFIT;	CFIT;	CFIT;	**CATASTROPHIC**	**IMPROBABLE**
1.3.1	CFIT Risk Analysis	CFIT Risk	Risk Score	Loss of Situational Awareness during departure/approach;	Collision with terrain or obstacles;	CFIT;	CFIT;	CFIT;	**CATASTROPHIC**	**IMPROBABLE**
2.1.1	Operations Engineering Department	Aerodrome Geographical Data	Aerodrome Elevation	Decreased air density; Reduced A/C performance; Possible proximity to mountainous terrain;	Collision with mountainous terrain; Collision with known obstacles due to lack of performance of PP;	CFIT; ADRM; CTOL;	CFIT;	Either;	**CATASTROPHIC**	**IMPROBABLE**
2.1.2	Operations Engineering Department	Aerodrome Geographical Data	Aerodrome Reference Temperature	Reduced powerplant performance;	Collision with known obstacles due to lack of performance of PP;	ADRM; CTOL;	Either;	Either;	**HAZARDOUS**	**IMPROBABLE**
2.1.3	Operations Engineering Department	Aerodrome Geographical Data	Aerodrome Reference Wind	Turbulence;	Loss of control inflight;	ADRM; LOC-I; TURB;	LOC-I;	LOC-I; TURB;	**CATASTROPHIC**	**REMOTE**
2.2.1	Operations Engineering Department	Operational Hours	Aerodrome Operating Hours	Possible unavailability when necessary	Aerodrome operations inefficiency	OTHR;	OTHR;	OTHR;	**MAJOR**	**IMPROBABLE**
2.2.2	Operations Engineering Department	Operational Hours	Fuelling Operating Hours	Possible unavailability when necessary	Aerodrome operations inefficiency	OTHR;	OTHR;	OTHR;	**MAJOR**	**IMPROBABLE**
2.2.3	Operations Engineering Department	Operational Hours	Health and Sanitation Operating Hours	Possible unavailability when necessary	Aerodrome operations inefficiency	OTHR;	OTHR;	OTHR;	**MAJOR**	**IMPROBABLE**
2.2.4	Operations Engineering Department	Operational Hours	METEO Operating Hours	Possible unavailability when necessary	Aerodrome operations inefficiency	OTHR;	OTHR;	OTHR;	**MAJOR**	**IMPROBABLE**
2.2.5	Operations Engineering Department	Operational Hours	ATS Operating Hours	Possible unavailability when necessary	Aerodrome operations inefficiency	ATM;	ATM;	ATM;	**MAJOR**	**IMPROBABLE**
2.2.6	Operations Engineering Department	Operational Hours	AIS Operating Hours	Possible unavailability when necessary	Aerodrome operations inefficiency	OTHR;	OTHR;	OTHR;	**MAJOR**	**IMPROBABLE**
2.2.7	Operations Engineering Department	Operational Hours	Handling Operating Hours	Possible unavailability when necessary	Aerodrome operations inefficiency	OTHR;	OTHR;	OTHR;	**MAJOR**	**IMPROBABLE**
2.2.8	Operations Engineering Department	Operational Hours	Public services (customs, currency control etc.)	Unavailability of passenger services;	Aerodrome operations inefficiency	OTHR;	OTHR;	OTHR;	**MAJOR**	**IMPROBABLE**
2.3.1	Operations Engineering Department	Rescue and Fire Fighting Services	Rescue and Fire Fighting Service capability	Insufficient RFFS capabilities in emergency situation;	Damage or loss of A/C due to fire on board;	F-NI; F-POST; ADRM;	F-POST;	F-NI;	**CATASTROPHIC**	**REMOTE**
2.4.1	Operations Engineering Department	Aprons, Taxiways and Check Locations Data	Average taxiways width	Lack of A/C maneuverability;	Collision between A/C on ground; Inefficient ground traffic movement;	GCOL; ADRM;	Either;	GCOL;	**HAZARDOUS**	**REMOTE**
2.4.2	Operations Engineering Department	Aprons, Taxyways and Check Locations Data	Average taxiway and apron pavement surface structures strenght	Possible pavement strengh classification exceeded;	Damage to runway pavement and/or A/C;	ADRM;	ADRM;	ADRM;	**HAZARDOUS**	**IMPROBABLE**
2.5.1	Operations Engineering Department	Surface Movement Guidance, Control System, Markings and Lighting	Aerodrome signals/ lighting/ surface marking including centreline	Loss of situational awareness during approach and/or during ground movement;	Runway overshoot/ undershoot; Collision on ground; Runway Incursion;	ADRM; GCOL; USOS; RI;	USOS;	GCOL; RI;	**CATASTROPHIC**	**REMOTE**
2.5.2	Operations Engineering Department	Surface Movement Guidance, Control System, Markings and Lighting	ATC issues related with intersecting or crossing runways	A/C crossing active runways while taxying;	Runway Incursion;	RI;	RI;	RI;	**MAJOR**	**REMOTE**
2.6.1	Operations Engineering Department	Aerodrome Obstacles	Aerodrome Circling Minima Height	Proximity of A/C flight path to mountainous terrain or obstacles;	Collision with mountainous terrain or obstacles during approach;	CFIT;	CFIT;	CFIT;	**CATASTROPHIC**	**IMPROBABLE**
2.6.2	Operations Engineering Department	Aerodrome Obstacles	Topography hazards	Proximity of A/C approach path to terrain or obstacles;	Collision with obstacles during take-off and landing;	CTOL;	CTOL;	CTOL;	**HAZARDOUS**	**IMPROBABLE**
2.7.1	Operations Engineering Department	Runway Physical Characteristics	Runway length (most demanding rwy available)	Runway too short for the intended aircraft type(s);	Runway excursion;	RE; ADRM;	Either;	RE;	**HAZARDOUS**	**REMOTE**
2.7.2	Operations Engineering Department	Runway Physical Characteristics	Runway width (most demanding rwy available)	Runway too narrow for the intended aircraft type(s);	Runway Excursion;	RE; ADRM;	Either;	RE;	**HAZARDOUS**	**REMOTE**
2.7.3	Operations Engineering Department	Runway Physical Characteristics	Runway pavement surface structures strenght	Pavement strengh classification exceeded;	Damage to runway pavement and/or A/C;	ADRM;	ADRM;	ADRM;	**HAZARDOUS**	**IMPROBABLE**

Table C.2: Severity and Probability Classifications obtained for ICAO Occurrence Category (ADREP) taxonomy.

Occurrence	Severity (Occurrence Class POV)	Severity (Injury Type POV)	Fatalities per Occurrence	Probability (Value)	Severity Classification	Probability Classification (FAA)	Probability Classification (ICAO)
ADRM	Accident	None	0,07	1,95E-08	**Hazardous**	EXTREMELY IMPROBABLE	**IMPROBABLE**
AMAN	Accident	None	0,69	2,43E-08	**Hazardous**	EXTREMELY IMPROBABLE	**IMPROBABLE**
ARC	Accident	None	0,21	3,23E-07	**Hazardous**	IMPROBABLE	**REMOTE**
ATM	Serious Incident	None	0,00	8,73E-08	**Major**	IMPROBABLE	**IMPROBABLE**
BIRD	Incident (Major/Significant included)	None	0,00	2,94E-08	**Minor**	EXTREMELY IMPROBABLE	**IMPROBABLE**
CABIN	Accident	None	0,02	1,24E-07	**Hazardous**	IMPROBABLE	**REMOTE**
CFIT	Accident	Fatal	6,41	7,58E-08	**Catastrophic**	IMPROBABLE	**IMPROBABLE**
CTOL	Accident	None	0,66	9,15E-08	**Hazardous**	IMPROBABLE	**IMPROBABLE**
EVAC	Accident	Serious	0,03	7,79E-08	**Hazardous**	IMPROBABLE	**IMPROBABLE**
EXTL	Accident	Fatal	0,86	7,39E-08	**Hazardous**	IMPROBABLE	**IMPROBABLE**
F-NI	Serious Incident	None	0,62	1,47E-07	**Major**	IMPROBABLE	**REMOTE**
F-POST	Accident	Fatal	8,98	4,88E-08	**Catastrophic**	IMPROBABLE	**IMPROBABLE**
FUEL	Serious Incident	None	0,13	9,04E-08	**Major**	IMPROBABLE	**IMPROBABLE**
GCOL	Accident	None	0,21	2,91E-07	**Hazardous**	IMPROBABLE	**REMOTE**
GTOW	-	-	-	-	**-**	-	**-**
ICE	Serious Incident	None	9,68	4,71E-08	**Catastrophic**	IMPROBABLE	**IMPROBABLE**
LALT	Accident	None	0,40	4,43E-08	**Hazardous**	IMPROBABLE	**IMPROBABLE**
LOC-G	Accident	None	0,05	6,50E-08	**Hazardous**	IMPROBABLE	**IMPROBABLE**
LOC-I	Accident	Fatal	7,43	1,09E-07	**Catastrophic**	IMPROBABLE	**REMOTE**
LOLI	-	-	-	-	**-**	-	**-**
MAC	Serious Incident	None	0,15	5,67E-07	**Major**	REMOTE	**REMOTE**
OTHR	Serious Incident	None	0,48	4,24E-08	**Major**	REMOTE	**IMPROBABLE**
RAMP	Accident	None	0,07	1,75E-07	**Hazardous**	REMOTE	**REMOTE**
RE	Accident	None	0,54	3,04E-07	**Hazardous**	IMPROBABLE	**REMOTE**
RI	Serious Incident	None	0,03	2,55E-07	**Major**	IMPROBABLE	**REMOTE**
RI-O	-	-	-	-	**-**	-	**-**
RI-VA	-	-	-	-	**-**	-	**-**
SCF-NP	Serious Incident	None	0,57	1,77E-07	**Major**	IMPROBABLE	**REMOTE**
SCF-PP	Serious Incident	None	1,02	2,16E-07	**Catastrophic**	IMPROBABLE	**REMOTE**
SEC	Accident	Fatal	18,18	8,63E-09	**Catastrophic**	IMPROBABLE	**IMPROBABLE**
TURB	Accident	Serious	0,45	3,79E-07	**Hazardous**	IMPROBABLE	**REMOTE**
UIMC	Accident	Fatal	2,13	1,65E-06	**Catastrophic**	REMOTE	**REMOTE**
UNK	Accident	Fatal	3,82	2,23E-08	**Catastrophic**	EXTREMELY IMPROBABLE	**IMPROBABLE**
USOS	Serious Incident	None	1,01	7,89E-08	**Catastrophic**	IMPROBABLE	**IMPROBABLE**
WILD	Accident	None	0,00	3,68E-08	**Hazardous**	EXTREMELY IMPROBABLE	**IMPROBABLE**
WSTRW	Accident	None	1,14	8,49E-08	**Catastrophic**	IMPROBABLE	**IMPROBABLE**