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**MANAGING FATIGUE IN A REGIONAL AIRCRAFT
OPERATOR: FATIGUE AND WORKLOAD ON MULTI-
SEGMENT OPERATIONS**

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Departamento de Aeronáutica e Transportes**

**Lisboa
Dezembro de 2015**

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“It amazes me that contemporary work and social culture glorifies sleeplessness in the way we once glorified people who could hold their liquor. We now know that 24 hours without sleep or a week of sleeping four or five hours a night induces an impairment equivalent to a blood alcohol level of 0.1%. We would never say, “This person is a great worker! He’s drunk all the time!” yet we continue to celebrate people who sacrifice sleep. The analogy to drunkenness is real because, like a drunk, a person who is sleep deprived has no idea how functionally impaired he or she truly is.” (Fryer & Czeisler, 2006)

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Abstract

Introduction: With the constant increase in air travel every year and the downfalls of the World's economy, airline managers face the need to optimize resources with the goal of reaching profit and reliability targets. This leads to higher utilization rates in commercial aircrews, with more hours of work and the consequence of less sleep and off time. As such, pilots and cabin crew face an increasing number of sleep disturbances, with the consequent alertness impairments and reduced performance. The concept of fatigue resumes these issues and has recently been addressed by several studies and documents, which prove its hazards and identifies them as risks to a flight's safety. The main goal of this study is the methodic identification of fatigue in a regional aircraft operator that, although not suffering from night circadian disruption has a major rostering structure of multi-flight operations with flights in the early hours of the day.

Methodology: The universe and the sample size of this study are equal and correspond to 52 airline pilots, 27 Captains and 25 First Officers, all males and an average age of 39.2 years old. The methodology used in this research consists of two interconnected principles: objective fatigue measurement, using bio-mathematical modeling through the SAFE model and subjective fatigue measurement through a 3 week daily survey applied to real operations, allowing the measurement of individual fatigue in the beginning of work and at top of descend on the last flight of the day. The survey was complemented by an adapted version of NASA's TLX workload measurement scale, allowing a more complete analysis of an additional fatigue cause that has impact in multi-segment operations. A questionnaire was also distributed in order to identify any variability factors that could influence the measurements and limit pilot's capabilities and performance.

Results: Results were determined by setting a methodic approach to schedule analysis, with 365 days of planned pilot rosters processed. Areas of high risk were identified, in particular on the early hours of the morning and the evening and on days with more than 4 sectors. With the surveys and when comparing both measurements, SAFE model predictions stay short of 5 in the Samn-Perelli Scale (Moderately tired. Let down.) whilst pilot reported fatigue values represent a 6 on the same scale (Extremely tired. Very difficult to concentrate.). A high relation was also found between the increase of fatigue, the number of sectors and time of day, revealing that workload might be caused by multi-segment operations and a hazard to what can be considered an acceptable level of safety to risk management in flight operations.

Conclusion: A new approach to workload in the fatigue and safety settings should be considered, and further research should strive to look at the impact of workload in multi-segment operations. This should all lead to new hazard identification and risk mitigation practices to be in place, joining flight safety and rostering departments in better and more robust schedules, with of course increased safety levels and better overhaul performance. There is also a

List of Abbreviations

- BAM – Boeing Alertness Model (by Boeing Jeppesen)
- CAA – UK Civil Aviation Authority
- CAS – Circadian Alertness Simulator (by Circadian)
- CASA – Civil Aviation Safety Authority (Australia)
- EASA – European Aviation Safety Agency
- EC – European Commission
- FAA – Federal Aviation Authority (USA)
- FAID – Fatigue Assessment Tool designed by Interdynamics
- FRI – Fatigue Risk Index (by Uk Health and Safety Executive)
- FRM – Fatigue Risk Management
- FRMS – Fatigue Risk Management System
- IATA – International Air Transport Association
- ICAO – International Civil Aviation Organization
- JAA – Joint Aviation Authorities
- NASA – National Aeronautics and Space Administration
- NPA – Notice of proposed amendment (EASA)
- REM – Rapid eye movement during sleep
- SAFE – System for Aircrew Fatigue Evaluation (by FRMSc)
- SAFTE – Sleep, Activity, Fatigue, and Task Effectiveness (by IBR Inc.)
- SMM – Safety Management Manual
- SMS – Safety Management System
- SPSS - Statistical Package for the Social Sciences (by IBM)
- SWP – Sleep/wake predictor (by the Karolinska Institute)
- TOD – Top of descend
- TLX – Task Load Index (NASA)

Table of Contents

Acknowledgements	3
Abstract.....	4
List of Abbreviations	6
List of Figures	9
List of Tables.....	10
1. Introduction.....	11
2. Aims, Objectives & Research Question of the Dissertation	13
3. Literature review	14
3.1. Fatigue in aviation	14
3.2. Fatigue, safety and risk: it’s all about compromise	17
3.3. Workload	19
3.4. Bio-mathematical modeling of fatigue	20
3.5. Regulatory framework.....	23
4. Methodology.....	27
4.1. Study Design & Strategy.....	27
4.1.1. Operational Context.....	27
4.1.2. Population and Sample.....	27
4.2. Tools and data analysis procedures	28
5. Results	31
5.1. Planned schedule analysis	31
5.1.1. Schedule structure.....	36
5.1.2. Risk assessment.....	38
5.2. Questionnaires and post-operational data: objective vs subjective data ..	42
5.2.1. Questionnaires	42
5.2.2. Live study analysis.....	43
6. Discussion	59
7. Recommendations.....	63

8. Conclusion.....	65
9. Bibliography.....	67
Annexes	I
Annex I – Questionnaire	II
Annex II – Diaries	IX
Annex III – Likelihood and Severity tables	XI
Annex IV – Samn-Perelli fatigue table	XIII

List of Figures

Figure 1 - Human sleep cycle (ICAO, 2012a).....	15
Figure 2 - Speculative interaction between homeostatic drive and circadian rhythm (Mallis et al., 2010).....	16
Figure 3 - Framework for examining the relationship between fatigue and safety (Williamson et al., 2011).....	18
Figure 4 - Model structure (adapted from Casa, 2014).....	21
Figure 5 - Hierarchy of legal instruments in Portugal (Source: Adapted from EASA, 2015) ..	24
Figure 6 - Pilot Age distribution and total flying hours.....	27
Figure 7 - Flight structure: landings on long vs short flights (x=0 corresponds to aircraft on ground)	32
Figure 8 - Total duty time in hours for 2014.....	33
Figure 9 – Sign-on (son) time for last year's duties in hours.....	34
Figure 10 - Relation between sign-on time and predicted fatigue levels using SAFE model.	35
Figure 11 - Count of number of sectors per sign-on time	37
Figure 12 – Distribution of Block and duty time for February 2015	43
Figure 13 - Sign-on time vs number of sectors flown.....	45
Figure 14 – Samn-Perelli reported at TOD (SPoff) per reporting time (sonintervalos) with number of sectors	46
Figure 15 – SAFE predicted Samn-Perelli values for each reporting time (sign on)	47
Figure 16 - Sign on times vs duty length	48
Figure 17 - Reported fatigue values at sign on and TOD	50
Figure 18 - Fatigue values by reporting time	51
Figure 19 - 'Heat map' correlating fatigue level differences	54
Figure 20 - TLX values vs sign on and number of sectors.....	55

List of Tables

Table 1 - Schedule interactions for fatigue evaluation	36
Table 2 - 2014 Schedule structure	36
Table 3 - ICAO severity scale to Samn-Perelli fatigue scale (ICAO, 2012b)	38
Table 4 - Likelihood table with assumed probabilities (ICAO, 2012b)	39
Table 5 - Fatigue values as predicted by SAFE model for year 2014	39
Table 6 - Risk Matrix with 2014 planned rosters.....	39
Table 7 - Hazard identification, consequent risk level increase and possible mitigations.....	41
Table 8 - Average block and duty hours February 2015.....	43
Table 9 – February 2015 Schedule structure	44
Table 10 - Fatigue values as predicted by SAFE model for February 2015.....	48
Table 11 - Risk Matrix for February 2015 - SAFE values from planned rosters	49
Table 12 - Model predicted values vs pilot reported values	52
Table 13 - Fatigue values as reported by pilots for February 2015.....	52
Table 14 - Risk Matrix for February 2015 with pilot reported values	53
Table 15 - Possible hazards, their description and mitigations	56

1. Introduction

Safety has been an issue in aviation for several decades now, but considering fatigue as a safety issue was underestimated until the very end of the last decade. At that point, the concept of safety has evolved from a technical only issue to one where the Human plays a big role and is the cause for more than three quarters of the accidents occurred. With growing safety concerns worldwide, raised by ICAO and other relevant aviation stakeholders, safety's shift changed, promoting an evolution in the point of view from which problems and solutions are perceived – from the cause of the simplest most naive error to the reason for major accidents, Safety issues are now looked from a systemic, organizational like point of view allowing new areas of interest to be explored. Subjects like Just Culture, Human Factors and Fatigue now have a place in how we look at safety in most aviation related areas. As such new regulations have been created by European and International boards, such as ICAO's Safety Management Manual and the European Union's laws on making Safety Management Systems mandatory in every European Aviation Safety Agency (EASA) Commercial Air Operator. Safety became the new global concern in aviation, with everyone involved working to keep the low accident rate that is only compared to the nuclear industry and is amongst the lowest worldwide (IATA, 2014b).

As airlines start flying earlier every day and finish latter, for greater fleet optimization and slot usage, fatigue has become an increasingly bigger hazard in the past years, where crew optimization and issues like ultra-long range or commuting brought to live concerns in the aeronautical community. In Portugal, a study revealed that 89.3% of 450 commercial aviation pilots reported high levels of fatigue. This study also proved that more than two thirds never reported this situation (Reis, Mestre, & Canh o, 2013) proving that fatigue is a severe issue and a major hazard for air operations. Other studies also support these findings, with cockpit and cabin crew fatigue levels rising very often to unacceptable levels (D. Powell, Spencer, Holland, & Petrie, 2008; D. M. C. Powell, Spencer, Holland, Broadbent, & Petrie, 2007; D. M. C. Powell, Spencer, & Petrie, 2011).

Following a lot of controversy and with the need to approach fatigue and define European industry standards on this problematic new flight time limitation rules were approved in 2014 by the European Parliament, opening the door to the implementation and extensive use of fatigue risk management as an alternative to prescriptive flight time limitations. As Fatigue Risk Management (FRM) will not be mandatory, the management of fatigue as a causal factor for hazards in flight operations is a part of what the European Aviation Safety Agency (EASA) considers essential on every airline's safety management system (European Commission, 2014). The objective of this research is to help elicit the actual requirements and difficulties in implementing such policies in an operator where at least part of its operation is based on multi-segment working days, and to establish a method to manage fatigue in the Safety Management System (SMS) structure, allowing the airline to achieve a full FRM through a wider implementation of the proposed structure.

This study will focus on the operator that, unlike major airline carriers, that have irregular night and early schedules that overlap circadian cycles, might struggle with fatigue from a stress and workload point of view due to the short duration of flights, the frequency of adverse weather days and the number of sectors flown in a single duty period. With the main goal of fatigue hazard diagnosis, in the first part there will be a revision of the state of the art, reflecting the questions and definitions surrounding fatigue in aviation, workload as well as the most recent studies of fatigue in aircrews and the latest International and European regulations and standards. This literature review will also set the scientific basis for the definition of a roadmap to implement FRM and is set to justify some of the options chosen. After defining the methods to be utilized, a live pilot study with flight crew will be carried out to validate the FRM processes described, as this should be the start point to grow a sustainable and solid fatigue risk management. The study consists in an overview and risk analysis on planned and already worked rosters over a 365 day period (one calendar year), followed by a questionnaire to segment and evaluate individualization, a big part of all human factors related subjects. The last part of data analysis will come from a live study conducted over a period of three weeks set to identify differences between algorithm generated fatigue levels and the subject values reported by the crews.

As an outcome of this research, there should be a methodology defined as to how fatigue can be approached in regional airlines, allowing further developments and wider studies on the field of workload, multi-segment operations and fatigue in aviation to be developed.

2. Aims, Objectives & Research Question of the Dissertation

The objectives of this research are:

- To identify the preeminence of the need to manage fatigue in air crew members;
- To integrate fatigue hazards and its risk management in the framework of an existing SMS according to the new ICAO and European regulations;
- To infer the real risk already present in the airline through subjective fatigue queries;
- To validate the chosen methods and processes so as to lead a sustainable FRMS implementation and maintenance.

These objectives are all centered on one fundamental research question:

What is the methodology that an Air Operator should follow for the correct management of risks associated with fatigue in their specific environment and current processes?

3. Literature review

3.1. Fatigue in aviation

The demand for air travel in the last few decades became increasingly high. To meet this demand, airline managers faced the need to reduce airfares and optimize resources to their fullest. Air crews were no exception and as flying hours increased there were enforced to a reduction in rest periods and consequently sleep time. This leads to the lack of alertness that is characterized as fatigue. A generic definition of fatigue is still to be achieved, with Williamson et al. (2011) probably delivering the most generic one “as a biological drive for recuperative rest” (Williamson et al., 2011). Aviation by itself has been one of the fields where these issues showed greater impact, amongst other transportation means, and where it has been addressed by several studies and documents proving it is a major question to be addressed with the need to identify hazards associated with fatigue as risks to flight safety (Williamson et al., 2011).

The records of studying fatigue go back to the 70s, where Captain Bader (Bader, 1972) found out that there was a need for the application of limits to the time pilots fly, and defined fatigue as “the reduced ability to carry out a task”. As a 70-year-old concept, fatigue was initially defined as a “decrease in performance or performance capability as a function of time on task” (Mallis, Banks, & Dinges, 2010). Through the years the concept evolved, proving that fatigue is a dynamic and nonlinear subject that affects Human performance and is conditioned by sleep, although it can also appear due to excessive workload (Mallis et al., 2010). ICAO defines it as a “physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member’s alertness and ability to safely operate an aircraft or perform safety-related duties” (ICAO, 2012a) and this is the most contemporary and commonly used and accepted definition of fatigue by air operators worldwide. It is then safe to say that fatigue impacts performance and decision making, increasing organizational risks and creating direct link with incidents and accidents (Akerstedt, 1995; Van Dongen & Hursh, 2011). The concept of fatigue can be further expanded into active and passive fatigue. As active fatigue is a “continuous and prolonged, task related psychomotor adjustment” (Desmond & Hancock, 2000, p. 601) relating to high workload situations and elevated task and cognitive demand, passive fatigue is the one induced during low-workload situations, in particular when there is a monotonous continuous

task that requires high vigilance with low input. It can be present in situations of “system monitoring with either rare or even no overt perceptual-motor requirements” (Desmond & Hancock, 2000)

Sleep is the best and maybe the only remedy for fatigue, but it is also one of its main causes and as such most fatigue related concepts are directly related to sleep and its disruption. Sleep can be set as a “reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment, (...) a complex amalgam of physiologic and behavioral processes” (Carskadon & Dement, 1994). It can also be defined as the time when *the brain goes ‘off-line’* and has almost no sensory information. This increases the body’s regenerative capacity and the processing of the day’s information and is a vital component to a healthy individual.

Sleep can be divided into two essential brain stages, Rapid Eye Movement (REM) and non-REM as it can be seen on figure 1 (Carskadon & Dement, 1994; IATA, ICAO, & IFALPA, 2011; ICAO, 2012a).

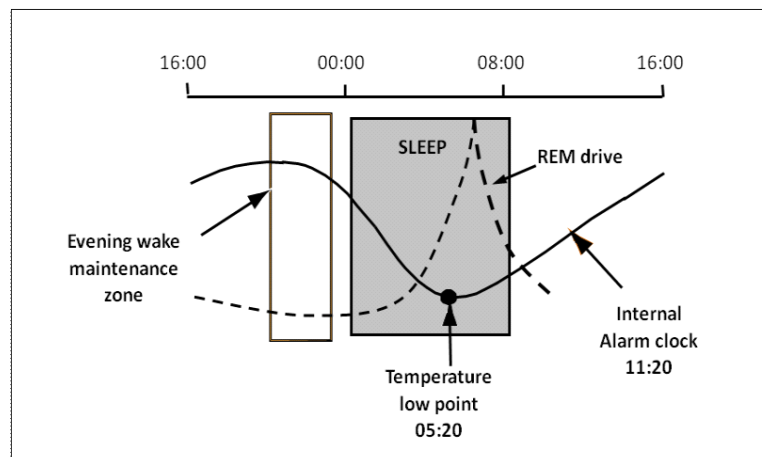


Figure 1 - Human sleep cycle (ICAO, 2012a)

However, because the Human body is not prepared for shift work, rapid time zone transitions and less than 7 to 9 hours of sleep, impairment and decreased levels of performance are often originated in air operations, together with a risk factor. (Caldwell & Mallis, 2013; Carskadon & Dement, 1994). The main reason for this are the primary biological regulations behind sleep and sleep structure:

- ⇒ Circadian Rhythm, is the biological ‘clock’ existent in mammals that is connected to the earth’s 24h rotation, and is primarily controlled by the suprachiasmatic nucleus located in the brain’s hypothalamus (Mallis et al., 2010)
- ⇒ Homeostatic Sleep Drive, can be summed as the pressure that builds up in mammals to the point it makes it very difficult or impossible to stay awake. It is set as 16 hours for most adults. Homeostatic pressure can build up due to increased time awake, insufficient sleep during one or several days, sleep pathology or environmental factors (Mallis et al., 2010)

Both mechanisms above are linked differently during the 24 hour circadian period (figure 1). During day time, these mechanisms act mostly in opposition to each other and whilst homeostatic pressure should keep an individual awake, the circadian rhythm can vary. During night time these mechanisms are in synergy in order to promote the 7 to 8 hours sleep required by the average human body (Mallis et al., 2010).

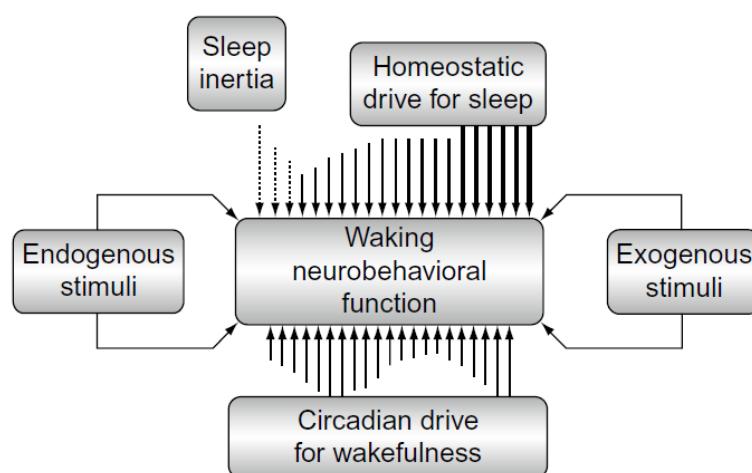


Figure 2 - Speculative interaction between homeostatic drive and circadian rhythm (Mallis et al., 2010)

Although fatigue is not necessarily the driver to an unsafe situation, there is a direct relation between the number of hours of sleep obtained and the levels of fatigue, A reference of 7.7 hours of sleep in one to two days before the beginning of a shift has been proven as a good sleep average, with a decrease in sleep time representing an increase in fatigue levels, increasing during the days of a set of consecutive shifts (Darwent, Dawson, Paterson, Roach, & Ferguson, 2015).

3.2. Fatigue, safety and risk: it’s all about compromise

“(...) the link between fatigue and safety is particularly difficult to establish because of the very low accident rate and the complexity of accident etiology.” (CASA, 2014)

Fatigue is a big scourge in flight operations and safety in the XXI century, as it affects human performance by limiting one’s physiologic capabilities (de Mello et al., 2008). Due to the maximization of the human resource and the need to keep some activities on a round the clock operation, employees that work shifts with more than 16 hours or at a low circadian phase (where one should be sleeping) present themselves with great decreases in performance and consequently increased risk to safety (Mallis et al., 2010). As several studies concluded, fatigue impairments are equivalent to the ones related to excessive alcohol consumption, with a performance decrease of 0.74% per hour between 10 to 16 hours of wakefulness which is equivalent to blood alcohol concentrations of 0.05% after 17 hours awake. This value can rise up to 0.10% within 24 hours of sustainable wakefulness (Dawson & Reid, 1997; Fryer & Czeisler, 2006; Lamond & Dawson, 1999). As a comparison, in Portugal the maximum alcohol limit for driving is 0.05% (Autoridade Nacional da Seguran a Rodovi aria, 2013).

According to Mallis et al. (2010), the primary causes of fatigue-related incidents and accidents are:

- Sleep loss;
- Alertness during extended duty periods;
- Circadian factors, primarily circadian misalignment.

Due to the need to perform some day-to-day activities (i.e. work), humans tend to disrupt the fairly regulated homeostatic/circadian relation, leading to arising situations of sleep disturbances that can be harmful to both health and safety, leading to (but not exclusively) cognitive deficits, reduced vigilance, hormonal disruptions and gastrointestinal issues (Mallis et al., 2010). A study by Williamson et al. (2011) correlated fatigue and how it impacts safety through circadian, task-related and homeostatic factors, as shown on figure 3, demonstrating as a fact that the lack of alertness reduces performance and cognitive capabilities, although there is still a need for further research to prove the link between circadian influences and performance. This is further demonstrated on some ultra-long haul flight operations studies, where there is an obvious link with sleep deprivation and time since

waking but no real proves on jet lag or other circadian disruption as such (CAA, 2005; Foundation, 2003; Williamson et al., 2011).

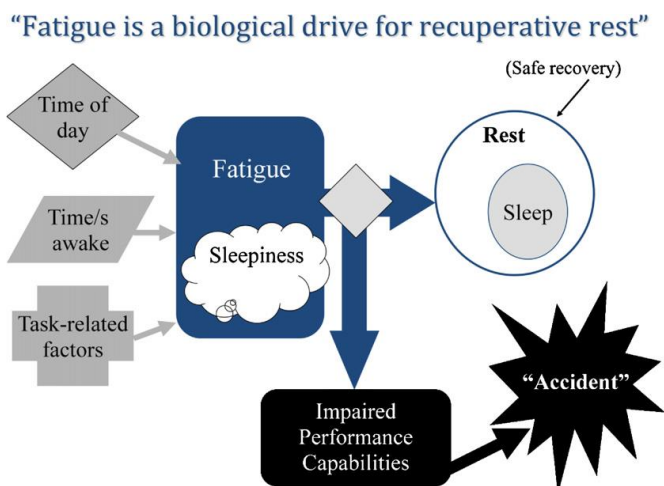


Figure 3 - Framework for examining the relationship between fatigue and safety (Williamson et al., 2011)

The link between fatigue and its impact on safety is also obvious through states of acute fatigue, punctual or chronic, arisen from one or cumulative nights of less than 7 hours of sleep have showed great decreases in cognitive performance whilst cases that slept generally more than 8 hours show no deficits or greater problems. A study conducted by the University College London revealed that there is a strong correlation between sleep problems and fatigue, as well as with anxiety and depression problems (Bostock & Steptoe, 2011). The study also shows that more than 75% of the studied pilots did not fill out fatigue report forms even when they thought they should have. Overall this study reveals the fragile and arising issue of fatigue, with 45% of the pilots participating in the study suffering from fatigue (Bostock & Steptoe, 2011).

3.3. Workload

“Why do workload, situational awareness, and performance dissociate, often making it difficult to predict one from the others?” (Durso & Alexander, 2010)

According to Hart (2006), “workload is a term that represents the cost of accomplishing mission requirements for the human operator”. Some studies validated the need to approach workload as a ‘hot topic’ regarding the threat it can pose to safety and its correlation with fatigue and the increase in risk situations. (Co, Gregory, Johnson, & Rosekind, 1999; Deros, 2012; Dorrian, Baulk, & Dawson, 2011; Silva, 2014) This proves that individual fatigue can be also defined as the resources required to perform a task, if they are the adequate to pursue such task and if not, what are the dangers imposed to the individual and its performance (Silva, 2014). A study by Hancock et al. (1997) demonstrated that workload increases with length of work and that “fatigue is directly related to the workload of sustain attention” (Hancock & Verwey, 1997). If looking into the particular definition of mental workload (and not workload as a whole), it “can be described as the relation between the function relating the mental resources demanded by a task and those resources available to be supplied by the human operator” (Parasuraman, Sheridan, & Wickens, 2008), demonstrating that in any case workload is a function of the too little or too much induced into one individual operator at one specific time when performing a specific task (Durso & Alexander, 2010).

The TLX or Task Load Index is a workload measuring method created by NASA used to help those who need more information on detailed workload values in their activities. It represents six clusters of variables (mental, physical and temporal demands; performance; effort; frustration) that in combination allow a representation of the Human performance capability at a given task. To encompass individual variability, different weights can be given by the individual to each variable, thus allowing a more reliable and trustworthy output (Hart, 2006; NASA Ames Research Center, n.d.).

3.4. Bio-mathematical modeling of fatigue

“(...) the most critical aspect of any model is its predictive validity, which in the case of fatigue models and risk management is the extent to which predicted performance decrements correspond to adverse performance outcomes in the operational environment.” (Roma, Hursh, Mead, & Nesthus, 2012)

Created mostly from the two or three process models of alertness, which explore the circadian cycle, homeostatic pressure and work-rest relations, bio-mathematical models have been developed with the purpose of supporting the management fatigue and shift work (Mushenko, 2014; Powell, Spencer & Petrie, 2014). These models are based on mathematical algorithms that explore the interactions between the circadian process, sleep inertia and the homeostatic drive (Hursh, Hans, & Dongen, 2011). More recent models like the Boeing Alertness Model (BAM), the System for Aircrew Fatigue Evaluation (SAFE), Fatigue Assessment Tool by Interdynamics (FAID) and others increase the model complexity and outcome reliability by adding extra variable, generating a more accurate prediction of fatigue and consequently better risk management (CASA, 2014; Mellor & Stone, 2012; Mushenko, Page, & Fletcher, n.d.). As shown on figure 4, the interactions between the different inputs and models can lead to the outcome of different sets of outputs. As a guarantee of integrity and reliability, model accuracy and validation plays an important role in defining the quality and capacity of outputs. Some models have been validated from its empirical settings to real world contexts and approved by the corresponding authorities (CASA, 2014; Ingre et al., 2014). These models need to guarantee both scientific and operational research and validation. Limitations to the extent that these models can be used include their inability to predict individual variability and the type of values generated, which are probabilistic (predictive), generic, and originated in a theoretical space, different from real/live operational context.

Some models, such as SAFE have been developed in cooperation with aviation Authorities (CAA, 2005) and validated as they proved a good correlation between subjective fatigue values reported by aircrews and the outputs generated by the model itself (Powell et al., 2011, 2014). A study by the FAA (2012) on the SAFTE fatigue model has also proved that objective fatigue measurements are well within acceptable values with the fatigue levels predicted by the model and both have proved a strong correlation, even though individual variability is a major factor.

Sleep and susceptibility to fatigue vary individually in the same way that the same group of factors impact different people (Roma et al., 2012). This research shown the important role of bio-mathematical models on setting up safer operations with better risk assessment. They are also an important tool in incident and accident investigations, when sufficient information is available (Pruchnicki, Wu, & Belenky, 2011; Roma et al., 2012).

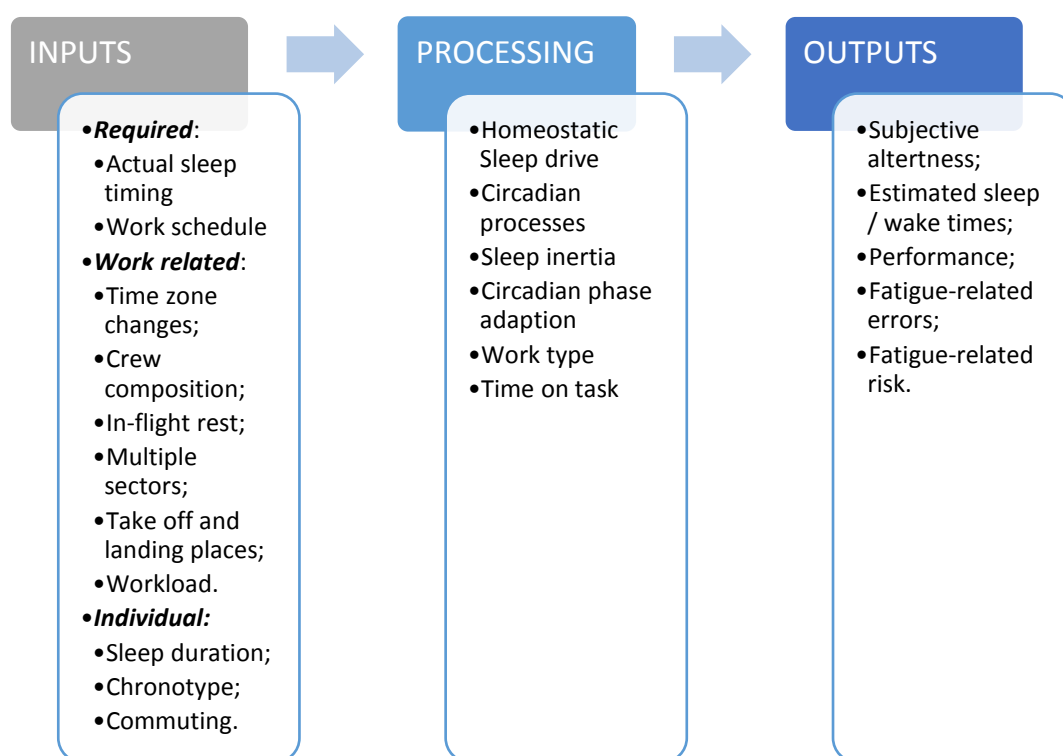


Figure 4 - Model structure (adapted from Casa, 2014)

A guidance document produced by the Australian Civil Aviation Safety Authority, CASA, provides an overview of the most commonly used models, their advantages and disadvantages, and also their applicability in flight operations (CASA, 2014). From this comparison, models like the BAM, Circadian Alertness Simulator (CAS), SAFE and Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) show the highest number of applications and most of them have the same set of components, with FAID and FRI showing an inferior number, independently from being two or three process models. The major differences amongst these models rest in the type and amount of inputs and outputs. BAM, CAS, FAID and SAFTE lead the list with the higher number of inputs. The greatest differences between the models relay in their features like workload or chronotype values and choices, with a high number of other optional setups on most of the models. The differences are also noticeable on the outputs produced where CAS, FAID and SWP are the most complete models: they

have biggest number of results and extra settings (for instance the ability to predict fatigue related errors or provide confidence intervals).

Bio-mathematical models are used for a number of different applications:

- Forward scheduling: to assist in all stages of crews scheduling and rostering practices, from the airline’s commercial flight schedule planning to planning monthly rosters, perform post operational analysis or irregular operations management;
- In flight patterns for augmented crews: to help in setting the best rest times for each crew member on one specific flight;
- Light exposure and napping countermeasures: used as an aid tool in planning rest times and advising crews on best sleep practices, helping to mitigate jet lag and circadian disruption;
- Training: as it can identify major risk factors and help in supporting training roles, in particular for decision makers and front-line workers;
- Individual fatigue: although models are programmed and based primarily on averages of wide populations, there is still a lot of room to encompass individual setups, alertness variations and performance variability;
- Safety investigation: with the correct data, models can provide a good tool for fatigue analysis in incidents and accidents, demonstrating if there is a reasonable belief of fatigue being a major factor or even absent at all from the investigation.

Despite all their benefits and applications, the use of models is still limited as they do not account for chronic effects of sleep deprivation and take no consideration on individual variability: they are built and created from average population measurements and not custom tailored. “As they stand the models can be used effectively to compare the relative merit of two or more work schedules, but cannot definitively answer the question as to whether a particular work schedule is acceptable or safe” (CASA, 2014)”.

3.5. Regulatory framework

“(...) from a historical standpoint, far more attention has been devoted to regulating hours on the job as opposed to ensuring sufficient hours of restorative sleep.” (Caldwell & Mallis, 2013)

The regulatory roadmap to fatigue started with ICAO's 6th Annex, recently updated to launch the first foundations for a worldwide integrated fatigue management and its associated risks, based on scientific principles and regulated by the different European state's authorities who should determine the minimums for its compliance (ICAO, 2010). IATA in its 2014 Safety report approaches fatigue as a safety concern, with a need for authorities and stakeholders worldwide to further overview and approach this subject (IATA, 2014b). At an European level, flight time limitation rules created and ruling in each country for many years have proven to be as diverse as they are insufficient in guarantying enough rest and thus fit-to-fly aircrews because of their 'one size fits all' status. This lead to discussions in recent years between the international associations like IATA and ICAO and the local regulators like JAA or EASA regarding the concept of fatigue and its integration in contemporary safety management systems as a way to create safer limits to fly with better rested aircrews (ECA, 2015; Graeber & Ph, 2011; IATA, 2010).

As part of one of the most discussed and controversial legislation packages created for Europe's aviation, the recent changes to flight time limitations impose a uniform and strict number of important rules and regulations that affect the way shiftwork is seen with aircrews, in particular when looking to safety related items (ECA, 2015).

Created in 2002 to replace the Joint Aviation Authorities (JAA), EASA's role has increased in importance during the past few years and is now the main institution responsible for standardizing and enforcing laws and rules in civil aviation through Europe, especially after Regulation (EC) 216/2008. EASA legislates through the European Commission and Parliament and produces both hard and soft laws that integrate the Portuguese legal system, as it can be seen on figure 5. Regulations (hard law) are of mandatory application in all EASA countries, and further expanded and guided through Guidance Materials, Acceptable and Alternate means of compliance and Certifications Specifications (soft law).

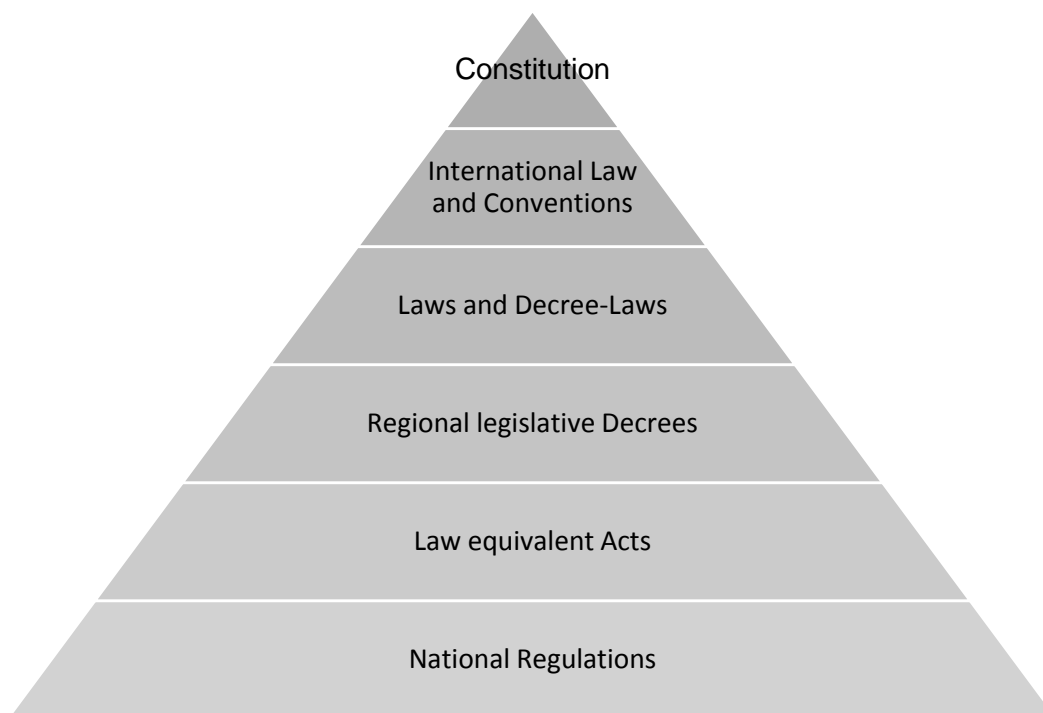


Figure 5 - Hierarchy of legal instruments in Portugal (Source: Adapted from EASA, 2015)

The stated principles lead to the creation publication of Regulation (EC) 83/2014, which reviews flight time limitations from the old EASA Subpart Q, enforcing equal rules across Europe. This reduces the allowed time to work in some countries, with the downside of increasing it in others (European Commission, 2014). As it is discussed that some countries will see increases in productivity, it has been proved that increases in working hours rarely lead to a proportional shift in safety (Hellerstr om, Eriksson, Romig, & Klemets, 2010). This regulation also incentives Commercial Air Operators to be less conservative with prescribed flight time limitations and create performance based rules that fit their individual operation, crews and needs, where airlines can decide what is the best compromise between safety, efficiency and costs that guarantee the best ‘as low as acceptable’ risk though the operation. This is the foundation principle of Fatigue Risk Management (IATA et al., 2011; ICAO, 2012a).

Lead by Safety management and supported by the rostering and crewing departments FRM can be integrated in air operations. Its structure imposed by ORO.FTL.120 in Regulation (EC) 83/2014 (European Commission, 2014):

1. Policy – each airline must establish its fatigue management policy, to which every employee from top management down to front line operational staff should commit and follow;
2. Documentation – essential in establishing not only guidelines but also the standardization of forms, reports and documents to be used and produced;
3. Scientific principles – it is well emphasized that FRM, unlike some other hazard identification methods and principles existent in actual SMSs must be scientifically based and driven by this, where common sense must be used very carefully and wisely;
4. Hazard identification methods – fatigue hazard identification is mandatory to Air Operators and its guidance can be found on EASA’s NPA 2010-14 and, although is not a requirement for airlines to have its FRM separated from the SMS or even a full FRM, fatigue related hazards must be identified and mitigated in the framework of the SMS. In order to achieve derogations and exceptions there is a need to have a well-functioning structure with some operational fatigue expertise proven, through (amongst others) statistics and scientific studies;
5. FRM assurance – as all safety methods, FRM needs to be a process of continuous improvement and development, hence good and reliable methods will need to be implemented to guarantee this;
6. Promotion – internal marketing on fatigue awareness and avoidance is one of the first major steps that should be accounted for when considering managing fatigue all together as well as the so important ‘change management’ plan that will set and influence the way people see and culturally accept and thrust this subject (Flaherty, 2015). As a way of promoting this subject even if a FRM is not in place, ORO.FTL.250 establishes mandatory training to all relevant staff, including a complete initial training and a recurrent review of the main subjects concerned.

The steps mentioned above get FRM running and approved according to EU's regulation, but only a thorough and rigorous commitment by national aviation authorities makes it possible and in line with the spirit it was created for. It is important for every civil aviation authority to have trained and specialized staff that will demand to airlines proof of how they're implementing and working with Reg. (EU) 84/2014 (Jones, 2015).

Fatigue risk management is also a data driven system and consequently dependent of a good reporting culture and proper measurement of crew performance through key and safety performance indicators that rely on good scientific knowledge. This can only be achieved with a solid presence of good just culture that keeps training, reporting and all levels of staff involved together with good management and high trust on safety management and culture (IATA, 2010, 2014a).

4. Methodology

4.1. Study Design & Strategy

4.1.1. Operational Context

This research was conducted in a regional airline that operates a fleet of seven aircraft, divided into two sub-fleets. The main commercial focus are the connections between nine islands, with the closest one situated two flying hours away from mainland. Their longest flight is approximately 02:00 long and the shortest 15 minutes total time. The airports characterize themselves by local, easy to operate fields in almost all operational aspects, although they pose a huge challenge with high terrains and periods of severe bad weather. This implies approaches that require high Human performance levels, from which high values of workload tend to arise.

4.1.2. Population and Sample

The universe of this research is constituted by the pilots of this regional airline, divided into two fleets and summing a total of 52 individuals, 27 Captains and 25 First officers, all males. Their average age is 39.2 (\pm 9.539) years old, with a median value of 37. The mean age of Captains is 44.2 (\pm 10.059) years old, with the youngest being 30 years old and the oldest 63 years old. First officers have an average age of 33.8 (\pm 5) years old, with a minimum of 26 years old and a maximum of 44 years old.

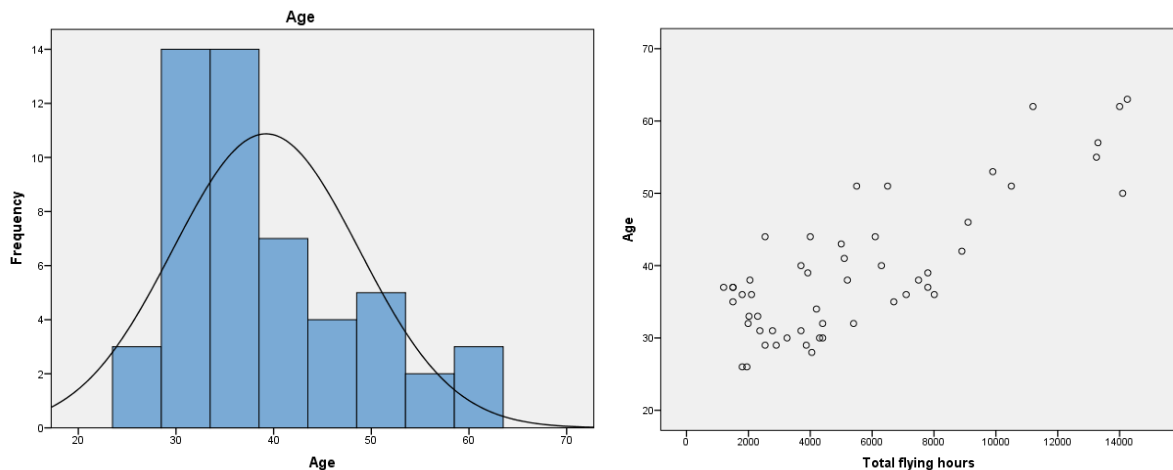


Figure 6 - Pilot Age distribution and total flying hours

Figure 6 shows the dispersion of total flying hours in each individual career. Although the mean value is 5521.92 flying hours and the median value 4350 flying hours, there is a high concentration of individuals below 5000 hours total time and a wide range of individual experience, ranging from a minimum of 1200 hours to a maximum of 14250 hours and proved by the high standard deviation of 3718 flying hours.

4.2. Tools and data analysis procedures

The study started with the literature review, as presented on the first chapters of this dissertation, where online research tools as Google Scholar, Ingentaconnect and Science Direct were widely used. The main keywords were fatigue, multi-segment operations, aircrew workload, shiftwork, regional air operations, safety risk management, human performance, human error, stress. As there was a limited number of studies on the specific theme of regional carriers and multi-segment operations, most studies related to fatigue and/or workload in aviation were included. There were no limits for the publication date of the researched papers. After consideration, some papers were excluded due to their low relation with the operational context of this research.

For data collection a time frame was set and a strategy defined consisting of:

- A questionnaire that was distributed electronically through Google Forms to all pilots during the period of one month (February 2015), and was created from NASA's study on fatigue in regional operators (Co et al., 1999), adapted to the cultural and social context of this particular airline and added by a measurement of perceived stress (Cohen, Kamark, & Mermelstein, 1983), so as to evaluate demographics, personal and social habits and global fatigue and stress levels in each individual. The questionnaire was responded by a total of 26 individuals from the total population;

- A diary where pilots could register their subjective fatigue measures on the start and finish of each working day during a period of one month (February 2015), distributed by the airline’s flight operations during the first briefing of the day to each crew pair, and returned to the researcher through electronic format. The diary consisted of:
 - o Start and end times for the duty day;
 - o Samn-Perelli Fatigue Scale (Samn & Perelli, 1982) and the Karolinska Sleepiness scale (Akerstedt & Gillberg, 1990), filled out both at the start and end of the working day;
 - o NASA’s TLX measurement, on a simplified version with only 6 readings adapted to this study. The score, ranging from 0 to 20, is equivalent to the regular rule measured 100 points, allowing simplicity in its usage by pilots during regular flight operations (NASA Ames Research Center, n.d.);
 - o Assessment of further disruptions during the day, i.e. weather or technical issues that could further increase workload and therefore fatigue.

A bio mathematical modeling software, SAFE version 6, will support the research by generating hypothesis and base values from a year of planned pilots rosters and the weeks of the live study. These last values will be validated by comparing them with the subjective measured data from the diaries, handed out to the pilots during the research.

After collecting all data a statistical analysis it was conducted mainly through descriptive statistics, using SPSS version 20, to depict and test the results and reach conclusions, as well as to perform additional comparisons with already existing results from the literature. One-sample t-tests, one-way anovas and direct correlation analysis showed no relevant results and excluded the use of statistical inference.

The diaries presented to pilots at their reporting time and with their daily operational briefing had the goal of retrieving data from both start and finishing times on actual fatigue levels experienced and perceived by each individual. As the end of the day could become a constraint and reduce the results, it was decided that the second part should be filled just before top of descend on the last flight of a working day, before a critical phase in a flight, and with the added value of having information before a critical stage of flight, the approach

and landing. It also included an adapted TLX workload assessment, converted into a 0 to 20 scale with the purpose of easing up the filling process. The regular rule measured scale was replaced by a single ordinal scale ranging from 0 to 20, with only integer numbers. There was no weighing of the different measurements, and an assumption was made that they had the same importance in workload measurement.

The method used to describe the results will be a framework encompassing the previous planned schedule assessment, risk matrixes and their comparison to actual fatigue values, as reported by a group of pilots during 139 working days. The framework consists of 8 points:

1. Identify total times for the period and their distributions;
2. Segment the flights by reporting time;
3. Detail early morning, late finishes and night duties;
4. Build a risk matrix based on probability predicted by the model;
5. Relate predicted fatigue values with subjectively measured fatigue values (identifying differences);
6. Build a new risk matrix on measured values;
7. Relate fatigue values with TLX measured workload;
8. Predict possible hazards liable of increasing risk levels.

For the purpose of the analysis, and as there is no other previous measure available, it will be assumed that values at the end of a working day reported by crews are the worst experienced during the day, so as to compare them with SAFE's worst fatigue value on each pairing/day. The Karolinska Sleepiness Scale obtained from the diaries will not be used in the analysis due to its similarity to the Samn-Perelli Fatigue Scale.

5. Results

5.1. Planned schedule analysis

This analysis was focused on the airline's 2014 planned rosters (365 days from January to December), as well as the planned rosters for the study period. The rosters were divided by start and end times, number of sectors and duty duration, and then processed by the SAFE bio-mathematical model. The analysis accounted 3920 pairings, where pairing is a portion of a crew member's schedule representing a flight, other official duty, or group of the previous, starting when a crew member reports for work at home base and ending when a crew member returns home at home base, considering mostly only flight duties and eliminating ground duties unless they were paired with flight duties in the same day.

A first evaluation was made using a set of roster metrics that allowed to verify possible exposure to fatigue by:

- The number of sectors and average sectors per day per crew member;
- The average flight time and duty time;
- Sign-on and sign-off times;

With a strong impact on regional operations, the number of sectors flown in a single day by each crew can influence fatigue through workload increase. Fatigue is defined by the state of alertness of an individual. So if by analogy we consider alertness to be fuel in a reservoir and workload the rate at which fuel is burned there is a relation between workload and fatigue in the sense that alertness is reduced quicker with higher levels of workload. Applying the concepts of active and passive fatigue (Hancock & Desmond, 2000), it is arguable if a long flight does have the same implications on fatigue as several short ones. In this research's operational case, since the longest flight duration is only 2 hours, the true concept of passive fatigue might never be felt, unlike active fatigue. It can be assumed that workload has a direct impact on active fatigue.

When analyzing rostered pairings in crew schedules, the shortest days account for only 1 sector per working day, whilst the longest go up to 8 sectors on a single day. The mean value shows an average of 4 to 5 sectors per working day but the mode reveals that this number varies between 4 or 6 sectors a day, with the 25% percentile set on the 3 to 4 sector value and a 75% percentile on 6 sectors, thus demonstrating that at least 50% of the crews rotations are between 4 to 6 legs. Going back to the fuel analogy, and looking at figure

7, we can easily see that at the same time a crew performs one 02:00 hour flight, not long enough for passive fatigue to be felt, a pilot in this operational setting lands up to 4 times. If we consider that the ‘fuel burn rate’ increases severely during take-offs and landings, it is then possible to relate a faster decrease in the alertness reserves with an inversely bigger increment in fatigue values and risk factors, proving that active fatigue is present in multi-sector operations.



Figure 7 - Flight structure: landings on long vs short flights (y=0 corresponds to aircraft on ground)

In order to understand shift work in short haul operations we will start this analysis by the airline’s 2014 (365 days from January to December) planned rosters, as well as the planned rosters for the study period. Rosters for this airline are established and published in advance so that crew members have opportunities to sleep and manage their rest. Pilot’s hours, namely duty and flight hours are distributed according to figures 8 and 9. As shown in figure 8, there is a concentration of total year duty time between 1000 hours and 1200 hours, with 28 pilots out of the total population averaging this values. The minimum values presented encompass a set of 7 pilots that had lower duty times either by fleet demands, parental leave or extended sick periods. On the other hand, pilots with high duty times also relate to a high number of duties with zero sectors, representing office and/or training duties with lower impact on their fatigue.

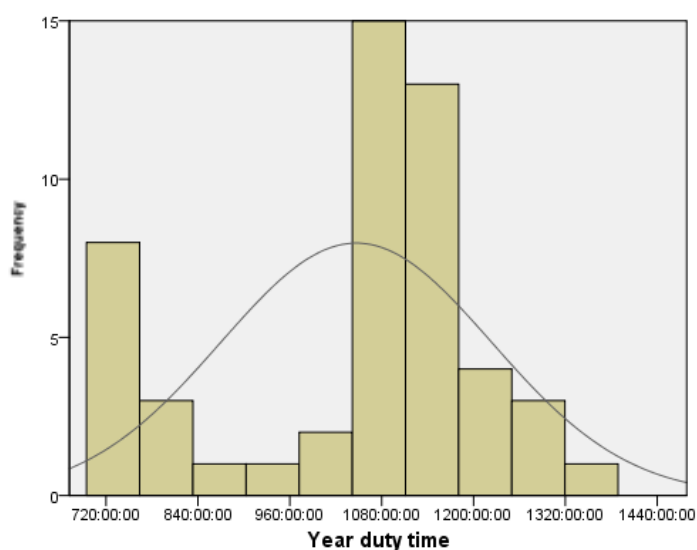


Figure 8 - Total duty time in hours for 2014

Figure 9 shows an overview of the yearly work day start times, with a clear uneven distribution during 3 periods of the day: 06:00, 08:00 and 14:00. Considering that 15 minutes of sleep are lost per hour in duties before 09:00, it can be concluded that duties starting at 08:00 only a 15 minute sleep loss effect and fit in the acceptable human sleep schedule, mitigating fatigue (Roach, Sargent, Darwent, & Dawson, 2012). Therefore, it is important to focus on the second and third most common reporting times that can pose problems to safety namely:

- 14:00 start times, that are usually in the post-lunch dip period and can extend into long hours of the night (working on maximum legal times duties can go past midnight);
- 06:00, or deep early starting times, that bring up the problem of circadian disruption as they can increase risk by almost 50% compared to other periods of the day and compel pilots to wake up inside the window of circadian low, reducing sleep in 1 hour or more per night (de Mello et al., 2008; D. Powell et al., 2008; Roach et al., 2012).

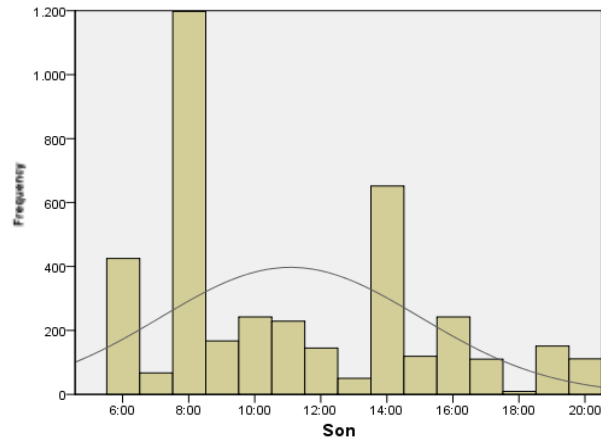


Figure 9 – Sign-on (son) time for last year's duties in hours

In Figure 10 it is observed the distribution of fatigue versus the start of the duty times as computed by SAFE model and it allows a good mapping of fatigue in 2014 amongst the population, regarding planned work hours and times. Cut off points of 4 and 4.5 have been assumed, following the recommendations by SAFE model owners and creators, present in the software operating manual. It is then possible to see that, despite the median value of 3.51 well below the reference maximum acceptable value, there are still a lot of duty days above the cut off values, raising safety concerns and motivating a deeper and more thorough analysis.

The next step of the research will be to compare and correlate the values obtained in the different models and surveys handed out daily to pilots, assessing their similarity and if there is a direct influence on the number of flights made to the increase in fatigue levels.

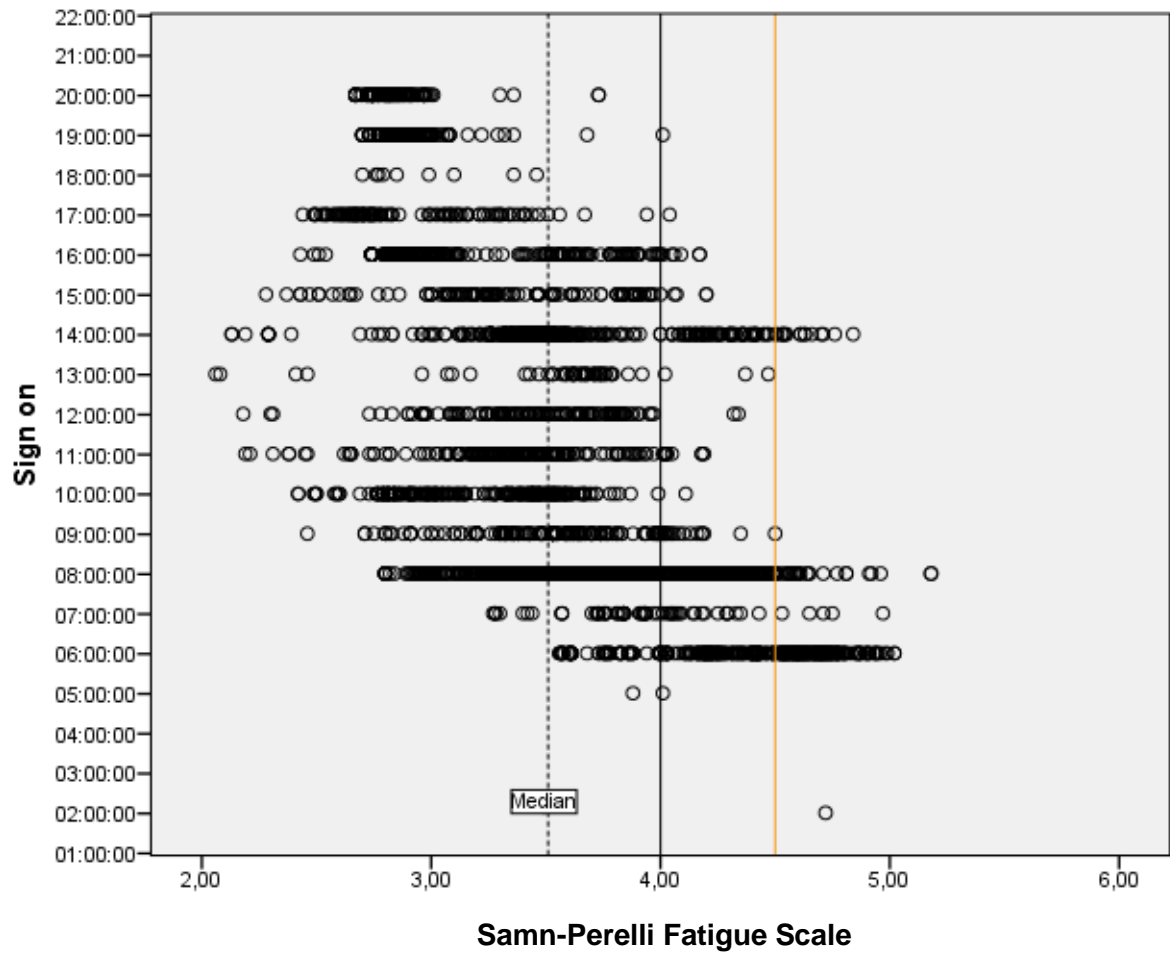


Figure 10 - Relation between sign-on time and predicted fatigue levels using SAFE model

5.1.1. Schedule structure

As explained before, sleep regulates the body and its basic regeneration processes, peaking during the stages of deep sleep where homeostatic pressure and the circadian rhythm are at its lowest. It is during this period that the body temperature hits the daily minimum. It is also at this time that there is a need for crew members to wake up so as to comply and fulfill their professional duties. Errors are more likely in the ‘predawn’ hours (Caldwell & Mallis, 2013), and it is important to analyze both the amount of duties starting in the early hours of the day as well as how this duties are structured.

Schedule assessment will have into account the following interactions:

Table 1 - Schedule interactions for fatigue evaluation

Reporting time	Previous day reporting
	Rest time
	Duty length
	Number of sectors
Rest time	Duty length
	Number of sectors
Duty length	Number of sectors

The analysis is made taking into account approximately 8100 duties, from ground and flight ones. Schedules are structured as bellow (average values):

Table 2 - 2014 Schedule structure

	Weight in total Operation	Sector count	Duty length	Rest time	Previous day start time
Up to 06:00	10 %	6	08:00	17:15	07:30 to 09:00
06:01 to 07:30	13,1 %	4	06:45	18:00	06:00 to 07:30
07:31 to 09:00	24,2 %	4	06:30	18:05	07:30 to 09:00
09:01 to 12:00	21,3 %	4	07:00	17:00	09:00 to 12:00
12:01 to 15:00	21 %	5	06:00	18:40	12:00 to 15:00
After 15:00	10,4 %	2	04:00	22:45	12:00 to 15:00

Almost 50% of duties start after 07:30 with their previous rest averaging around 18 hours, making such conditions acceptable and with low circadian disruption. Some problems can be identified in the table above (table 2) and need to be further developed, such as

- Highest sector count with deep early reporting times;
- The biggest average duty length is on the deep early reporting times;
- High sector count on the 2nd shortest duty length;
- Actual and previous reporting time on the early time frame.

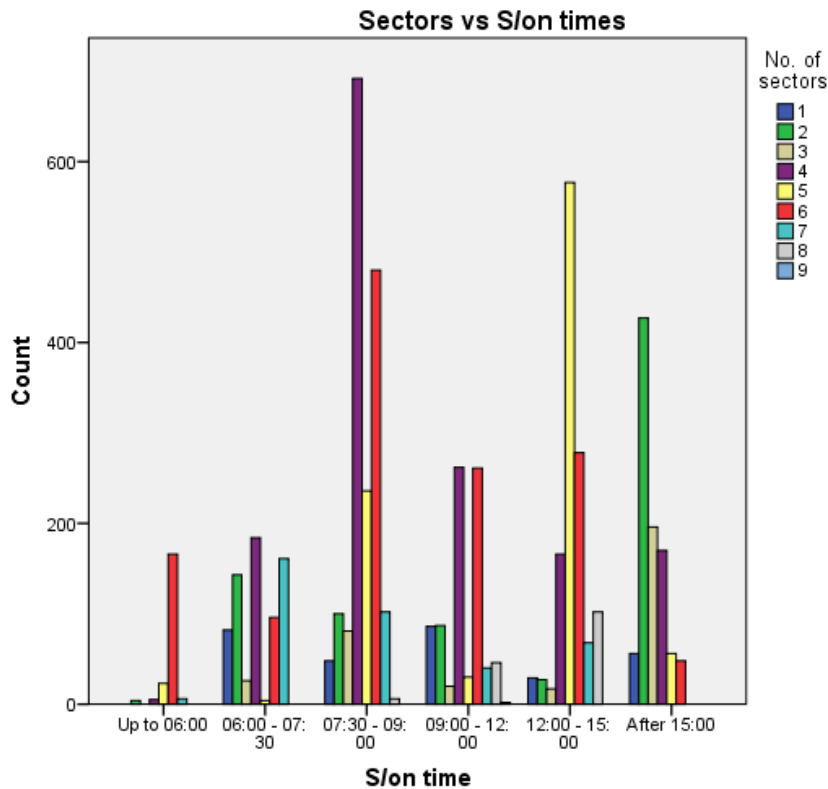


Figure 11 - Count of number of sectors per sign-on time

The graph above shows the distribution of the number of sectors per start hour time frame. In duties starting up to (and including) 06:00, a very high count of approximately 82% encompasses 6 sectors, a high number if compared to the average of duties after 07:30 until 15:00. Together with sleep cycle disruption, the long days with high workload can induce a lack of alertness and performance big enough to increase the potential for human errors and consequently the risk of the associated hazards.

5.1.2. Risk assessment

As a valuable tool, risk assessment on planned schedules is an important method to find gaps in the operation and help mitigate fatigue related hazards. The analysis is made by generating fatigue values from running a bio-mathematical model, in this case SAFE, that generates Samn-Perelli fatigue values. Figure 10 shows the distribution of fatigue levels through different start times. As before there is a cut-off assumed at 4.5, above which values can be observed in particular on the 06:00 to 08:00 reporting time, together with some duties that start just after lunch time around 14:00. These working schedules comprise higher risks to the operational environment and must be monitored and evaluated. In order to do so, risk assessment matrixes are created according to ICAO’s Safety Management Manual (SMM), and the values will be translated into the ICAO Severity Scale (ICAO, 2012b) according to table 3 below. Due to the presence of a safe system, values above 4.5 on the scale will be rated in the 5 category.

Table 3 - ICAO severity scale to Samn-Perelli fatigue scale (ICAO, 2012b)

ICAO severity Scale	Descriptor	Samn-Perelli Scale
Insignificant	Fully alert, wide awake	1
	Very lively, responsive, but not at peak	2
Minor	Okay, somewhat fresh	3
	a little tired, less than fresh	4
Major	Moderately tired, let down	5
Hazardous	Extremely tired, very difficult to concentrate	6
Catastrophic	Completely exhausted, unable to function	7

The likelihood of the event will be based upon the number of occurrences for each Samn-Perelli value, adjusted from the ICAO Safety Management Manual (ICAO, 2012b). An equivalent percent of the values is assumed for this research as follows:

Table 4 - Likelihood table with assumed probabilities (ICAO, 2012b)

Likelihood	Meaning	Value	Percent
Frequent	Likely to occur many times (occurred frequently)	5	> 25%
Occasional	Likely to occur sometimes (occurred infrequently)	4	15 - 25%
Remote	Unlikely to occur, but possible (occurred rarely)	3	5 - 15%
Improbable	Very unlikely to occur (not known to have occurred)	2	1 - 5%
Extremely improbable	Almost inconceivable that the event will occur	1	< 1%

Using the principles and assumptions stated above it is possible to design a risk assessment matrix that reflects the position of the different fatigue levels, according to the percent of occurrence in the period examined versus its risk severity. With the matrix it is then possible to have a wider view of the safety status of a crew's operational schedule and anticipate arising hazards and its risks.

Table 5 - Fatigue values as predicted by SAFE model for year 2014

Samn-Perelli value	1	2	3	4	5	6
Percent	0 %	0 %	49.4 %	44.2 %	6.4 %	0 %

Table 6 - Risk Matrix with 2014 planned rosters

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

From the risk matrix above there is a good outcome for most fatigue levels as they are inside tolerable areas. But integrating risk and hazard mitigation into a highly dynamic operation requires a preventive look on the outcomes of increasing fatigue levels. Although further analysis is deemed necessary and will be carried out in the paragraphs bellow, it is

already possible to see that duties with level 4 or greater of fatigue can easily step one box to the left and enter into an intolerable region. Because the hazard's occurrence is already set at the maximum, the increase in probability will not have a big impact and the only path to transform this tolerable risk into an intolerable one is by increasing fatigue levels. That will be achieved if there is:

- Sleep loss: a factor that is impossible to control, but where the operator can provide crews with adequate training and trustworthy reporting systems, allowing a sleep deprived crew member to stay home;
- Extended wakefulness: that can be achieved through delays in daily operations and, despite the existing legal framework, duties up to fifteen hours can be achieved with long hours awake (i.e. a crew member with an early wake up due to its natural body regulation can work until unplanned long hours in the night).
- Circadian phase disruption: in this operator's particular schedule only existent in early duty starts. A study on regional pilots showed that regular bed times are around 00:00 with wake ups averaging 08:00, proving that starts up to the 08:00 to 09:00 time band can be a cause for sleep disruption and consequently fatigue (Deros, 2012);
- Workload: due to the operational environment found, workload in this operation can easily be seen as a major factor to increase fatigue levels. The amount of sectors combined with low duty times (thus small length flights) has been seen in recent studies as a link with fatigue, with increases in objective and subjective levels of fatigue (Belenky et al., n.d.; Powell et al., 2008; Van Dongen, 2015)

Table 7 bellow identifies how duties in the risk matrix above can suffer changes to its state and be positioned in areas that can be of higher risk in a safety context. By identifying the trigger, it is possible to preview consequences to a set of schedules and what will be their new risk level. As new risk and a higher level is not desirable nor acceptable, mitigation measures can be recommended to avoid it and to perhaps bring a hazard to an even lower risk position than before.

Table 7 - Hazard identification, consequent risk level increase and possible mitigations

Hazard	Consequences	Probable risk level	Mitigations
Reduced sleep	Lack of alertness due to a personal inability to manage adequate sleep (as reduced rests are generally not applied in the operation)	unknown	Adequate training and fatigue reporting policies together with scientific studies on crewmember's sleep habits
Flight delays + high sector count	Extended time awake, in particular when reporting on deep earlies. Levels of workload incompatible with a crewmember's actual performance capability	Major	Monitoring delays and long duties, as well as Captain's discretion. If needed, crewing policies can be put in place to avoid such events.
Cumulative sleep loss	Due to two or more days of any type of early duties, a cumulative sleep loss can arise from a wake up in the window of circadian low, thus leading to reduced performance.	Major to Hazardous	As there can be a trigger through big increases in fatigue levels from extended cumulative sleep loss or from repetitive scheduling of consecutive night duties, mitigations shall include planning practices that avoid scheduling more than one consecutive early duty.

5.2. Questionnaires and post-operational data: objective vs subjective data

5.2.1. Questionnaires

As a proactive measure, defined to try to identify arising hazards and limitations, questionnaires were distributed and filled in. A sample of 26 individuals responded and after the closing date the results were then introduced in SPSS. The sample was validated as representative through the one-sample t-test on age: $t(52)=29.462$; $t(26)=25.327$; $p<.005$; and on total flying hours: $t(52)=10.247$; $t(26)=10.709$; $p<.005$. A more in depth view of demographics and sleep habits should come out of this research instrument, complementing the results obtained from the fatigue scales and bio-mathematical models.

The first analyzed research method is the questionnaire. Despite mainly focused on reactive fatigue analysis, it can also be considered a very good proactive tool as it can identify possible issues that otherwise are not detected daily on the operation.

Validated from the NASA report on regional operations (NASA Ames Research Center, n.d.), this survey is divided into 4 different sections:

1. Demographics;
2. Sleep and sleep quality;
3. Daytime sleepiness and fatigue;
4. Stress

The analyzed sample can be described as follows:

- Average age of approx. 37 years old, with 50% of the respondents being below this age (figure 6), minimum age 26 years old and maximum 55 years old;
- Approx. 70% of married individuals with 6 single and only 2 divorced;
- 42,3% have no dependents, whilst the remaining are spread up to 3 dependents;
- High school education represents 50% of this sample, and from the other 50% only 1 has more than graduated studies;
- 30% are smokers;
- 85% practice exercise 1 and up to 3 times a week;
- 76,9% say they ingest caffeine daily at least once;
- The sample's diet is mostly healthy or typical Portuguese/Mediterranean.

5.2.2. Live study analysis

For a period of 3 weeks, and with the objective of comparing bio-mathematical modeling and subjective fatigue ratings, as well as measuring workload on an operational environment, a single double-sided paper sheet was handed out to pilots during their briefing, consisting of both Samn-Perelli fatigue scales (Samn & Perelli, 1982) and Karolinska sleepiness scales (Akerstedt & Gillberg, 1990). The Karolinska sleepiness scale was later decided not to be used for the purpose of this study. Data collected was analyzed through a 7 step methodology.

1. Identify total times for the period and their distributions

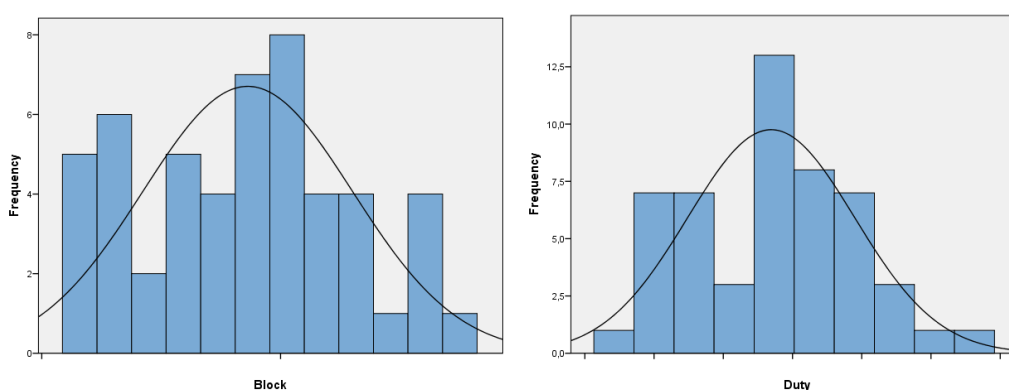


Figure 12 – Distribution of Block and duty time for February 2015

Table 8 - Average block and duty hours February 2015

	Average	Median	Minimum	Maximum
Duty	88:35 (+- 28:57)	88:00	27:09	159:31
Block	20:40 (+- 10:32)	22:00	02:05	42:03

The first point is to identify total working hours for the period and its distribution amongst the pilots for the period in study. Although we can see from figure 12 a lack of normal/regular distribution over block hours, consideration must be taken as there were a lot of individuals on leaves (annual, sick, parent, amongst others leaves). They correspond to the lower end of both graphs, and pilots with ground duties correspond to the upper end of the duty graph. Maximum block times performed are approximately 10 hours above the average for the monthly duty compared with the previous year analysis. Minimums are justified by the same reason as low duties. Despite this, there is a big variability amongst

pilots, with high standard deviations on both duty and block times. By looking at figure 12 we can see a more uneven distribution on the block hours side when comparing it with duty time that, although also disperse and uneven, is averaging more individuals closer to the middle.

The differences presented suggest that there can be significant alertness variations at sign-on time due to higher cumulative sleep debt and accumulated stress and tiredness on some individuals, and returns from prolonged off time in others. In a two crew operation this fact can be presented both as a safety net and a cause for concern. A safety net is in place if at least one of the pilots has had enough extended rest prior to its working day and is well rested. But as the number of crews reduces during leave periods, it can also be argued that both crew members can be on the top of block vs duty values and consequently with reduced rests, greater sleep deprivation and greater lack of alertness.

2. Segment the flights by reporting time

Table 9 – February 2015 Schedule structure

	Weight in total Operation	Sector count	Duty length	Rest time	Top previous day reporting
06:00 to 07:30	28,7 %	6	07:00	15:30	06:00 – 07:30
07:31 to 09:00	9,3 %	5	06:30	13:20	06:00 – 07:30
09:01 to 12:00	29,8 %	6	08:00	14:55	09:00 – 12:00
12:01 to 15:00	24,1 %	6	07:45	17:35	09:00 – 12:00
After 15:00	8,1 %	2	03:00	21:20	09:00 – 12:00

Table 9 segments the planned operation by time of day. The first conclusion is that, unlike the yearly roster analysis, there are no deep early start times in the trial period. Despite that, more than 25% of the scheduled start times are before 07:30 (28.7%), still on the early hours of the day. Most of the crew pairings are built to start on a time frame between 09:00 and 15:00, with the majority starting until 12:00 (29.8%). Only a small amount of flights start after 15:00, with the late afternoon shifts having high rest times with low duty length and sector count, and no previous planned circadian disruption. Duties between 07:30 and 09:00 weight only 9.3% of the schedules and are a compromise on sleeping times, requiring proper management so that the crewmember doesn't enter into a lack of alertness situation.

In figure 13 it is possible to have an overview of the number of flights (sectors) per working day, where most of the day's sector count is bigger than 4, as we can observe with the percentile distribution. This by itself is a sign of possible high workload, which is considered a major causal effect of fatigue.

Early hours of the day show that more than 50% of the flights comprised in this period have up to 8 sectors, with the earliest hours precluding up to 7 sectors. On the other hand, duties in the latter hours have low sector counts. As they do not enter in the hours of circadian sleep, they don't pose a significant threat to safety. Duties from 09:00 until 12:00, despite they are in the most acceptable time frame fatiguewise, have no sector counts bellow 4 and, with the right combination of factors, can also induce highly fatiguing work days.

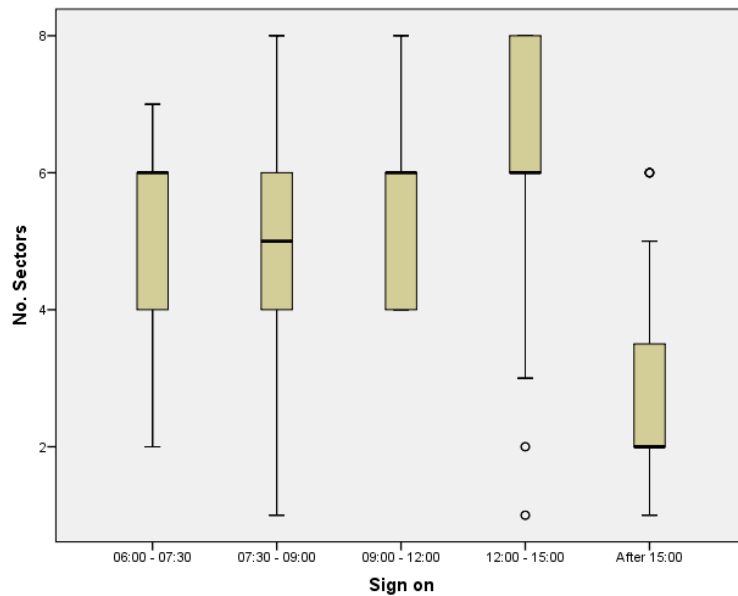


Figure 13 - Sign-on time vs number of sectors flown

3. Detail early morning, late finishes and night duties

As late finishes are not a factor in this operational context nor there is a regular operation that includes flying into the hours of darkness, with flights after 15:00 ending no later than 23:00, the focus on this point returns to the early shifts.

There are two main risk factors that should be taken in consideration: the sector count and the previous day reporting time (as detailed in the previous chapter). Averaging 6 sectors, the earliest period of the day encompasses values as low as 2 flights and as high as 7, well above the average flight count for a normal pairing in the aviation industry (usually not going above 4 flights a day per crew). Through figure 14 it is possible to have a view on pilot reported fatigue levels at different times of the day. Fatigue levels, their median values and percentiles don't go above 4 in most cases and stay below the assumed cutoff fatigue level. There is nevertheless a few causes for concern as there are some scattered high values throughout the high ranges of the graph. There is a high distribution on the days where pilots fly 5 sectors with start times until 07:30.

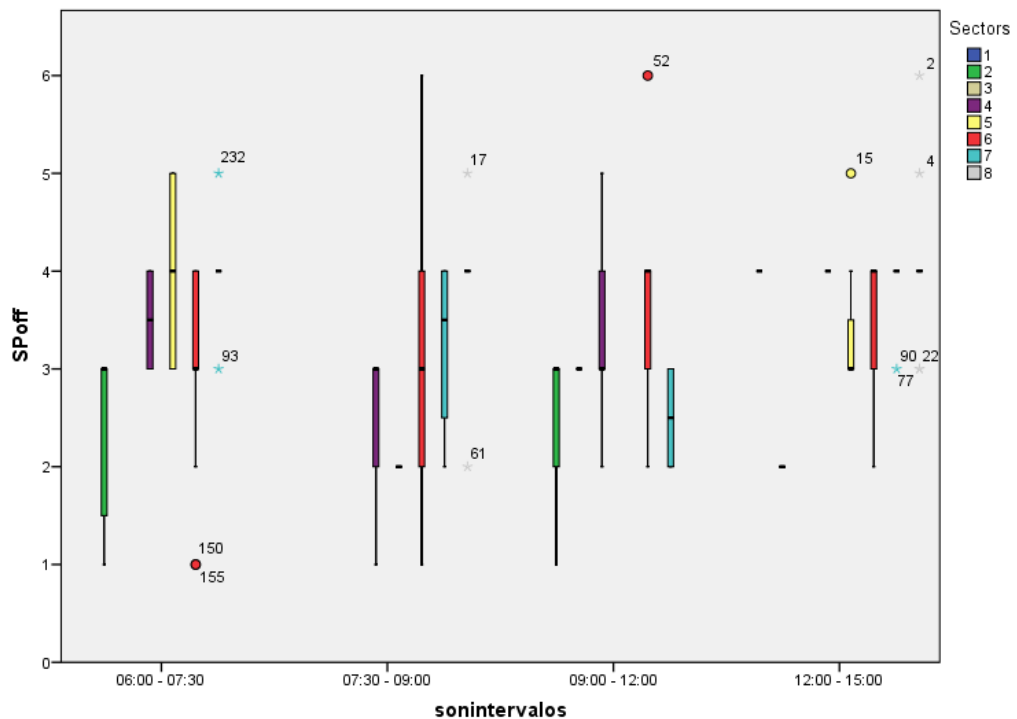


Figure 14 – Samn-Perelli reported at TOD (SPoff) per reporting time (sonintervalos) with number of sectors

The second risk factor is set by the sleep disturbances and accumulated sleep debt that can be associated closely with early morning flights. When looking at table 9, we can see that previous start times are mostly situated on the same time frame, the early hours of the day, where a wake up in or close to the lowest peak of the circadian rhythm represents disrupted sleep and very likely more than one night of reduced rest. In figure 15 we can see that the highest predicted fatigue values are situated in this time frame, thus proving the risk associated with early hours. Although with a lower weight on the overall numbers, duties between 07:30 and 09:00 are within a combination of high sector count, low duty time, the lowest rest times (close to minimum) and disruptive/early previous start times. As time of day wouldn't be the seldom factor to consider those shifts risky, the combination here established is one of high risk, that can induce a state of low alertness to a crewmember similar or even bigger than the one caused by a 06:00 start, in deep early hours.

Time on duty is mostly well managed, being higher for duties on the late hours of the morning, where a crew member should be well rested and Human performance should be is at its optimal.

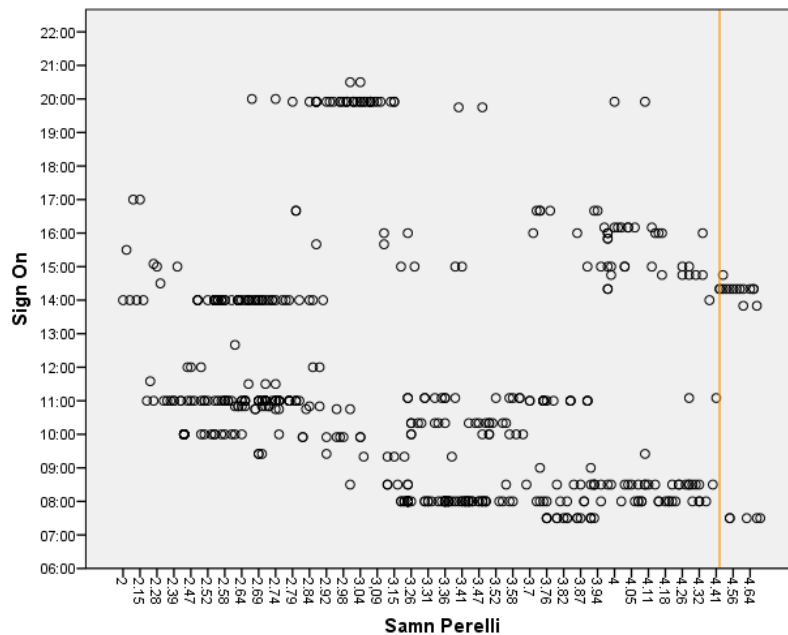


Figure 15 – SAFE predicted Samn-Perelli values for each reporting time (sign on)

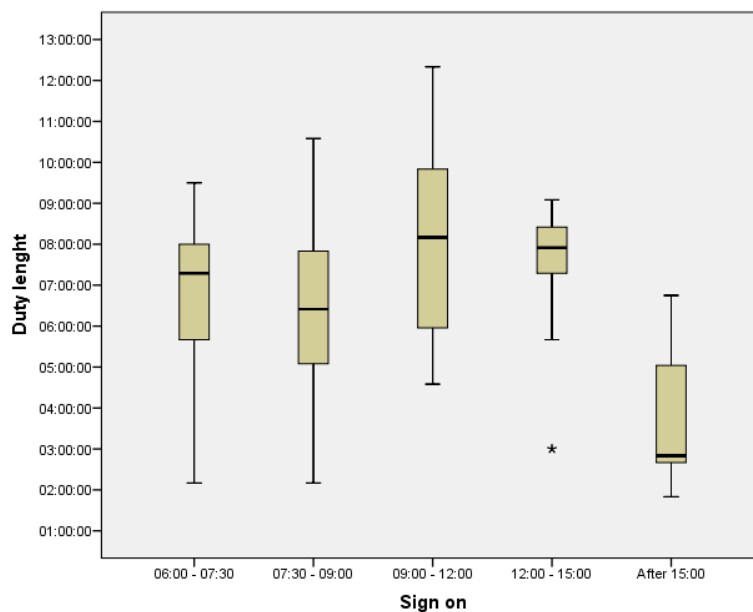


Figure 16 - Sign on times vs duty length

4. Build a risk matrix based on probability predicted by the model

From figure 15 we can have an overview of the fatigue levels predicted for each working day. During the period concerned, only a small amount of rosters are above the 4.5 cutoff on the Samn-Perelli scale. The 516 pairings analysed have the following distribution:

Table 10 - Fatigue values as predicted by SAFE model for February 2015

Samn-Perelli value	1	2	3	4	5	6
Percent	0 %	6.8 %	57 %	32.8 %	3.5 %	0 %

Table 11 - Risk Matrix for February 2015 - SAFE values from planned rosters

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

The risk matrix above is similar to the matrix generated by yearly rosters and shows that higher values of fatigue are situated on areas of either low probability or acceptable severity. Despite this, with a specific set of factors (i.e. weather, delays, technical failures) values can occasionally suffer major increments in the severity scale and there is a high likelihood of entering into non-acceptable levels of safety, demanding a thorough and frequent review by safety personnel.

Over the next three steps of this methodology, pilot's reported values will be looked at and a new matrix built so as to compare both modeled and subjective fatigue ratings, with an in depth analysis on workload. This will lead to a table of hazards in the last point, reviewing fatigue consequences and possible mitigations.

5. **Relation between predicted fatigue values and subjectively measured fatigue values (identifying differences)**

So far there has been a seldom focus on predicted and model computed values only. However, fatigue is a dynamic and personal state, and it is important to evaluate both data on daily operational settings and its comparison with predicted values.

Figure 17 encompasses fatigue reported by pilots and the variation between initial fatigue values and the ones reported at top of descend (TOD). All values correspond to the Samn-Perelli scale. From the 240 observations, minimums at both sign on and TOD are reported as 1. Maximums go as high as 5 for sign on and 6 for TOD, revealing an important cluster for concern and high risk.

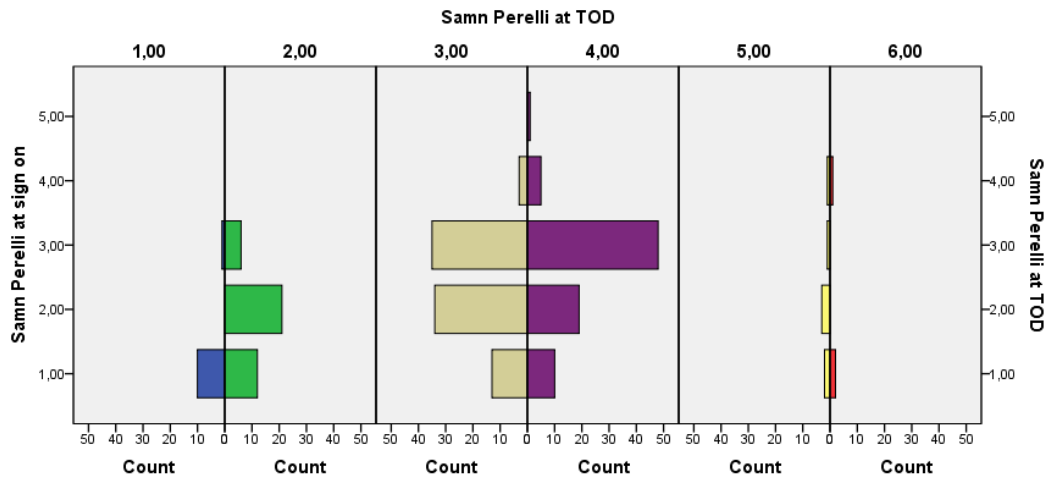


Figure 17 - Reported fatigue values at sign on and TOD

Sign on values average 2.26 on the fatigue scale and have a mode value of 3, with 56% of the pilots being at or below this value and 95% at or below 4. At TOD there is a similar set of values with a slightly higher average of 3.2 and a mode value of 4. Values of 3 or below were reported by 58% and 98% are within a level 4 on the fatigue scale. Eleven pilots reported a level higher than 4. Despite these can be considered acceptable values, from figure 17 we can observe that there is a visible increase by one level on fatigue values of 3. Fatigue reports of 4 tend to remain within the same value with only a few pilots reporting an increase to 5. There is also a cause for concern on fatigue levels of 1 that reported at TOD values of 5 and 6. As this is a big increase, it is also a drive for investigation. The

common factor to all individuals is their daily number of legs, with the lowest performing six flights in a work day and the highest eight. That increase also correlates to the highest increase in fatigue. Sign on times range from 07:30 up to 13:20, with duties up to 09h20 of duration.

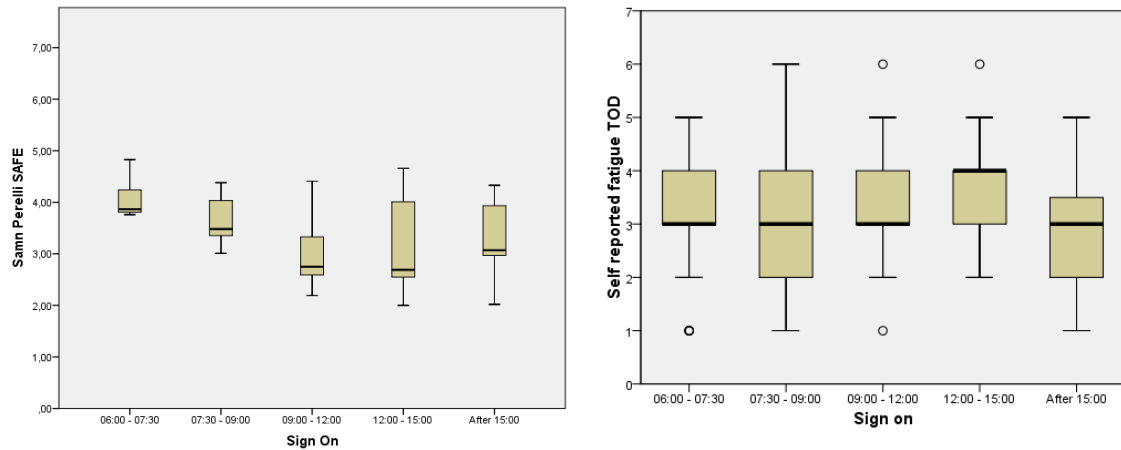


Figure 18 - Fatigue values by reporting time

With figure 18 and the table below (table 12), it is possible to compare both predicted model and reported values. Higher differences between both are marked by different colors in table 12, namely the ones that represent high risk values (high fatigue at one or both values). From there we can see that, although the central values are within the same average, minimum reported fatigue ranges from 1 to 3. Pilot reports represent the lowest values, on the early hours, against the higher values predicted by SAFE. The explanation might be based on individual biological clocks, proving that no two individuals are alike, and that variability should be taken into account as to optimize both safety and crew’s rosters. Questionnaires like Ostberg’s “morning-eveningness” or objective studies like the Performance Validation Test (PVT) or sleep measurement tools (i.e. wrist actimetry) can be used in further studies that enhance alertness and reduce fatigue (Horne & Ostberg, 1976; Thun et al., 2012).

Despite similar average and median values on the period ranging from 07:30 to 12:00, there is a big difference on maximums, with reported values by pilots up to 6 (extremely tired) against the 4.5 predicted. Individuals with such high levels of fatigue are in a position of major alertness deficits and the simplest of tasks can become a hazard that requires additional mitigation measures so as to avoid further consequences. This can also question algorithmic predictions and demonstrate that there is a need to carefully interpret generated results and not use them as the only source for fatigue management.

Table 12 - Model predicted values vs pilot reported values

Average / Median Minimum / Maximum	SAFE model	Pilot reports
Time frame		
06:00 – 07:30	4.1 / 3.86 3.76 / 4.83	3.30 / 3.00 1 / 5
07:30 – 09:00	3.65 / 3.48 3 / 4.38	2.98 / 3.00 1 / 6
09:00 – 12:00	2.9 / 2.75 2.19 / 4.41	3.38 / 3.00 1 / 6
12:00 – 15:00	3.2 / 2.7 2 / 4.6	3.61 / 4.00 2 / 6
After 15:00	3.3 / 3 2 / 4.3	2.87 / 3.00 1 / 5

6. Build a new risk matrix on measured values

The distribution on table 13 was calculated from the values reported in the diaries and represent the weight of fatigue ratings at TOD on each diary, as assumed the worst case scenario.

Table 13 - Fatigue values as reported by pilots for February 2015

Samn-Perelli value	1	2	3	4	5	6
Percent	4.7 %	16.9%	36.4 %	37.3 %	3.4 %	1.3 %

The inputs were then made to the risk matrix following the method established on 5.1.2.

Table 14 - Risk Matrix for February 2015 with pilot reported values

Risk Probability	Risk Severity				
	Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent 5				3 / 4	
Occasional 4					2
Remote 3					
Improbable 2		6	5		1
Extremely improbable 1					

By comparing the risk matrix above with the one created for in chapter five, it is possible to see the added values on levels 1 and 6, and an increase in the probability of level 2. Levels 1 and 2 do not represent a significant cause for concern. Level 6 is considered a hazardous situation and although still acceptable, it should be reduced to a lower probability. As seen before, level 6 fatigue values correspond to reports between 07:30 and 15:00. This correspond to days of six to eight sectors and a big increase in fatigue, with initial subjective values set as low as 1.

7. Relate fatigue values with TLX measured workload

The heat map created by SPSS (figure 19) reflects, for each reported fatigue value at sign on, its difference to the TOD point, i.e. in an 8 sector day there is an average increase of 3 points in the fatigue scale. The biggest differences are situated on five, seven and eight sectors a day. Schedules of four sectors and above show a general increase in fatigue, even if there is only a one level increase, whilst some days of two sectors show an actual, unexplained decrease in fatigue, with no relation to other factors in this research.

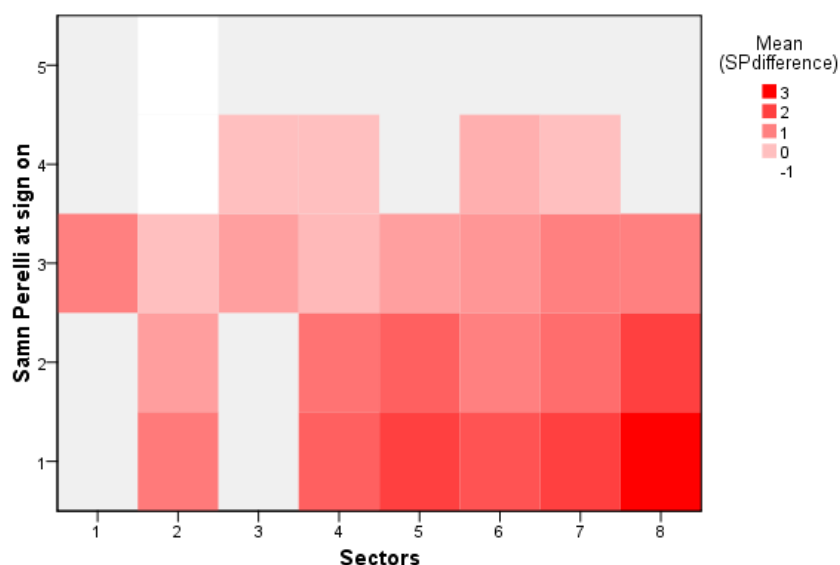


Figure 19 - 'Heat map' correlating fatigue level differences

Despite the differences shown in figure 20, it is possible to observe the distribution and correlation on task load with the number of sectors flown and reporting time. There is a big range of workload values for each similar working day, proving variability and subjectivity on alertness and each individual's capacity to cope with different tasks and task levels. It is also clear an increase in median task load index values as the number of sectors increases, with an increase in percentile distribution. Values in the two sector days are as low as 60s, and go as high as 80 to 90 on the eight sector days. Exception is made on the few one and three sector days showing high workload count. There is a decrease in the values of the six sector day, mainly as this type of shift has later reporting times. By observing figure 20, workload increases in a similar approximate rate as the hours of the day, although the same relation is not present between the number of sectors and workload variations. Days after 09:00 and particularly after 15:00 tend to reveal the highest workload values, despite of the lowest sector count and duty duration.

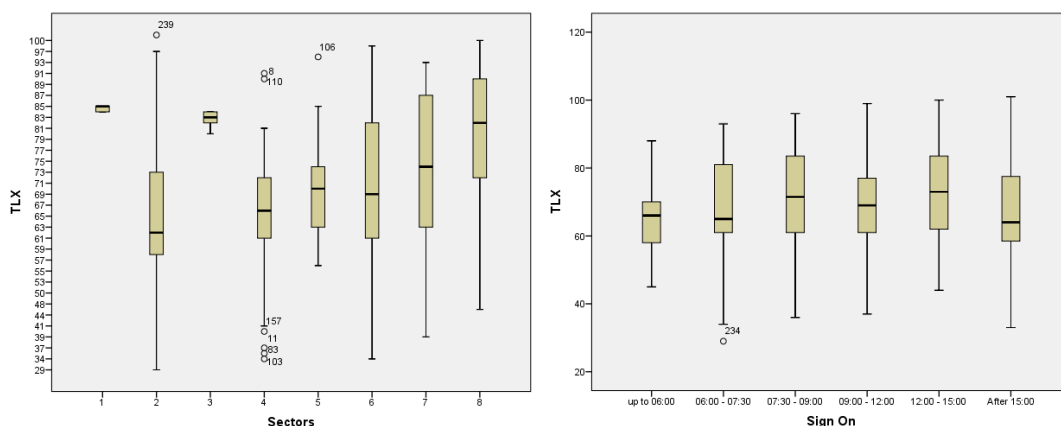


Figure 20 - TLX values vs sign on and number of sectors

8. Predict possible hazards liable of increasing risk levels

As workload has been identified as a main cause and concern together with early days and some specific factor combinations (i.e. short early duties with 6 sectors), the table bellow, based on the factors presented in some studies (Bourgeois-Bougrine, Cabon, Mollard, Coblenz, & Speyer, 2003; CAA, 2005; Co et al., 1999) aims at targeting some of the hazards arising from the lack of alertness, helping on the role of mitigating fatigue associated risks to acceptable levels of safety. The classification of the hazard's cause is the one according to ICAO's definition of fatigue presented in chapter 1 (ICAO, 2012a):

- Sleep loss;
- Extended wakefulness;
- Circadian phase;
- Workload;

and the risk level increase classified as 'low', 'medium', 'hazardous', 'catastrophic' as the risk tables in the previous chapters.

Table 15 - Possible hazards, their description and mitigations

Hazard	Cause	Risk level	Description (D) and mitigations (M)
LONG DUTY DAY / DELAYS	Extended Wakefulness	Hazardous	<p>D: As there is a high number of duty days with high sector counts, this hazard becomes hazardous due to the increase in workload arising from such days.</p> <p>M: Crewing department can be setup with a bio-mathematical model as an aid tool and additional policies can be put in place when some combinations take place in a crew member's day</p>
ROSTER DISRUPTION	Extended Wakefulness Circadian phase	Low	<p>D: This is considered an hazard mostly because of day-night shifts and early days not booked sufficiently ahead on a set schedule</p> <p>M: As there are no night flights, additional care should be taken when rebooking a schedule with an early start, in particular if it is a deep early day.</p>
LONG TERM FATIGUE	Sleep loss	Hazardous	<p>D: Long term fatigue can be a serious issue, involving both physical and psychological disorders that need proper medical care. When not looked after, long term sleep loss can become a very serious performance impairment hazard.</p> <p>M: To train crewmembers to know themselves and to support them in case any assistance is required.</p>
EARLY START	Circadian phase	Medium	<p>D: Early starts tend to wake the individual in the lowest period of the circadian rythm, disturbing the optimal window of sleep.</p> <p>M: As early starts are part of a commercial airline operation, careful planning should be made with regards to the number of sectors and the rest permitted before such hours of work.</p>

HEALTH	Sleep loss	Low	<p>D: An unhealthy life style can lead to low sleep quality and difficulties in falling asleep.</p> <p>M: After the questionnaire results, it was easy to perceive that crews have somewhat healthy and good life styles posing at the moment a low threat. This should be closely monitored as changes can have repercussions in this risk level</p>
ADDITIONAL NON-FLYING TASKS	<p>Extended Wakefulness</p> <p>Workload</p> <p>Sleep loss</p>	Low	<p>D: Some crews may perform other duties, either office related in the airline or other professional affairs outside the airline. This might represent extended work periods and stressors and affect both sleep quantity and quality as well as the amount of work a particular individual is subjected daily.</p> <p>M: When questioned, there weren't a lot of individuals with such duties, although there wasn't in this study an analysis of pilots with office duties. It should rest on each individual their own capability to manage stress and rest so as to be fit to fly. Close monitoring should be maintained for this item with future studies on such tasks.</p>
DIFFICULT FLIGHT / BAD WEATHER / TECHNICAL FAULT	Workload	Hazardous	<p>D: Difficult flights, with disruptions of all kinds can greatly increase workload to a point where it becomes too much for the operator to handle. In this particular operation, bad weather is a concern for analysis as there are days with severe bad weather that can exhaust the individual and lead to high performance impairments</p> <p>M: The amount and type of flights that can be considered more difficult can be analyzed either by a separate independent study or just by the analysis of fatigue report forms. In severe bad weather days, considerations should be made as crews should be swapped when back at home base or even augmented if the previous is not possible.</p>

<p>CONSECUTIVE EARLY STARTS</p>	<p>Circadian phase Sleep loss</p>	<p>Hazardous</p>	<p>D: As early starts are situated in the optimum window of sleep, consecutive early starts can lead to accumulated sleep loss and severe circadian disruption.</p> <p>M: To put in place measures that limit, monitor and assess rosters and early starts and to take action in case this becomes too frequent as a scheduling practice.</p>
<p>ADAPTING BETWEEN EARLY AND LATE DUTIES</p>	<p>Circadian phase</p>	<p>Medium</p>	<p>D: Unlike a transition from early to late duties, shifting from late to early duties can be hard to the Human body to adapt, as circadian rhythms deal well with forward adaptation but not the other way around.</p> <p>M: Schedules should be planned as to avoid such transitions and when there is a need for it, additional rest should be put in place. Training can also help by teaching how to adapt sleep and daily routines to such transitions.</p>

6. Discussion

The study object is a regional aircraft operator that due to its very specific route structure incorporates a high percentage of very short flights (under 1h) in a challenging and demanding environment. The universe involved is constituted by 52 airline pilots, Captains and First Officers, where the study sample is equal to the universe. Their average age is 39.2 years old and more than 50% have less than 5000 flight hours. With such a young aged population, the first conclusion is that age related factors must be closely monitored. Age has been proved to be an influence in sleep and alertness and periodic studies should evaluate detriments arising from it (Majumdar, Wu, Subotic, Stewart, & Holmes, 2009).

The research continued with data collection tools that could suit both the analysis of planned airline schedules and of pilot reports through a fatigue survey. A questionnaire was digitally handed out to all individuals where responses were obtained from 26 pilots that have no significant age and experience differences from the study population, representing it and from where conclusions can be drawn. The questionnaires objective was to measure individual factors of influence, as fatigue is a subjective state, revealing in this case a very homogenous and similar set of individuals, with very little variations in the results obtained and no significant sleep disturbances. The only variable that as identified as being worthy of concern is that 50% of the individuals have up to 3 dependents. This is a factor that can influence sleep and workload on mundane day-to-day tasks and contribute to extended periods of sleep deprivation.

As there was no previous fatigue risk analysis in this particular operator, the next step was to obtain fatigue values from last year's planned schedules through the SAFE bio mathematical model. This created both controlling values for the proposed methodology and allowed a broader overview on crew members work shifts. Samn-Perelli scale values, obtained as an output from the SAFE model, where segmented by reporting time and further analysis carried out according to this. Results showed evidence of high fatiguing days on the very early hours of the morning, with duties starting up to 07h30 representing approx. 25% of the operation and fatigue values above 4 (a little tired, less than fresh) and up to almost 5 (moderately tired, let down) being frequent in more than 25% of the analyzed patterns. There was also a high relation between such days and the number of sectors flown.

With the benchmark on planned schedules completed and some references established, there was a need for an organized, methodic evaluation of fatigue, its related hazards and risks in a live operational environment, where the variability and subjectivity of differences between Humans and a model could be evidenced, as powerful as the last one may be. For this, a simple daily form was distributed to all flying pilots and its resulting data analyzed through a framework. Being an analysis framework, it was designed for a more organized overview of the focus points, weaknesses and strengths and consisted of eight steps, from fatigue identification and measurement to risk mapping, hazard control and prediction:

1. Identify total times for the period and their distributions;
2. Segment the flights by reporting time;
3. Detail early morning, late finishes and night duties;
4. Build a risk matrix based on probability predicted by the model;
5. Relate predicted fatigue values with subjectively measured fatigue values (identifying differences);
6. Build a new risk matrix on measured values;
7. Relate fatigue values with TLX measured workload;
8. Predict possible hazards liable of increasing risk levels.

Graphs and statistical values were produced in step 1 to assess disparities between crew members on their working rosters. Average and median values obtained are similar but as graph dispersion is very scattered it can be assumed that there is an unequal distribution of work along the study period with a very disperse pattern. Although this will present a much lower risk to a big group of pilots in the lower hours, it also places the group of individuals with the biggest amount of hours in a potentially hazardous situation. They will present increased values of accumulated sleep debt and a greater lack of alertness. After knowing average working values and distribution for a set period, in points 2 and 3 flights were distributed so as to divide and segment them, reducing the viewing spectrum and analyzing how work is distributed on a daily basis. It was here found that in the very early hours of the morning, that represent one quarter of the total duties reviewed, there is a combination in manageable fatigue levels. This can surpass acceptable levels of safety with very little disruption and be worsened with specific combinations as early start plus high sector count and low duty time. Early starts strongly affect the ability to sleep and its quality, and legal regulations allow morning duties at least 3 to 4 more hours without further

permissions so extended wakefulness can be added to circadian disruption and workload, creating a dangerous alertness state to the individual.

In point 4 the ICAO risk matrix was applied to the data set with duties processed by SAFE. There were no major risks found other than the previously stated combinations in the early mornings. Sets of duties that represent higher risk severity are well inside the acceptable areas.

Data from pilot reports was overviewed in point 5. This was made having into consideration the bio mathematical model values. The results were set by two comparisons: the one between the model and the value reported at TOD and the other one between pilot reports at the beginning and the end of the working day, that is, between a prediction and a real felt value, and between two important reference points. Both comparisons revealed relevant results. The first one evidenced differences between what was felt and predicted. As models never went above values of 5, pilot reported fatigue was greatly up to the hazardous level 6. There was also a difference on the start of the day values, with some pilots reporting they were better rested than the model previewed, proving individual complexity and variability. The second comparison took the analysis deeper to find a common effect between the high fatigue increases. In most individuals this was a consequence of the number of sectors flown in a single day and lead to chapter seven further ahead in the method.

The next step taken was, as on point 4, to plot the reported values on the risk matrix by severity vs probability. Results are very similar, with new low and high values. The conclusions here drawn are similar to the ones as above, differing with the presence in this table of the hazardous ‘extremely tired, very difficult to concentrate’ fatigue value of 6. Although improbable, this requires proper management and a good solid definition of what is acceptable in such high fatigue, due to the very low levels of alertness and possible compromise to safety.

Most fatigue causes have been approached. But bearing in mind this airline’s very specific operation (short flights) and with legal regulations allowing pilots to work more than four sectors each day, workload can be a consequence and is a very significant causal factor. As seen on the literature review, workload can be defined as the capability of the Human to perform a given task with its own limited resources (the rate at which the ‘alertness reservoir’ empties out). When the resource level becomes low, alertness tends to decrease

together with the increase in fatigue. Take-offs and landings are high resource situations that require concentration (mental workload) and high physical capability, especially in challenging environments and bad weather situations. The workload analysis performed was based on the NASA TLX method that, although simplified, proved to be a good quick tool for the needs of this study. It revealed high differences between the start and the end of the day, linking it to previously reported fatigue and allowing to draw the conclusion that workload does affect flight operations when flying more than six flights a day. High workload values were found also on two sector days, with no other apparent than the early reporting times up to 07:30 in the morning. From this it is possible to conclude that two factors impact workload values: high number of flights on a single day and early start times.

Based on the results, literature review and this airline’s specific operation the last item on the methodology guarantees that a number of main safety problems are mitigated. A list was created with some hazards, but they are not exclusive of other possible problems detected nor will it be possible to control every item by the safety teams. Acceptable levels of safety need to be the target but they also need to be realistic and plausible. This table is an overview of ‘worst case scenarios’ and should not represent the daily operation’s hazards: they should be exceptional. If they do become the trend, safety levels should be reviewed with due diligence. The table defines the specific hazard and its origin from ICAO’s fatigue definition and sets the highest risk level that can be reached defining each hazard together with a possible individual mitigation strategy. Other mitigations are also correct and can be pursued.

7. Recommendations

Having into account the results discussed in the previous chapter, the following recommendations can be issued:

- ⇒ A proper overview and control should be maintained in the groups that have higher duty and block hours on specific periods and throughout the year as to maintain them in an acceptable level of safety and capable of dealing with the risks on the daily basis, in particular the ones known but where its occurrence cannot be predicted in time.
- ⇒ Early hours of the morning need to be monitored by the safety teams for their dangers of circadian disruption and extended wakefulness. Workload needs to be carefully adjusted according to the type of operation performed, length of the day and weather season. This group of variables also needs a further in depth study to further enhance the understanding on how they work together, how they influence each other and how to deal with them.
- ⇒ Duties set as ‘a little tired, less than fresh’, or a level 4 in the Samn-Perelli fatigue scale can escalate to higher levels of fatigue, as proven by the individually collected data. Performance indicators that monitor this increase should be put in place (i.e. how often it occurs, what were the consequences and what could have been the outcome) to guarantee that their recurrence probability remains below remote and acceptable under the Safety management terms.
- ⇒ Further validation should be done of the simplified NASA TLX method used, as a tool to quickly and practically measure workload in flight. That would allow it to be present in simpler and broader workload studies of multi-segment operations.
- ⇒ A wider, year-round study should be performed to have into consideration operational, weather and other related issues as well as the differences between the winter schedules and the tighter and denser summer schedules. This study should also consider an actigraphy measurement to collect and obtain objective sleep in aircrews and identify disturbances, thus further validating the results.

- ⇒ Bio mathematical models should have into consideration this type of operations (multi-segment) and be reviewed to accommodate the nefarious effects of high workload situations in the smaller regional operators.

8. Conclusion

Fatigue is a big scourge to flight safety and flight operations, with a big impact on individual performance. The risks associated with lack of alertness, particularly in today's busy optimized airline schedules can represent hazards that jeopardize and compromise what is considered as an acceptable level of safety to many. This study aimed at starting a method on the identification of such hazards, by measuring fatigue through subjective and objective tools in both pre and live operational contexts.

The start point was the literature review, where we found that fatigue is still a very relative concept although some of its definitions have been commonly accepted by most stakeholders. Most of the studies that approached this subject study long-haul routes and medium-haul operations, where the first ones were created for ultra-long haul routes and most thereafter followed this line of thought. Very few studies have embraced the problematic of smaller regional operators that fly short and very particular routes. Some studies and papers noted the link between safety and fatigue, demonstrating that in aviation they are two concepts that cannot be dissociated. There is a lack of studies and papers in the real effect of workload in aviation, with the existing information focused mostly on transportation means other than airplanes. Despite it all, the studies above helped out in the development of sustainable and reliable bio-mathematical models, helping the job of fatigue investigators and managers in the analysis of schedules and fatigue related incidents and accidents. They are also a complement to the regulations that will shortly be mandatory on the task of assessing fatigue related hazards. With the new regulations, operators will have the chance to pursue EASAs objective on performance based regulations and, after setting a solid Fatigue Risk Management structure (or system) they will be able to create their own flight time limits, rules and regulations.

The methodology chosen was a study on individual variability, a schedule analysis with planned values and computer generated fatigue levels, and a live study where pilots could report their own, felt fatigue levels as well as workload. The universe was found to be of a very young age, representing both advantages and a good lead for further studies on the long run. Results showed higher levels of fatigue in schedules flown in the early hours of the morning and also in schedules with more than 4 to 5 flights per day. There was also a combination that was found to be a trigger for higher levels of fatigue, when putting together early starts with shorter days and higher flight numbers. Evidence of a direct relation between workload and fatigue was also found and confirmed by pilot reported values, with

fatigue reports going below and above the predicted ones by the bio mathematical model. The risk matrixes, produced according to ICAO's manuals allowed a systematization of the analysis of fatigue through a tool that quickly could produce an overview to safety managers and all of the concerned staff. The overview of the risk matrixes showed that high 'hazardous' values of fatigue can and should be a concern to safety departments and reason enough for further developments and studies to monitor and mitigate them. The limitations found were mostly related to time: the short period of the study and the time frame where it took place yearly wise.

There were a number of limitations in this study:

- The operational situation in this particular airline tends to change with IATA's flight seasons and is usually busier during the summer period. As the study was done during a winter month, flight schedules were milder and could impact the results on accumulated fatigue effects;
- The study was performed during a very limited amount of time and while it is possible in the time analyzed to detect fatigue issues, it is very difficult to conclude if they will pose a greater risk and impact safety in the long haul.
- The lack of studies in the area of workload related fatigue and regional airline operations created a barrier in finding studies and study models to apply in this particular case. As such, studies generally used for major carriers that suffer from jet lag and circadian disruption had to be used and adapted.
- As there was no continuous presence of the investigator on site, it was impossible to guarantee the correct distribution and control of the questionnaires and diaries. By delegating this job to the competent airline management and operational staff, an assumption of confidence was made as to the results would be valid and reliable.

In the end it can be said that there is a need to further study the effects of workload in pilots and how it impacts alertness, safety and in the end fatigue. It is also needed to approach fatigue as the issue it is in flight operations nowadays. Fatigue and its related matters need to be an integral part of an Airline's culture and not only a regulatory requirement, and Safety departments together with aviation Authorities should strive for this change in the near future.

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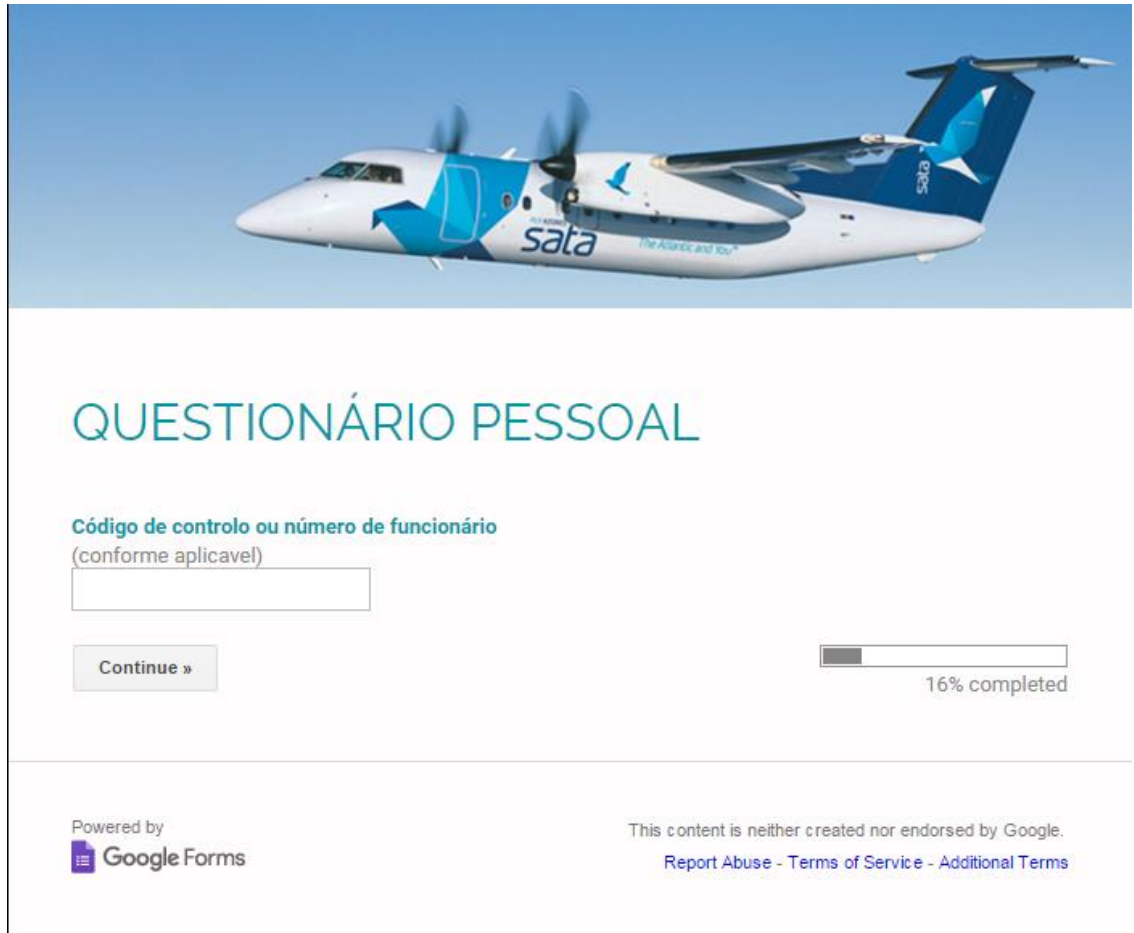
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Annexes

Annex I – Questionnaire

The following questionnaire was distributed and made available to all of the airline’s pilots through a google forms link.




QUESTIONÁRIO PESSOAL

C digo de controlo ou n mero de funcion rio
(conforme aplicavel)

Continue »

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QUESTION RIO PESSOAL

Idade

Estado Civil

Dependentes a cargo

Escolaridade

Horas de voo (aproximadas)

Onde costuma passar as suas folgas?

- Ilha de S o Miguel
- Outra Ilha no Arquip lago dos A ores
- Arquip lago da Madeira
- Portugal Continental
- Other:

Tem alguma outra actividade profissional para al m de Piloto de Linha A rea?

- Sim
- N o

  fumador?

- Sim
- N o

Com que frequ ncia toma bebidas alcoolicas no seu tempo livre?

- Nunca
- Socialmente
- 2 a 3 vezes por semana
- 1 a 2 vezes por dia
- Mais de 2 vezes por dia

Pratica exercicio fisico?

- Raramente ou nunca
- 1 a 2 vezes por semana
- 3 a 4 vezes por semana
- Di riamente

Toma diariamente bebidas com cafe na?

- Sim
- N o

Como caracterizaria a sua dieta?

- 'Fast Food'
- T pica Portuguesa
- Saudavel

Qual a sua hora normal de deitar?

(assuma que n o tem restri es no despertar)

--:--

Example: 11:00 AM

Costuma ter dificuldade em adormecer?

- Sim
 N o

Quanto tempo ap s deitar demora normalmente a adormecer?

(em minutos)

Quais das actividades abaixo executa quando est  na cama?

- Ver Tv
 Ler
 Conversar com o/a parceiro/a
 Escrever
 Comer
 Pensar nos problemas do dia
 Other:

Toma regularmente algum tipo de medica o para adormecer?

- Sim
 N o

Durante o sono:

	Raramente/Nunca	Ocasionalmente	Frequentemente
Costuma acordar e ter dificuldade em voltar a adormecer?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sofre de sonambulismo?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Verifica o rel�gio frequentemente?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Tem pesadelos?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Range os dentes?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fala?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ronca?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sofre de apneia do sono?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Sofre de alguma outra patologia do sono diagnosticada?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

A que horas costuma acordar?

(assumindo que acorda espontaneamente)

--:--

Example: 11:00 AM

Nos dias de trabalho, dorme em m dia quantas horas por noite?

E nos dias de folga, quantas horas dorme em m dia por noite?

Costuma despertar com:

	Raramente/Nunca	Ocasionalmente	Frequentemente
dores de cabe�a?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
confuso ou desorientado?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
cansado?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

O sono   frequentemente perturbado?

(escolha n o ou a(s) op oes v lidas)

- N o
- Sinusite ou constipa  o
- Desconforto nas pernas
- Falta de ar ou sensa  o de sufoco
- Sonhos agitados ou pesadelos
- Necessidade de urinar
- Indigest o
- Dor
- Fome
- Pessoa com quem dorme
- Animais
- Asma
- Tosse
- Crian as
- Sede
- Barulho
- Stress
- Other:

Qual o impacto em rela  o a um periodo de assist ncia de manh  no seu sono:

1 2 3 4 5

Acordo frequentemente Sem impacto

Quantas horas deveria dormir por dia para se sentir no seu melhor?

Em rela  o a servi o de voo, em que periodo do dia sente que deveria ser a hora de apresenta  o para a sua performance individual m xima?

- Antes das 07h00
- Entre as 07h00 e as 09h00
- Entre as 09h00 e as 12h00
- Entre as 12h00 e as 15h00
- Ap s as 15h00

Sente sonol ncia durante o dia?

- Raramente/Nunca
- Ocasionalmente
- Frequentemente

Acha que a fadiga   uma ocorr ncia recorrente em opera  es de voo?

- Sim
 N o

Na sua opini o, em que medida acha que a fadiga   um grande flagelo em opera  es de transporte a reo regional?

1 2 3 4 5

N o   factor Muito grave

Quando uma situa  o de fadiga ocorre, qu o grande acha que   o risco de 'safety' a ela associado?

1 2 3 4 5

Muito baixo Muito elevado

Em que medida acha que a fadiga afecta a sua performance em voo?

1 2 3 4 5

Nada Muito

Com que frequ ncia acha que adormece inadvertidamente em voo?

0 1 2 3 4 5

Nunca Frequentemente

Quando lhe   mais dif cil manter o estado de alerta?

- Descolagem
 Aproxima  o/aterragem
 Indiferente

Como mantem o estado de alerta quando se sente fatigado?

- Caf  / bebidas cafe nadas
 Conversando
 Lendo
 Outras actividades
 Eu nunca fico fatigado
 Other:

Costuma organizar tempo de descanso durante o voo?

0 1 2 3 4 5

Nunca Frequentemente

Acha que o Acordo de empresa em vigor altera e/ou melhora os n veis de fadiga do seu operador?

0 1 2 3 4 5

Indiferente Grandes altera  es

Em que medida acha que os seguintes factores influenciam o seu n vel di rio de fadiga e que podem levar ao seu aumento?

| 0. NADA | 1. MUITO POUCO | 2. POUCO | 3. ELEVADO | 4. MUITO ELEVADO

	0	1	2	3	4
Turbul�ncia ligeira	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Turbul�ncia moderada / severa	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ventos fortes em pelo menos 1 das aterragens	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Intera�o com os passageiros	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mais de 2 voos num dia	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Entre 3 a 6 voos num dia	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Mais de 6 voos num dia	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Voar sem piloto autom�tico	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Praticas de planeamento e escalas da empresa	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Vibra�o do avio�	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Falta de alimenta�o adequada	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Desidrata�o	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Itera�o com colegas de trabalho	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ru�do	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Alguma vez n o foi trabalhar por se sentir demasiado cansado ou n o achar estar no seu melhor estado de alerta?

- Sim
- N o

Nas quest es abaixo dever  responder o n mero de vezes que se sentiu ou pensou dessa mesma forma, sendo:

0 = NUNCA | 1 = QUASE NUNCA | 2 = ALGUMAS VEZES | 3 = FREQUENTEMENTE | 4= MUITO FREQUENTEMENTE

	0	1	2	3	4
Quantas vezes ficou chateado por algo que aconteceu de forma inesperada?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes achou que n�o conseguia controlar elementos importantes da sua vida?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes se sentiu nervoso e "stressado"?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes se sentiu confiante na sua capacidade de gerir os seus problemas pessoais?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes sentiu que as coisas lhe corriam bem para si?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes achou que n�o conseguia lidar com tudo o que tinha para fazer?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes conseguiu controlar momentos mais propensos a situa�es nervosas?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes sentiu que tinha dom�nio das suas actividades?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes ficou irritado e chateado por algo que ficou fora do seu controlo?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Quantas vezes sentiu que as dificuldades se acumulavam tanto que n�o as conseguia superar?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Annex II – Diaries

The diaries were handed out with the pilot’s briefing on the beginning of the working day.

REGISTO DI ARIO

O question rio abaixo dever  ser preenchido no in cio e final do per odo de servi o de voo. Todos os dados ser o tratados de forma an nima.

A PREENCHER NO MOMENTO DA APRESENTA O COM O BRIEFING

Hora de Apresenta o _____ H _____ Comandante

C digo de controlo ou n mero de funcion rio _____ Oficial Piloto

Assinale com uma cruz nos n meros o que mais se aproxima ao seu estado actual nas seguintes tabelas:

1	Extremamente Alerta
2	Muito Alerta
3	Alerta
4	Mais ou menos alerta
5	Nem alerta, nem sonolento
6	Com um pouco de sono
7	Com sono, mas consigo ficar acordado
8	Com sono, fazendo algum esfor�o para me manter acordado
9	Muito sonolento, lutando contra o sono

1	Completamente alerta, muito desperto
2	Muito ativo, mas n�o no meu m�ximo
3	Estou bem, sinto-me activo
4	Um pouco cansado e pouco activo
5	Moderadamente cansado, tenho dificuldade em manter-me ativo
6	Extremamente cansado, tenho muita dificuldade em concentrar-me
7	Completamente exausto, n�o sou capaz de funcionar

Votos de bons voos

Preencher verso no final do dia



A PREENCHER NO MOMENTO DE CONCLUS O DO PERIODO DE TRABALHO DI ARIO

Hora de 'sign/off' _____ H _____ N  de sectores voados _____

Assinale com uma cruz nos n meros o que mais se aproxima ao seu estado actual nas seguintes tabelas:

1	Extremamente Alerta
2	Muito Alerta
3	Alerta
4	Mais ou menos alerta
5	Nem alerta, nem sonolento
6	Com um pouco de sono
7	Com sono, mas consigo ficar acordado
8	Com sono, fazendo algum esfor�o para me manter acordado
9	Muito sonolento, lutando contra o sono

1	Completamente alerta, muito desperto
2	Muito ativo, mas n�o no meu m�ximo
3	Estou bem, sinto-me activo
4	Um pouco cansado e pouco activo
5	Moderadamente cansado, tenho dificuldade em manter-me ativo
6	Extremamente cansado, tenho muita dificuldade em concentrar-me
7	Completamente exausto, n�o sou capaz de funcionar

Assinale com uma cruz o que mais se aproxima ao periodo de trabalho de hoje nas seguintes linhas:

<p>Mental Demand How mentally demanding was the task?</p> <p>Very Low Very High</p>	<p>Performance How successful were you in accomplishing what you were asked to do?</p> <p>Perfect Failure</p>
<p>Physical Demand How physically demanding was the task?</p> <p>Very Low Very High</p>	<p>Effort How hard did you have to work to accomplish your level of performance?</p> <p>Very Low Very High</p>
<p>Temporal Demand How hurried or rushed was the pace of the task?</p> <p>Very Low Very High</p>	<p>Frustration How insecure, discouraged, irritated, stressed, and annoyed were you?</p> <p>Very Low Very High</p>

Em rela o aos voos de hoje:

Condi es meteo adversas? SIM N O

Algun factor adicional de stress ou workload? SIM N O

Se sim, qual? _____

Houve lugar a descanso a bordo? SIM N O

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Annex III – Likelihood and Severity tables

From ICAO's Doc. 9966

Table 4-2a Defining fatigue risk probability

Fatigue risk probability		
	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

Table 4-2b Defining fatigue risk severity

Fatigue risk severity		
	Meaning	Value
Catastrophic	<ul style="list-style-type: none"> – Multiple deaths – Equipment destroyed 	A
Hazardous	<ul style="list-style-type: none"> – A large reduction in safety margins, physical distress or a workload such that crew members cannot be relied upon to perform their tasks accurately or completely – Serious injury – Major equipment damage 	B
Major	<ul style="list-style-type: none"> – A significant reduction in safety margins, a reduction in the ability of crew members to cope with adverse operating conditions as a result of increase in workload or as a result of conditions impairing their efficiency – Serious incident – Injury to persons 	C
Minor	<ul style="list-style-type: none"> – Nuisance – Operating limitations – Use of emergency procedures – Minor incident 	D
Negligible	<ul style="list-style-type: none"> – No significant consequences 	E

Table 4-2c Fatigue risk assessment matrix

Risk probability		Fatigue risk				
		Risk severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely Improbable	1	1A	1B	1C	1D	1E

Table 4-2d ICAO risk tolerability matrix

Suggested criteria	Assessment risk index	Suggested criteria
Intolerable region	5A, 5B, 5C 4A, 4B, 3A	Unacceptable under the existing circumstances
Tolerable region	5D, 5E, 4C, 4D 4E, 3B, 3C, 3D 2A, 2B, 2C	Acceptable based on risk mitigation. May require management decision
Acceptable region	3E, 2D, 2E, 1A 1B, 1C, 1D, 1E	Acceptable

Annex IV – Samn-Perelli fatigue table

The Samn-Perelli Crew Status Check

This scale asks people to rate their level of fatigue right now and is a simplified version of the Samn-Perelli Checklist⁶.

- | |
|--|
| 1 = fully alert, wide awake |
| 2 = very lively, responsive, but not at peak |
| 3 = okay, somewhat fresh |
| 4 = a little tired, less than fresh |
| 5 = moderately tired, let down |
| 6 = extremely tired, very difficult to concentrate |
| 7 = completely exhausted, unable to function effectively |