CITY UNIVERSITY LONDON

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Fatigue Risk Management System Introduction into a Long-haul Airline

Submitted as part of the requirement for the award of MSc in Air Transport Management at City University London

I certify that this project is wholly my own work, that all material that has been extracted from others has been clearly referenced, that it is in accordance with the project guidelines and that I have read the Project Guidelines in full.

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Executive Summary

Today's UK pilot fatigue management Flight Time Limitations (FTL) regulations were set out in the 1970s and, as research into fatigue was in its infancy, were based more on operational practices developed since the 1950s rather than on scientific or medical understanding such as it was at the time. These regulations have remained substantially unchanged to the present day and, it has to be said, served the industry well, but with the introduction of the low cost carrier (LCC) business model of intensive short haul operations and the ultra long range operations now being conducted, the robustness of these regulations is being pressure tested to breaking point particularly now in light of the commercial challenges brought about by the downturn in the world economy.

International bodies and regulators are recognising that FTLs in their present form are outliving their usefulness, indeed being used to regulate, probably, a much wider spectrum of activity than was ever originally intended. In its place they are now embracing the idea of moving towards fatigue management schemes that are a more credible means of preventing the insidious and debilitating effects of fatigue on flight operations due to being formulated by reference to medical and scientific knowledge.

Recently it has been reported that the International Civil Aviation Organisation (ICAO), in response to at least 10 serious fatal, fatigue related accidents to commercial operations since 1993, is to mandate the requirement for states to have scientifically based FTLs as well as dedicated, operationally tailored fatigue risk management systems (FRMS). In response the rulemaking directorate of the European Aviation Safety Agency (EASA) is proposing to compel European operators to adopt the use of FRMS for managing pilot fatigue.

This project, through a study of fatigue theory and discussion of UK flight crew FTL schemes' history, development and employment, highlights the disadvantages of the continued use of prescriptive FTLs and describes how an holistic FRMS specifically adapted to each operators' operational circumstances and integral to their safety management system can not only satisfy the regulatory requirements but also bring about direct and diverse tangible benefits to the company whilst paving the way for introducing the latest scientifically backed approach to pilot fatigue management.

The main conclusions drawn from this project are:

- A substantial body of evidence exists to cast doubt on the effectiveness of current, prescriptive FTLs and their suitability for continued use in the future;

- A FRMS that either enhances current FTL schemes or replaces them entirely is essential for the diverse types of operations that are likely to prevail in the future;

- Successful FRMS implementation relies on:

    - A comprehensive change management process that promotes:
        - A major cultural shift in organisational, safety management thinking which requires a strong focus on education;
        - Whole hearted acceptance of FRMS philosophy by all stakeholders in the operation;
        - A company culture that is receptive to and embraces the "shared ownership" and "just culture" doctrines.

    - Close regulator monitoring during implementation phase of FRMS.

- Computer fatigue modeling can play a proactive role in a long-haul airline's FRMS.

- Significant benefits can be derived from FRMS introduction.

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Glossary

AAIB	-	Air Accident Investigation Board (UK)
AME	-	Aviation Medical Examiner
ANO	-	Air Navigation Order (UK)
ANZ	-	Air New Zealand
AS	-	Australia Standard
ASR	-	Air Safety Report
ATSB	-	Australian Transport Safety Board
BALPA	-	British Air Lines Pilot Association
CAA	-	Civil Aviation Authority (UK)
CAANZ	-	Civil Aviation Authority, New Zealand
CAAS	-	Civil Aviation Authority of Singapore
CAO	-	Civil Aviation Order (Australia)
CAP	-	Civil Aviation Publication (UK)
CAR	-	Civil Aviation Regulations (Canada)
CASA	-	Civil Aviation Safety Authority (Australia)
CHIRP	-	Confidential HF Incident Reporting Programme (UK)
CRR	-	Controlled Rest Recovery
EASA	-	European Aviation Safety Authority
EEG	-	Electroencephalogram
EMG	-	Electromyogram
EOG	-	Electrooculogram
EU	-	European Union
FAA	-	Federal Aviation Administration (USA)
FAID	-	Fatigue Audit InterDyne (Centre for Sleep Research)
FAST	-	Fatigue Avoidance Scheduling Tool (USAF)
FCFSG	-	Flight Crew Fatigue Study Group (ANZ)
FDM	-	Flight Data Monitoring
FDP	-	Flight Duty Period
FDT	-	Flight Duty Times
FL2	-	Florida 2 Variation (UK CAA FTL Dispensation)
FMS	-	Fatigue Management System
FMSC	-	Fatigue Management Steering Committee
FOQA	-	Flight Operations Quality Assurance
FRAM	-	Functional Resonance Accident Model
FRMS	-	Fatigue Risk Management System
FSF	-	Flight Safety Foundation
FTL	-	Flight Time Limitation
HFMP	-	Human Factors Monitoring Programme
HILAS	-	Human Interaction in Lifecycle of Aviation Systems
HoW	-	Hours of Work
IATA	-	International Air Transport Association
ICAO	-	International Civil Aviation Organisation
JAA	-	Joint Aviation Authorities (Europe)
LCC	-	Low Cost Carrier
LOSA	-	Line Orientated Safety Audit
MBTR	-	Minimum Base Turn Round
MEL	-	Minimum Equipment List

MSLT	-	Multiple Sleep Latency Test
NAA	-	National Aviation Authority
NASA	-	National Aeronautics and Space Agency (USA)
NTSB	-	National Transportation Safety Agency (USA)
NZS	-	New Zealand Standard
PACTS	-	Parliamentary Advisory Committee on Trnspt Safety
PATANZ	-	Pilot Alertness Test, Air New Zealand
PF	-	Pilot Flying
PNF	-	Pilot Not Flying
PVT	-	Psychomotor Vigilance Task
SAFE	-	System for Aircrew Fatigue Evaluation (QinetiQ)
SARP	-	Standards And Recommended Practices (ICAO)
SIA	-	Singapore Airlines
SIRA	-	System for Integrated Risk Assessment (easyJet)
SMS	-	Safety Management System
SP	-	Samn-Perelli
SWS	-	Slow Wave Sleep
TC	-	Transport Canada
TLX	-	Task Load Index (NASA)
TOD	-	Top Of Drop
ULR	-	Ultra Long Range
VAA	-	Virgin Atlantic Airlines
WOCL	-	Window Of Circadian Low

IATA Airfield Decodes

LHR	-	London, Heathrow
LGW	-	London, Gatwick
HKG	-	Hong Kong
SYD	-	Sydney
MCO	-	Orlando

1.0 Introduction

In the United Kingdom, since the early 1950s control over commercial aviation pilots' hours of duty, for the purpose of avoiding fatigue, has been exercised via means of prescriptive flight time limitation (FTL) schemes. These Civil Aviation Authority (CAA) approved schemes have set hours of work (HoW) limitations on flight duties, rest periods, cumulative duty hours and length of duty cycle (Bader, 1973). To cater for the burgeoning variety and complexity of commercial air transport operations, these schemes have become ever more complicated to the point where their ability to protect pilots from risk-inducing levels of fatigue has become questionable.

Exacerbating this situation has been the move by the European Aviation Safety Authority (EASA) the former European Joint Aviation Authorities (JAA), to harmonise all European countries' FTLs under one standard set of rules for flight time limitation known as "EU-OPS, Subpart Q" which became effective in July 2008. As the UK's approved schemes legislate to stricter limits than those set out by EU-OPS these have been allowed to continue in force. However in April 2012 European operators will be required to adopt either EU-OPS, Subpart Q rules or adopt "alternative schemes" (EASA, 2009).

A further level of complication has arisen as the International Civil Aviation Organisation (ICAO) has given notice that it is to recommend that operators employ a fatigue management scheme that is *"…based upon scientific principles and knowledge where available…"*(CAA, 2009c) acting upon which EASA has mandated that operators implement fatigue risk management systems (FRMS) by April 2012.

As a scientific and medical evaluation of Subpart Q rules commissioned by EASA has criticised their effectiveness in regulating fatigue (Moebus, 2008), at present the only viable option for European airlines, to comply with ICAO recommendations, is to adopt an FRMS fatigue management scheme as an "alternative scheme".

This project sets out the case for FRMS introduction. It begins with a discussion on the theory of fatigue and how it impacts on the safety of airline operations. This leads on to a review of the history of UK FTLs, showing how they have developed through the years to the present day and examines the challenges that the current schemes face. An assessment of the effectiveness of FTLs is made by way of a study of accident and incident reports, pilot confidential reporting and a fatigue survey of Virgin Atlantic Airways (VAA) pilots. The reports and results suggest that there is substantial evidence of the prevalence of unacceptable fatigue risk in current operations although it is acknowledge that this evidence can only ever be circumstantial.

There follows a description of FRMS, explaining the definition and theory, legal and human factors background and structure of the system and how it interacts with a company's safety management system (SMS). Emphasis is made of the holistic, safety performance driven nature of the system, its philosophy of “shared ownership” and “just culture” reporting. Also explained is the risk assessment/management function which lies at the heart of FRMS and the physiological monitoring and alertness testing tools and computer fatigue modelling programmes that are key elements in that process. It is suggested how FRMS might be implemented into an airline through a process of change management. The operational benefits that accrue from its introduction as they apply to the employee, flight operations department, company and regulator, are highlighted.

An appraisal of FRMSs already in operation is made by analysis of company schemes at Singapore Airlines (SIA) and easyJet and fatigue management system regulation put in place or trialled by the New Zealand Civil Aviation Authority (CAANZ) and the Australian Civil Aviation Safety Authority (CASA). Critical reviews of these first examples of FRMS point to the enormity of the cultural change and task of education required to bring about this new concept of safety management and that thorough planning is needed prior to implementation.

The detail, sequence and timeline of FRMS introduction are contemplated by learning the lessons of previous operators’ findings and adopting best practice. An appreciation of the regulatory environment is described that explains the legislative imperative for adoption. The process of implementation is proposed with reference to the easyJet and SIA examples. The purpose and objectives of a safety case are outlined and examples are provided of trip rotation analysis by QinetiQ’s System for Aircrew Fatigue Evaluation (SAFE) computer fatigue modelling programme, to demonstrate the results of fatigue mitigating measures.

Subsequent sections cover FRMS integration into a company’s SMS organisational structure, system ownership, the importance of education and training, and a proposal for how the SAFE programme could be incorporated into a risk assessment/management process. Company FRMS policy is laid out with a depiction of how policy guidance might be drawn up for key operational areas of the airline.

Crucially, a case is advanced for regulators to step up their oversight function during a company’s FRMS implementation phase.

An appreciation of the pros and cons of FRMS introduction and an anticipation of union/employer acceptance issues are considered and a suggestion is advanced as to how universal flight crew physiological monitoring could enhance FRMS in the future.

FRMS is recommended as the most appropriate pilot fatigue management system to accommodate the increasing complexity of present and future long-haul airline operations. Other recommendations are made for the airline industry and regulators to encourage and facilitate FRMS adoption.

Finally future potential areas of study are proposed particularly with respect to the relationship between fatigue and safety.

The 5 objectives of the project are:

- Establish the case for replacing current FTLs.
- Explain the theory and development of FRMS.
- Envisage how an FRMS can be introduced into a long-haul operation as an integral part of the SMS.
- Examine the arguments for and against FRMS acceptance with respect to airline employers and pilot unions.
- Explore how an FRMS could be developed to accommodate fatigue modeling systems that accurately predict pilot fatigue levels over the course of a roster period resulting in "smarter" rostering and daily (dynamic) crewing.

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2.0 Project Aim

The aim of this project is to state the case for introduction of a Fatigue Risk Management System (FRMS) into a long-haul airline.

3.0 Method

Information for this project has come from a variety of sources including reports, publications and articles in the aviation media. With a background knowledge gained as a result of a career in commercial aviation and with first hand experience of the issues, the author has a professional interest and concern for the matters discussed.

An appreciation of the theory of fatigue, the historical context of FTLs and data on accident/incident reports as well as confidential reporting has all been sourced from commercially available literature, ICAO, EASA, CAA and other industry body produced publications and project reports researched from the internet and fellow students.

To add relevance and applicability to this project a fatigue survey of VAA's pilots was conducted using an online questionnaire via the facility of surveymonkey.com.

Information on FRMS was gleaned principally from papers written by the main proponents of FRMS, transcripts of presentations made to workshops and conferences on crew management, through direct contact with the speakers, as well as information already in the public domain on the internet and in trade journals.

The Australian Civil Aviation Safety Agency (CASA), Australian Transport Safety Board (ATSB), the New Zealand Civil Aviation Authority, Transport Canada, Clockwork Research Limited, Flight Safety Foundation (FSF) and The Centre for Sleep Research at The University of Southern Australia in Adelaide all have a considerable wealth of data and material readily available on the internet detailing past and current thinking on FRMS and this has been a valuable resource.

Particularly helpful have been the papers written by Simon Stewart detailing the introduction of FRMS into the easyJet operation.

Finally, Dr. Karen Robertson of QinetiQ has been of invaluable assistance in providing advice and SAFE computer modeling analysis of specific trip patterns.

4.0 Fatigue in Aviation

4.1 Theory

Definitions abound for what fatigue is. In 1972 the Bader Commission considered fatigue to be:

> *"…a markedly reduced ability to carry out a task. It is a condition of reduced performance from which there is no certainty that a person can be aroused in an emergency, even when considerable stimulus is present."*

(Bader, 1973)

Today the European Aviation Safety Authority (EASA) and the International Civil Aviation Organisation (ICAO) FRMS subgroup, describe fatigue as:

> *"A physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness and/or physical activity that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety related duties"*

(EASA, 2009)

Fatigue can either be physical, with an inability to continue functioning at the level of one's normal abilities due to a lack of strength usually as a consequence of heavy exercise; or mental, which manifests itself either in somnolence, a state between wakefulness and sleep including microlapses or micorsleeps, or just as a general decreased level of concentration not necessarily connected with sleepiness. This latter condition, most commonly associated with flight crews, has implications for the operation of vehicles and is the main area of concern with regard to fatigue in aviation.

The symptoms of mental fatigue can take the form of:

- Difficulty concentrating on task;
- Lapses in attention;
- Difficulty remembering what you are doing;
- Failure to communicate important information;
- Failure to anticipate events or actions; and
- Accidentally doing the wrong thing or not doing the right thing.

Also, in terms of work place interaction with colleagues, mental fatigue can make one:

- More quiet or withdrawn;
- Lacking in energy;
- Lacking in motivation to do the task well; and
- Irritable or grumpy.

(Transport Canada, 2007c)

Ninety five percent of reported fatigue cases are as a result of inadequate amounts of sleep (Caldwell et al, 2003). Other causes of mental fatigue include mental stress, over/under stimulation, disease, dietary deficiencies, obesity and jet lag. Whatever the causes, the drive for sleep emanating from fatigue cannot be consciously controlled. It is as basic a physiological need as eating or drinking. No amount of commitment to the task can counteract the effects of fatigue induced decrements in alertness and progressive onset of sleep.

Several factors combine to influence an individual's state of fatigue. These are:

- Homeostatic process; the amount of time spent awake since the last sleep period;
- Circadian rhythm; the phase of the internal body clock;
- Sleep inertia; the initial period of consciousness while recovering from deep sleep;
- Sleep debt; the accumulation of fatigue due to prior inadequate rest periods either through inappropriate timing or length of rest;
- Task load; the rate of working since the last sleep period;
- Personal sleep physiology;
    - Tolerance to above factors;
    - Whether one is a "morning" or "afternoon" person;
    - Ability to adapt to restricted sleep.

The first 2 of these factors in combination, homeostatic process and circadian rhythm, are considered to have the greatest influence on alertness levels. The former can be thought of as an internal drive for sleep, which increases across a normal day of wakefulness and contributes to maintaining sleep at night. The latter is a function of the brain that controls the diurnal peaks and troughs of a range of physiological and behavioural variables, including temperature, hormone levels, the sleep wake cycle and intellectual performance (Dijk, 1997).

It is the variation of body temperature that is used as a proxy for the biological clock in circadian rhythm studies. These studies have shown that the body uses external environmental cues or zeitgebers such as daylight, meal times and work/rest schedules to keep the body synchronised to the local time zone. It is recognised that the desynchronistion of this process leads to fatigue, malaise, sleepiness, lack of motivation, confusion, insomnia and digestive disorders (Caldwell et al, 2003).

The graphs that follow show how homeostatic process and circadian rhythm effect alertness in isolation:

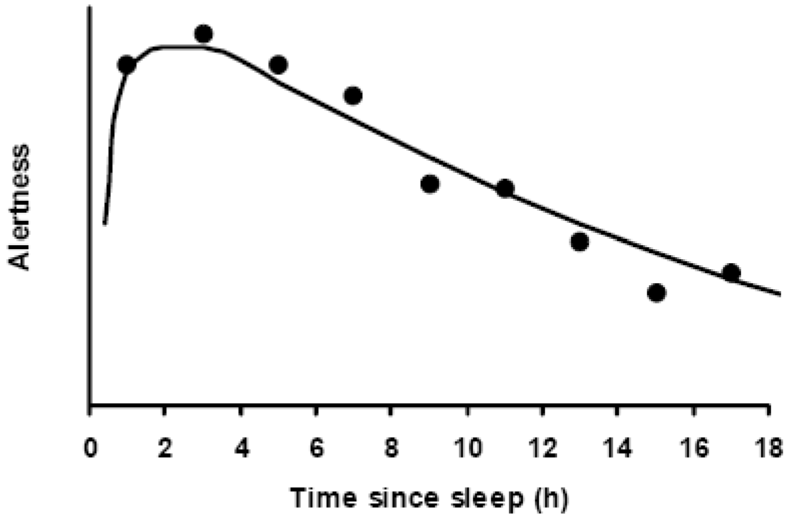

Figure 1. Change in Alertness with Increasing Wakefulness due to Homeostatic Process

(CAA, 2005b)

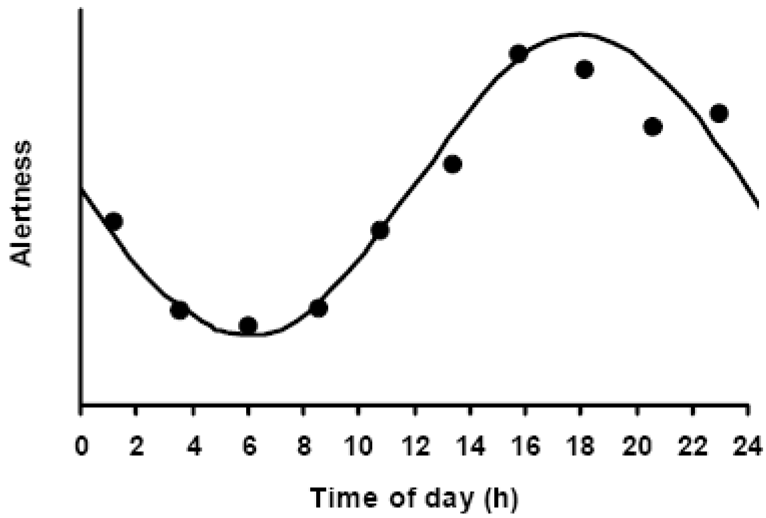

Figure 2. Diurnal Variation of Alertness due to Circadian Rhythm

(CAA, 2005b)

By taking the example of shift workers awaking at 8am and finding difficulty obtaining further sleep during the day prior to going on night shift in the evening, the amplitude of their combined alertness values, represented by these 2 graphs, reaches a nadir in the early morning between 3 and 5am; the window of circadian low (WOCL). Interestingly, this period has been the local time window when several major disasters in recent history have occurred such as the Three Mile Island and Chernobyl nuclear power station accidents, the grounding of the

Exxon Valdez supertanker off Alaska and was the timing of the decision making process that led to the Challenger Space Shuttle explosion.

A description of the mechanism and structure of sleep can be found at Appendix A.

Another important contributor to fatigue is sleep inertia, the sensation of grogginess experienced after awakening from a deep, slow wave sleep (SWS). This can last for several minutes and dramatically impair a pilot's performance particularly in the context of the working environment of a flight deck

The normal requirement for sleep is around 8 hours per night varying between individuals from 7 to 9 hours. If this is not achieved due to shift patterns or trans meridian time shifts disrupting the restorative quality of sleep then a sleep debt accumulates which cannot be dismissed as a physiological weakness that can be overridden. This cumulative sleep loss can become substantial overtime leading to degraded performance and increased risk exacerbated by an individual's inability to gauge their own level of impairment (Caldwell et al, 2003).

With regard to long-haul crews' work routine, early studies found that, to offset the effects of cumulative fatigue, transient sleep loss over a period of consecutive duty days would be unlikely to occur if the rate of working reduced in a logarithmic manner in relation to the increase in days of the schedule. This relationship became known as the Nicholson Curve and informs the regulations of present day FTL schemes (CAA, 2005b).

The fatiguing effects of work orientated task load are complex with wide variations in perceptions of ease or difficulty of a particular duty and the actual contribution it makes to overall fatigue depending on the individual's training, experience, personal outlook and, the organisation's culture. A NASA paper concerning the development of the NASA Task Load Index (TLX) discusses these factors (NASA, 1988).

Every individual has different tolerances to the many factors influencing fatigue and succumb to their effects at varying rates and degrees. An important aspect of fatigue management, discussed later, is an individual's awareness of their susceptibility to fatigue and the characteristics of their physiological propensity for sleep such as whether they are a "morning" or an "afternoon" person and how well they can function with reduced rest.

Unfortunately for the long-haul airline the nature of the operation is predisposed to creating fatigue. The task is characterised by long periods of sometimes continuous duty involving crossing several time zones, opportunities for rest that are out of synch with the internal body clock and flights conducted at times when the body is more normally expecting to be asleep.

4.2 Consequences of Fatigue

In a safety critical, risk-averse industry that thrives on defining and quantifying every component feature of its existence the imprecise, diverse and insidious nature of fatigue is an anathema. Yet the industry has been able to recognise the many characteristics of fatigue which impair the cognitive skills of memory, decision making, and communication and that compromise the effective functioning of individuals performing complex tasks such as operating aircraft. Some of the threats that fatigue presents are:

- Unconscious acceptance of lower standards of performance as accuracy and timing degrade;
- Inability to make sense of and integrate information;
- Narrowing of attention accompanied by forgetfulness and absentmindedness;
- Inconsistent performance particularly during night hours;
- Slower problem solving and reasoning;
- Degraded psychomotor skills;
- Increased rate of false responding;
- Poorer risk awareness and less risk aversion;
- Reduced social interaction accentuated by a highly automated environment; and,
- Loss of task resource prioritisation.

Increased incidences of irritability, impatience and reduced social inhibitions have been manifestations of reduced ability to control mood and behaviour due to sleep deprivation and that these symptoms have been magnified when the tasks being performed have been more demanding and complex. Significantly, the biological effects of fatigue will impair even the most highly skilled and motivated individuals irrespective of their training and experience and cannot be overridden by inducements (ATSB, 2006).

Examples of embedded fatigue risk in regulation, systems and procedures that have developed into incidents and accidents are recorded later in this project.

4.3 Fatigue Counter Measures

In commercial aviation the responsibility for fatigue avoidance is shared between the operator and the flight crew member. The airline is bound by regulation and law to adopt practices and procedures that prevent the onset of fatigue and the crew member has a duty to arrive for duty in a fit and rested state.

From the perspective of the individual, the counter measures that can be employed to offset fatigue are, in the main, lifestyle type choices that reduce stress through promoting regimes such as:

- Maintaining a healthy diet and taking regular exercise;
- Keeping to a regular sleep routine at home:
- Adopting good “sleep hygiene” i.e. measures that make sleep more conducive when preparing for sleep:
    - Ensuring no noise disturbance and interruptions, wearing ear plugs if necessary and placing “Do Not Disturb” signs;
    - Blocking out daylight, if sleeping in daytime;
    - Setting room temperature to a colder setting than normal (16-20C);
    - Preventing drafts from windows, fans and air conditioning units;
    - Limiting alcohol consumption before sleep;
    - Avoiding heavy meals before turning in; and,
    - Trying to obtain a comfortable bed.

If sleep deprivation does lead to fatigue the pilot should seek aviation medical examiner (AME) advice on possible sleep disorders and/or use of medication.

For the long-haul pilot contending with sleep pattern and circadian rhythm disruption, a good knowledge of sleep physiology and awareness of their own personal physiological traits are important to predict the best times to take rest periods when sleep can be achieved and, if the facility is available, bid for the roster patterns that most appropriately conform to the diurnal variations of their metabolism.

For the airline some alleviation from fatigue risk is achieved through sympathetic and preferential rostering where pilots can influence their allocation of trips. Scheduling and rostering department staff should be trained in company procedures that protect pilots from trip pairings and the juxtapositioning of consecutive trips which can induce considerable fatigue despite being “legal”.

The traditional method of fatigue counter measure for the organisation has been compliance with a regulator approved FTL scheme. These schemes have relied more on preventing fatigue by limiting HoW than providing opportunities for rest. Indeed, for the long-haul airline, the minimum periods set out for recovery from duty do not respect the body’s time dictated biological propensity for sleep and are more closely aligned with recovery from physical fatigue, possibly reflecting the heritage of FTLs dating back to the 1950s when the distinction between physical and mental fatigue was less appreciated.

Alternative means of fatigue management are starting to be introduced into the industry that take a more holistic, multi-faceted and flexible approach based on scientific findings. The main features of this approach comprise of; clear workplace policies and procedures, good rostering practices, an informed work group, active management involvement and effective monitoring of safety-related outcomes (ATSB, 2006). These are the elements that make up what has generally become known as a fatigue risk management system (FRMS).

5.0 Flight Time Limitations

5.1 History and Development

The catalyst for the start of UK FTL regulation was the statement in both the accident reports of 2 passenger aircraft crashes in the early 1950s, that pilot fatigue may have been a contributory cause. From their beginning the schemes have had to define a delicate balance between commercial interests and safety. In designing the Civil Aviation Authority's (CAA) Civil Aviation Publication (CAP) 371 document, "The Avoidance of Excessive Fatigue In Aircrews", it was acknowledged that much weight had been put on industry best practice which had little medical foundation. The small concession made for the effects of circadian rhythm disturbance of long-haul operations was also criticised.

The development of CAP 371 to its present day form has been driven by events in the aviation industry. Over the years the intent of the regulation has frequently been open to poor interpretation and abuse resulting in a high oversight commitment from the regulator. Appendix B charts the history and development of UK FTLs.

5.3 Current Operations

As the fourth edition of CAP 371 matches or exceeds the commonly established procedures under European legislation it continues in force as the UK's national provision on FTLs until such time that the Community rules based on scientific knowledge and best practise are established (CAA 2009a). These new rules, EASA EU Ops Subpart Q, have been constructed with the intention of harmonising all European national FTLs into one legislative document but as Captain R Williams of the Air Safety Group that advises the Parliamentary Advisory Council for Transport Safety (PACTS) commented in June 2007 "*… the way Subpart Q is currently written will allow all sorts of excesses, the intent in places is unclear and it is anticipated that fatigue in crews will become evident within a relatively short time following its introduction…*"(Williams, 2007). Indeed a recent scientific and medical evaluation, commissioned by EASA, conducted by a team of internationally recognised experts in the field of human factors study drew the same conclusions in their report (Moebus, 2008).

Presently the responsibility for management of fatigue risk is still placed on both operators and crew members and is mitigated by the adoption of an approved FTL scheme which is properly owned, implemented and monitored by the operator and provides for good rostering and other best practice recommendations of CAP371. The CAA oversees FTL compliance through audits of operator's Quality System and Safety Management System/Fatigue Risk Management System as appropriate (CAA, 2009a).

Apart from the ANO, CAP 371 and EASA EU Ops Subpart Q other legislation has appeared in recent times which also sets limits on a crew member's flight and duty time such as the Civil Aviation (Working Time) Regulations and Health and Safety at Work Regulations. Very much akin to the state of affairs leading to the "Bader Report" there is now a plethora of sometimes conflicting, ambiguous and inconsistent regulation waiting in the wings and uncertainty as to which authority will ultimately be responsible for oversight of aircrew fatigue management (Williams, 2007).

Meanwhile developments over the last 10 years have seen regulator approval of in seat, in-flight napping strategies recognising NASA research that showed that a short "power nap" during a quiet period of the cruise could temporarily increase alertness and performance for the more demanding phases of approach and landing with particular relevance for the long range sector, 2 pilot crew aircraft operation (CAA, 2003).

The results of other research carried out by QinetiQ and its predecessor organisations dating back to the early 80s into the sleep and wakefulness of aircrew are now starting to be applied in the form of a complex fatigue modelling programme, SAFE, which is being employed to predict the fatigue levels associated with operating new trip rotations especially those that fall outside normal FTL schemes and require variations to the schemes (CAA, 2005b and CAA, 2009b).

These are amongst the first examples of the outcome of dedicated scientific/medical research having a baring on pilot fatigue management whereas in the past changes have come about through a process of industrial negotiation necessitated by the demands of the prevailing commercial environment which have not always been sympathetic to the best physiological interests of crew. Indeed many of the revisions in edition 3 of CAP 371 were instigated as a direct result of AMEs detecting signs of fatigue amongst pilots whilst undergoing their aircrew medical renewals (Williams, 2007).

In other jurisdictions, that comply with an FTL regime similar to the UK's CAP 371, ultra long range (ULR), scheduled flights lasting over 16 hours have entered into regular service under special ULR operations rules that use human factor and FRMS strategies that ensure that the fatigue risk encountered is equivalent to that of a shorter flight operated within the existing FTL scheme. These rules were formulated through consultation between ICAO and the participating aviation authorities including the JAA and the US Federal Aviation Administration (FAA). Amongst other industry body consultees, scientific advice was taken from QinetiQ resulting in the first case of FRMS principles being used in the construction of a long-haul trip roster pattern (Singh, 2003).

5.4 Commercial Challenges

Throughout the history of FTL regulation the commercial environment that airlines have operated in, very often using the same equipment on similar route structures under common regulatory supervision, has become evermore competitive and one of the main levers companies have had at their disposal to gain commercial advantage has been the manipulation of aircrew FTLs. Their sometimes cynical interpretation was noted by Captain D Quilley, CAA head of flight operations when he commented, in 1989, on the liberties that many British airlines were taking at the time, stating *"... some rosters obviously assumed the commander's discretion was available to be used* (at the planning stage). *While the hours were not planned to run over maximum duty time, they were close to the maxima during operating periods when delay was normal."* (Flight International, 1989).

The hard monthly and annual limits set down in the first edition of CAP 371, that remain in force today, were stipulated in a much gentler commercial environment where the average line pilot was stated to be achieving about 500 hours a year and the highest annual average flying hours for any company was 745 hours (Bader, 1973) whereas now some data analysis suggests these figures, in recent years, could have approached 650 hours (enhanced by suggested 20% to reflect average line pilot hours) with some pilots averaging "…*in excess of 800 hours per annum."* (Paton, 2009). These restrictions were set out to be absolute limits, enforced by statute of the Air Navigation Order (ANO, 2005), which were intended to be approached on an occasional basis yet monthly limits are now regularly tested by seasonal operators and the annual limit has become commonly regarded in scheduling agreements as a target to be achieved year in year out. Highly efficient computer driven rostering processes ensure that these targets are consistently achieved.

With advances in technology allowing aircraft to travel further distances and for longer durations by ensuring the integrity of onboard systems (and thereby reducing the likelihood of diversion) the limiting constraint has become the endurance of the operating crew and the provisions of the conventional FTL scheme under which they work (Flight International 2004).

Further commercial challenges for the regulation of FTLs are materialising now through the onset of the world economic downturn and many airlines' struggle for survival by trimming all aspects of their operations to the minimum and squeezing the remaining assets to achieve the maximum advantage. As the second most expensive resource cost (to fuel) pilots are an obvious target for more effective "resource management" especially as, in comparison to the employment groups they work alongside, pilots are perceived to enjoy high pay for undemanding work routines.

The relatively short term economic imperative is used as argument to impose ever more punitive industrial work agreements, with respect to FTLs and scheduling practices, that then outlast the current crisis and go on to have a lasting impact on future working practises and associated fatigue.

An example of this is the situation that VAA pilots faced during the restructuring of the airline in the wake of the 9/11 terrorist attacks. The company, having decided to retire the 3 crew (2 pilots and an engineer) Classic B742 and replace it on the Florida route with the 2 pilot crew B744, succeeded in getting temporary approval to invoke the Florida 2 variation to CAP 371 in order to be able to operate these routes with unaugmented, 2 pilot crews. This variation had been designed to allow occasional flights to Florida and the Caribbean by holiday charter airlines that would otherwise have been restricted by CAP 371 FTLs. With the consent of the pilot union and the CAA, due to the extraordinary commercial conditions prevailing at the time, VAA was allowed to use this variation to run a daily schedule. Some 8 years of operation later the temporary nature of this arrangement has developed a permanency, and in the mean time, the company has reaped the commercial benefit of being the only scheduled operator to use this variation and in the process accepted the associated risk of increased fatigue amongst the pilot workforce.

The arrival of the 2 pilot long-haul flight deck and the demise of the flight engineer is further example of where CAP 371 has not kept pace with changes in the industry (Flight International, 1980). The issue concerns the rostering of a third pilot on a 2 crew flight deck to take advantage of longer permitted flight duty periods (FDPs) that were originally specified for a 3 crew (including engineer) operation. Theoretically, the third pilot, sat on the jump seat, can play no part in the conduct of the flight because the procedures are designed for 2 pilots and yet individual sector times, particularly on multi sector flights, are often not long enough to allow proper use of in-flight relief where a third pilot can enhance the FDP by taking the place of an operating pilot during the cruise (CHIRP, 2008).

For the post “credit crunch” future the whole landscape of the aviation industry is likely to undergo seismic changes. Present airline business models will be severely tested with long-haul airlines feeling the economic effects most keenly. It is conceivable that they will have to increasingly adopt the practices that, up to now, have been the sole preserve of short haul low cost carrier operations in order to survive. These new practices will undoubtedly impact on pilot work routines with inevitable, further challenges to fatigue management.

5.5 Effectiveness

The insidious nature of fatigue is such that it makes it enormously difficult for anybody to accurately assess their own state of fatigue and most methods of self evaluation will be prone to wide variations of subjectivity according to the environment, circumstances and mood that the individual is experiencing. Clinical, objective testing is also problematic outside of the laboratory; there is no simple breath or blood test for fatigue as there is for alcohol intoxication and, indeed, it is not fatigue itself that can be measured but only decrements in alertness. These facts considered in combination with an industry that has inherited, from the earliest days of wartime military aviation, a “macho” attitude which tends to turn a blind eye towards the subject means that any discussion of fatigue does not benefit from a wealth of reports of solid, empirical data. Accident investigators, until quite recently, would not attribute fatigue as a causal factor in their reports relying on the presumption that, if FTLs had been complied with, fatigue could not have been a contributory factor, preferring to state “pilot error” instead. Furthermore, given the hitherto poor understanding of the subject and its somewhat intangible relationship with operational safety pitted against an acute awareness of how fatigue countermeasures are perceived to directly impact on an operation’s productivity (and commercial viability), any debate on fatigue has necessarily been contentious.

To date, commercial aviation culture has not condoned fatigue reporting by pilots and traditional prescriptive fatigue management systems have not specified any requirements for systematic monitoring of fatigue risks. It is reasonable to comment that fatigue is and has always been present in commercial aviation; the question is at what level has fatigue become a risk and at what level has that risk become unacceptable? It is therefore hard to definitively gauge the effectiveness of prescriptive FTL schemes in contributing to the avoidance of fatigue risk and whether or not the right balance between productivity and safety has and is being achieved.

It is unlikely that an FTL scheme devised in the early 1970’s, when much less was known about the science of fatigue, and which has largely evolved through a process of industrially negotiated trade offs to arrive at its present day manifestation, would be as valid today for regulating an industry where working routines and demands on aircrew have changed out of all recognition through the embracing of huge advances in both technological and commercial practices. Perhaps the proliferation of variations (exemptions in other regulatory regimes) to FTLs, new ULR rules and the condoning of in-seat napping strategies, all introduced to cater for the more extreme areas of present day airline activity, are symptoms of the increasing inadequacy of traditional, one size fits all, prescriptive FTLs to regulate fatigue in the modern industry.

It is also valid to argue, in as much as historic poor understanding of the causes of fatigue has contributed to ineffective FTLs, then the very same lack of understanding will have, in some instances, lead to overly restrictive FTLs limiting operations that are indeed safe. One result of a recent fatigue survey suggests that present regulations might be too focused on limiting hours of duty rather than maximising sleep opportunities (Roach et al, 2006).

5.5.1 Accident/Incident Reports

Inspection of the UK's Air Accident Investigation Branch (AAIB) online accident report database reveals that in the period 1980 to the present day only 2 reports indicate that fatigue was a contributory cause to accidents or incidents occurring to fixed wing pilots operating under a CAA approved FTL scheme. These were:

Date	Event	Aircraft	Registration	Flight Phase	Location
6 Jun 1998	Incident	HS748-2A	G-BIUV and G-BGMO	approach	Ronaldsway, Isle of Man
15 Mar 2005	Accident	BN2B-26 (Islander)	G-BOMG	approach	Campbeltown, Argyll, Scotland

Table 2. Fatigue Related UK Registered Aircraft Accident/Incidents

(AAIB, 2009)

However, one of most deserving incidents in recent times for a AAIB human factors investigation was that which befell the crew of the British Airways B747-136 aircraft, G-AWNO on 21 November 1989 who, at the end of an operationally difficult flight from Bahrain with problems compounded by crew sickness, mishandled a go-around from an approach in thick fog to runway 27R at London Heathrow and in doing so came very close to the nearby Penta Hotel. With on going investigations into the Pan Am Lockerbie disaster and the British Midland, Kegworth accident, AAIB resources were already stretched and so an opportunity to learn valuable lessons about how systemic short comings can lead to the possibility of fatigue induced hazards was lost (Wilkinson, 1993).

The first accident in history to have fatigue cited as a primary cause was the crash of the Kalitta International DC-8-61F at Guantanamo Bay in 1993. Since then the following accidents, to aircraft operated by crews regulated by prescriptive FTLs of other National Aviation Authorities (NAAs), have had fatigue recorded as a cause:

Year	Company	Aircraft	Location
1994	Air Algerie	B737-200F	Coventry, UK
1997	Korean Air	B747-300	Guam, Pacific Ocean
1999	American Airlines	MD-82	Little Rock, TX, USA
2001	Crossair	BAe146	Zurich, Switzerland
2002	AgcoCorp	Challenger 604	Birmingham, UK
2004	MK Airlines	B747-200F	Halifax, Nova Scotia
2004	Corporate Airlines	BAe Jetstream 31	Kirksville, USA
2004	Med Air	Learjet 35A	San Bernadino, CA, USA

Table 3. Fatigue Related Non UK Registered Aircraft Accidents

(Learmont, 2009a)

In the following more recent events fatigue is being investigated as a possible cause:

Date	Company	Aircraft	Event	Location
27 Aug 2006	Comair	CRJ100	Crashed on Take off	Lexington, KY, USA
12 Jun 2007	Cathay Pacific	B747-400F	Ground Collision on Start Up	Stockholm Arlanda, Sweden
16 Sep 2007	One-Two-Go	MD-82	Overran Runway on Landing	Phuket, Thailand
12 Feb 2009	Colgan	Dash 8-Q400	Crashed on Approach in Icing	Buffalo, NY, USA
20 Mar 2009	Emirates	A340-500	TODC Error – Tailstrike on Take off	Melbourne, Australia

Table 4. Accidents/Incidents where Fatigue Being Investigated as a a Possible Cause

(Learmont, 2009a)

Currently, the US National Safety Transportation Board (NTSB), in its August 2009 report into the Go! Airlines incident where both pilots fell asleep at the controls of their CRJ200 aircraft on a short haul flight between Honolulu and Hilo, Hawaii on 13 February 2008 and could not be raised by air traffic control for some 25 minutes as they flew 26 nautical miles past their destination at cruise altitude, has made 6 recommendations to the FAA. All relate to pilot fatigue, 3 of which urge that research should be carried out with a view to implementing FRMS into short haul carriers' operating procedures (Ranson, 2009).

5.5.2 Confidential Reporting

The UK's Confidential Human Factors Incident Reporting Programme's (CHIRP) states that "*Duty related issues are one of the most frequently reported topics by flight crew in confidential reports*" with alleged fatigue contributing 11, 39 and 20% respectively of the total reports filed in years 2006, 2007 and 2008 (CHIRP, 2008). A review of the 19 CHIRP Feedback magazines between January 2003 and June 2009 reveals that duty related reports topped the league of issues on all but 3 occasions.

A similar confidential aircrew reporting programme for commercial aviation in the USA recorded 227 schedule related, fatigue incident reports made by pilots between 1994 and 1998 amounting to an average of 45 reports a year (NASA, 1999). Indeed the Safety Board of the NTSB has had "fatigue" on its most wanted list since 1990 and made 32 aviation fatigue recommendations since 1972, most concerning flight and duty time regulations and policies (NTSB, 2008).

5.5.3 Survey

In order to gauge the effectiveness of VAA's FTL scheme and lend weight to the argument for introducing FRMS a fatigue survey was conducted amongst the pilot workforce (Appendix B).

The results of the survey did indicate that sickness rates for pilots on the Airbus fleet were 22.6% higher than those on the Boeing fleet (differences in general levels of sickness between the fleets might suggest a route structure that is more prone to cause fatigue). The data also showed a consensus on each fleet as to which respective trip rotation was considered to be the most tiring and that Samn-Perelli Seven Point Fatigue Scale (Appendix C) scores for these trips recorded levels of fatigue that were not commensurate with the safe operation of an aircraft, particularly so for the Airbus rotation to Hong Kong and Sydney. On one trip pattern there was some evidence to suggest an aspect of cumulative fatigue.

6.0 Fatigue Risk Management System

6.1 Definition and Theory

ICAO has defined FRMS as a *"scientifically based, data driven, addition/alternative to prescriptive flight and duty time limitations which manages crew fatigue in a flexible manner appropriate to the level of risk exposure and the nature of the operation"* (ICAO, 2008).

Essentially, through an integrated set of management policies, procedures and practices, it moves away from the traditional, scientifically doubtful, hours of work limits as a means of controlling fatigue in the work place and takes a much broader, holistic perspective of the causes of fatigue on duty with respect to organisational, environmental, physiological and other factors.

FRMS principles should prevail from roster design through all stages to crew rest and recovery. The philosophy recognises that different influences will affect levels of fatigue on otherwise similar duties and that a "one size fits all" prescriptive hours limitation scheme cannot effectively regulate for this. In an FRMS every duty will have its own bespoke hours limitations formulated through a process of multi faceted monitoring and reporting, evaluation, timely modification of limits and procedures, and integral, systematic feedback loop for continuous fatigue risk assessment for that particular operation. It is a performance outcome driven system relying on a "just" culture reporting, intended to be as much proactive as it is reactive.

FRMS is a risk management function which is allied to and designed to be an integral part of an organisation's SMS. Akin to SMS, FRMS requires the implementation of multiple defences against fatigue at various organisational levels according to James Reason's "Swiss cheese" model. This suggests that such multiple defences must be put in place to prevent alignment of failures (holes) in the layers of the organisation (slices of the cheese) which may result in an incident (Reason, 1997).

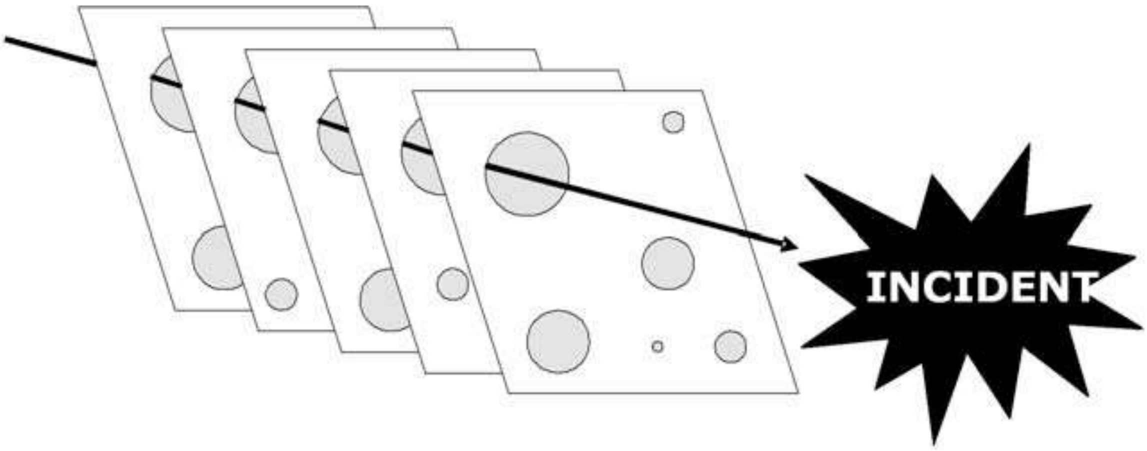

Figure 6. An incident trajectory demonstrates how failures or "holes" in management systems can provide opportunity for incidents

(Transport Canada, 2007a)

A major element of an FRMS is the identification of fatigue hazard, evaluation of its severity and likelihood of occurring, assessment of the risk that it posses and implementation of mitigating risk reduction measures. Figure 7 summarise the risk reduction process.

Figure 7. Risk Reduction Process

(VAA, 2009)

An important concept of FRMS is shared ownership. Figure 8 represents how consultation and communication among all involved parties influences and shapes the principle functions of the system in a dynamic process of continual development.

Figure 8. Effective Fatigue Risk Management Systems

(McCulloch, 2003)

6.1.1 Human Factors Perspective

Improved understanding of fatigue risk hazards has lead to the realisation that all stakeholders (regulators, employers, employees) share responsibility for minimising risk and increasing the safety of the operation. In the past human error, considered the primary cause of accidents and incidents, had been associated with operations personnel (pilots, engineers, dispatchers, controllers etc). Analysis of recent major accidents in aviation and other industries has revealed that managerial decision making failures, primarily related to latent risk embedded in an organisation's procedures or structure, have also been a contributory factor. Table 5 illustrates how this new thinking translates into the allocation of FRMS responsibilities.

The integrity of this system relies upon an open, honest and non-punitive reporting culture, appropriate regulatory oversight and confidence that an organisation's management will not be tempted to abuse the FRMS process for commercial advantage and similarly that employees do not overstate fatigue issues for lighter work schedules. Ideally this moves the fatigue management process out of the labour/management negotiation regime into the domain of safety management where lifestyle issues are respected and where all operational, ancillary and directing staff have a stake and are able to contribute to the process.

Government/Regulatory Responsibilities	Organisational Responsibilities	Individual Responsibilities
* Prescribe requirements/ framework for FRMS.	* Provide support - Compliance with legislation. - Policy development. - Training and education. - Error/incident reporting systems.	* Use time away from work appropriately to obtain adequate rest and recovery, and ensure fitness for work.
* Assess compliance.	* Ensure work schedules provide adequate opportunities for rest and recovery between shifts.	* Report any potential risks to manager if experiencing fatigue-related symptoms.
* Audit non-compliance.	* Assess specific work tasks for fatigue- related risk.	* Report any situation that may present fatigue-related risk.
* Where appropriate, Investigate accidents/incident		

Table 5. Responsibilities for Fatigue Risk Management

(Transport Canada, 2007a)

6.1.2 The Legal Perspective

With changes in the law concerned with corporate governance and duty of care brought about as a result of the Zeebrugge Ferry sinking, Clapham Rail crash and Piper Alpha Oil Platform fire disasters, ignorance of risk is now not a defence against the new charge of corporate manslaughter (Ministry of Justice UK, 2007). It cannot necessarily be assumed that adherence to legal duty hour limits will prevent fatigue risk and, in the event of a fatigue induced accident, the operator could be found responsible and accountable for such a risk (CAA, 2007). A properly run FRMS mitigates the liability to such a charge.

6.2 System Description

The Transport Canada FRMS Toolbox publication lays out the components parts of an FRMS under 6 headings which are closely aligned with the ICAO draft proposals. These headings with their associated elements are as follows:

Policies and Procedures

- Outline the commitment of organisational management to manage fatigue-related risk
- Detail the required procedures for managing fatigue at the operational level

Responsibilities

- List personnel responsible for FRMS design, implementation and maintenance
- Document responsibilities of individual employees and work groups

Risk Assessment/Management

- Scheduled versus actual hours of work
- Individual sleep patterns
- Symptom checklists
- Error/incident reporting

Training

- Promote knowledge in the workplace about risks, causes and consequences of fatigue
- Ensure employees understand and can apply FMRS strategies

Controls and Action Plans

- Toolbox of methods used within FRMS, including error reduction techniques (“fatigue proofing” rather than “fatigue reduction”)
- Clear decision trees for managers and employees to use when fatigue has been identified as a risk

Audit and Review

- Documentation and data collection at regular intervals monitoring how FRMS is working
- Review of FRMS based on audit results

(Transport Canada, 2007a)

This format replicates the typical structure of an airline’s SMS allowing an FRMS to be superimposed as an extra safety related dimension onto the functioning of an already operating organisational system and thereby facilitating its introduction, reducing duplication of effort and benefiting from a common human factors philosophy of a “just safety culture” and shared system ownership and responsibilities.

Furthermore the Transport Canada guidance identifies 5 defensive layers (or levels of control in managing fatigue risk) against an error trajectory analogous to Reason’s “Swiss cheese” model. The 5 levels are:

Level 1 (organisational): making sure that scheduling gives employees adequate opportunity to sleep:

Level 2 (individual): ensuring employees actually get sufficient sleep:

Level 3 (behavioural): monitoring for symptoms that indicate employee fatigue:

Level 4 (error): strategies to prevent workplace fatigue resulting in errors or incidents:

Level 5 (incident): determining the role of fatigue in workplace errors or incidents.

These are represented in Figure 9.

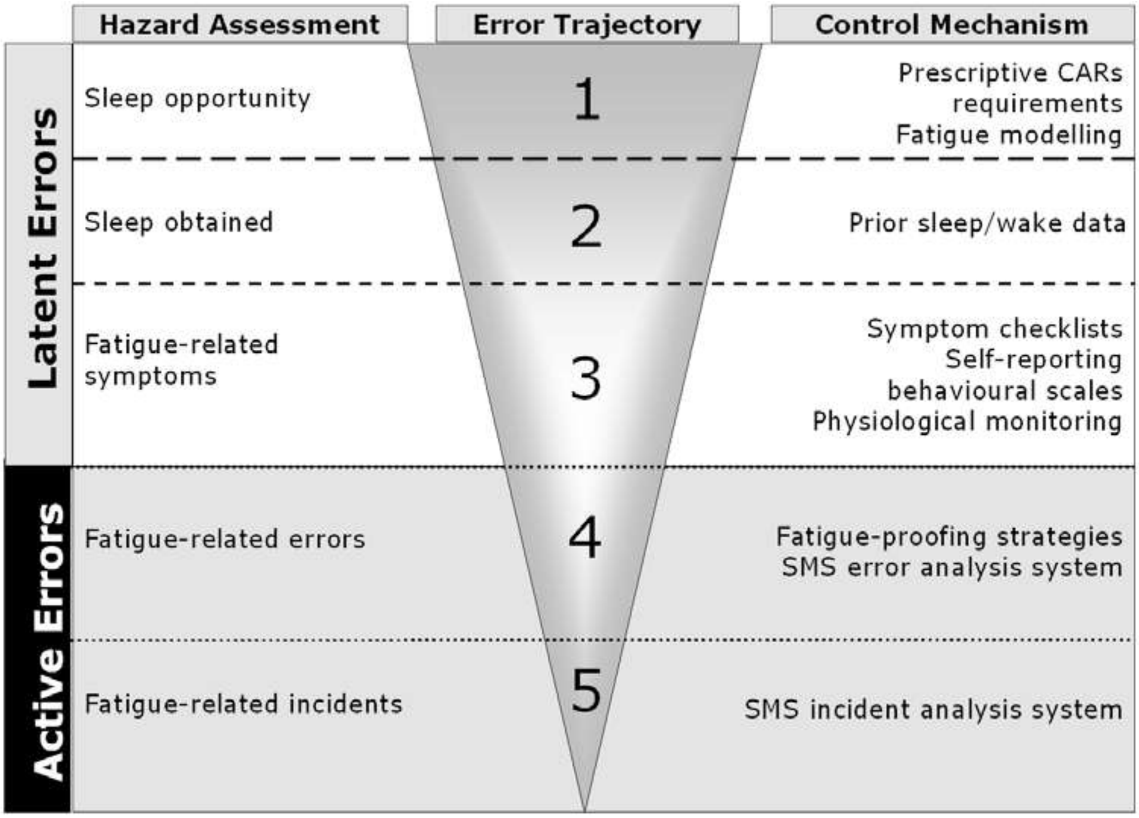

Figure 9. Hazard-Control Model for Fatigue Risk Management

(Transport Canada, 2007a)

By comparison, FTL schemes just have the one defensive layer, that of duty hours limitation.

Overseeing and acting as a focal point for all the FRMS processes in an organisation is the Fatigue Management Steering Committee (FMSC). The FSF lists the functions of this body as follows:

- monitoring fatigue information sources;
- investigating fatigue-related issues;
- requesting internal audit of specific issues;
- proposing solutions to fatigue related issues;
- recommending priorities for targeting fatigue management resources;
- providing transparent and timely feedback to management and workforce;
- cooperating with internal and external audits; and,
- overseeing the quality assurance of FRMS training in whole organisation.

It goes on to recommend that this group is made up of representatives drawn from:

- pilots and cabin crew
- medical staff
- establishment planners/rostering staff
- commercial/marketing departments
- training establishment
- engineering
- safety services
- flight operations,

achieving a balance of company and employee staff with access to scientific/specialist advice as required (FSF, 2005a).

The organisational structure of an FRMS is represented in Figure 10.

Figure 10. An FRMS Organisational Chart

(FSF, 2005a)

6.2.1 Risk Assessment/Management

Fatigue risk is difficult to predict and quantify with any accuracy within a risk management system. Indeed the relationship of fatigue and risk is non linear and poorly understood (Roach et al, 2006)(Folkard et al, 2007). However the Functional Resonance Accident Model (FRAM) of risk suggests that increased fatigue does lead to increased risk and this is an assumption common to both FRMS and FTL schemes (Hollnagel, 2004).

With FTL schemes the risk assessment and management has been a predominantly reactive process, adopting a compromise between best practice and commercial imperative. In a FRMS this process is a central function which binds the system together using reactive and proactive components. The reactive part comprises a "risk radar" that senses fatigue hazard via 4 layers of reporting chains:

- Routine reports;
  i.e. Flight Data Monitoring (FDM), Flight Reports, Roster Stability Data, Sickness Rates, Aviation Medical Examiners' Reports, etc.,

- Ad hoc reports;
  i.e. FRMS Audits, Crew Surveys, Safety Walks, Line Orientated Safety Audits (LOSA), Flight Operations Quality Assurance (FOQA), etc.,

- Incident (Accident)/Risk driven reports;
  i.e. Air Safety Reports (ASRs), CHIRP, Fatigue Incident Report Forms, Crew Welfare Report Forms, Fatigue Investigations, Discretion Reports, etc.,

- Long term fatigue studies;
  i.e. Human Factors Monitoring Programmes (HFMP), Human Interaction in the Lifecycle of Aviation Systems (HILAS) project, etc.

(Stewart, 2008)

Far greater and immediate relevance is given to these sources of information than is the case with FTL schemes. The data is processed in relation to a series of functions that investigate, analyse, assess and rate according to the context of the operation. This establishes a defined risk for the reported hazard and, if the metrics of the risk exceed a set threshold, this leads to a process of operational change and risk mitigation, the level of which is dictated by the severity of the risk. The system is, therefore, procedurally and dynamically adapted to mitigate fatigue risk.

The output of this process can be either immediate, tactical modifications to, say, a specific trip rotation or long-term strategic changes to, for example, rostering policy, both of which are informed by organisational learning processes and/or feedback loops (Stewart, 2008).

Figure 11 is a diagrammatic representation of the risk management process promoted by International Risk Management Standard 4360 (AS/NZS, 2004).

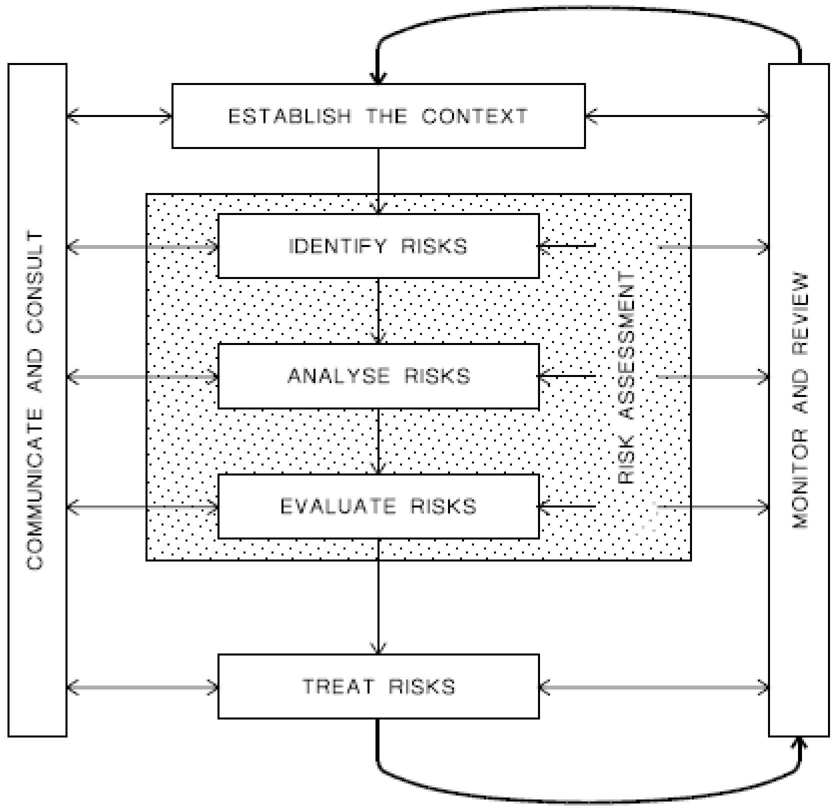

Figure 11. The Risk Management Process

(AS/NZS, 2004)

The complexity of modern day air transport operations and higher expectations of safety demands a system with a greater proactive emphasis. This can be provided by computer fatigue modelling programmes that can predict generic fatigue levels at any point of an FDP and can be instrumental in the assessment of the fatigue risk associated with new trip patterns. This, then, can influence the risk management process resulting in the deployment of proactive fatigue risk mitigating measures.

6.2.2 Physiological Monitoring and Alertness Testing

Fatigue studies have employed a range of methods to collect data about flight crew's quality of sleep, susceptibility for sleep (multiple sleep latency tests - MSLT) and state of alertness. In controlled scientific studies polysomnographic monitoring, which uses electroencephalograms (EEG), electrooculograms (EOG) and electromyograms (EMG) to record brain activity, eye movement and chin muscles tension respectively, has been used to assess the structure of sleep following disturbed rest associated with shift work or time zone change. In other scientific tests measures have included; the readings of individual's body temperature (using Biorhythm watches) and salivary melatonin to establish phase of the internal body clock and rate of adaptation to new time zones, the wearing of Actilumes and Actiwatches (watch like devices that detect light and movement respectively) to record when sleep was likely to have occurred, and Psychomotor Vigilance Task (PVT) and Palm Pilot computer alertness tests. To compliment these objective tests, subjective assessment has usually been conducted in tandem for comparison and validation purposes and these have taken the form of sleep diaries and alertness report forms.

The 3 most practical and commonly used means for targeted FRMS data retrieval have been the Actiwatch, Palm Pilot and PVT computer tests, as depicted in Figure 12, together with alertness report forms.

Figure 12. Actiwatch, Palm Pilot and PVT Computer
(courtesy Air New Zealand)

6.2.3 Computer Fatigue Modelling

The principle method for proactively predicting fatigue levels associated with proposed duties and therefore a key component of an FRMS is the computer fatigue modelling programme. There are several programmes in widespread use today, not just in the aviation industry, such as the UK Health and Safety

Executive's Fatigue and Risk Index Calculator, the NASA – TLX (Task Load Index), the USAF's FAST (Fatigue Avoidance Scheduling Tool) and the FAID (Fatigue Audit InterDyne) risk management tool used by easyJet for their FRMS.

The programme most appropriate for assessing the fatigue generated by the long duty hours, irregular patterns of work and rest, and time zone shifts common place in long-haul rosters is the UK's QinetiQ developed SAFE.

Developed from research conducted on behalf of the UK's CAA into sleep and wakefulness of airline pilots, SAFE incorporates the QinetiQ alertness model based on basic physiological factors derived from laboratory studies, the 2 principle components of which being the effects of circadian rhythm and proceeding patterns of sleep and wakefulness. Through a series of studies of aircrew alertness conducted over several years the fatigue model has been refined, enhanced and validated to the point where it is now a valuable aid for the appraisal of aircrew rosters, capable of illuminating potential areas of fatigue risk. It is this aspect that makes SAFE ideally suited to play an integral part in a long-haul operation's FRMS (QinetiQ, 2004).

Data entry for SAFE includes information about crew composition, in-flight rest and time zone transition as well as schedule, duty time and sectors operated. Computed analysis output takes several forms listed as follows:

- Workload and Alertness Summary; indicating problem areas/transgressions within a particular duty;
- Cumulative Workload; successive duty workload comparison with Nicholson Curve; (as explained in Section 4.1);
- Body Clock Desynchronisation;
- Duty Hours;
- Blood Alcohol Concentration;
- Equivalent Alertness Scales; including Samn-Perelli Seven-point Scale and Karolinska Sleepiness Scale,
- Estimated Sleep Period; prediction of time when sleep may be achieved.

(QinetiQ, 2009)

Several examples of SAFE trip rotation analyses are produced in Appendix F.

6.2.4 Operational Introduction

Implementation of FRMS will be a change management process that will need to be a continuous process to reflect the dynamic, ever adapting nature of this safety management function.

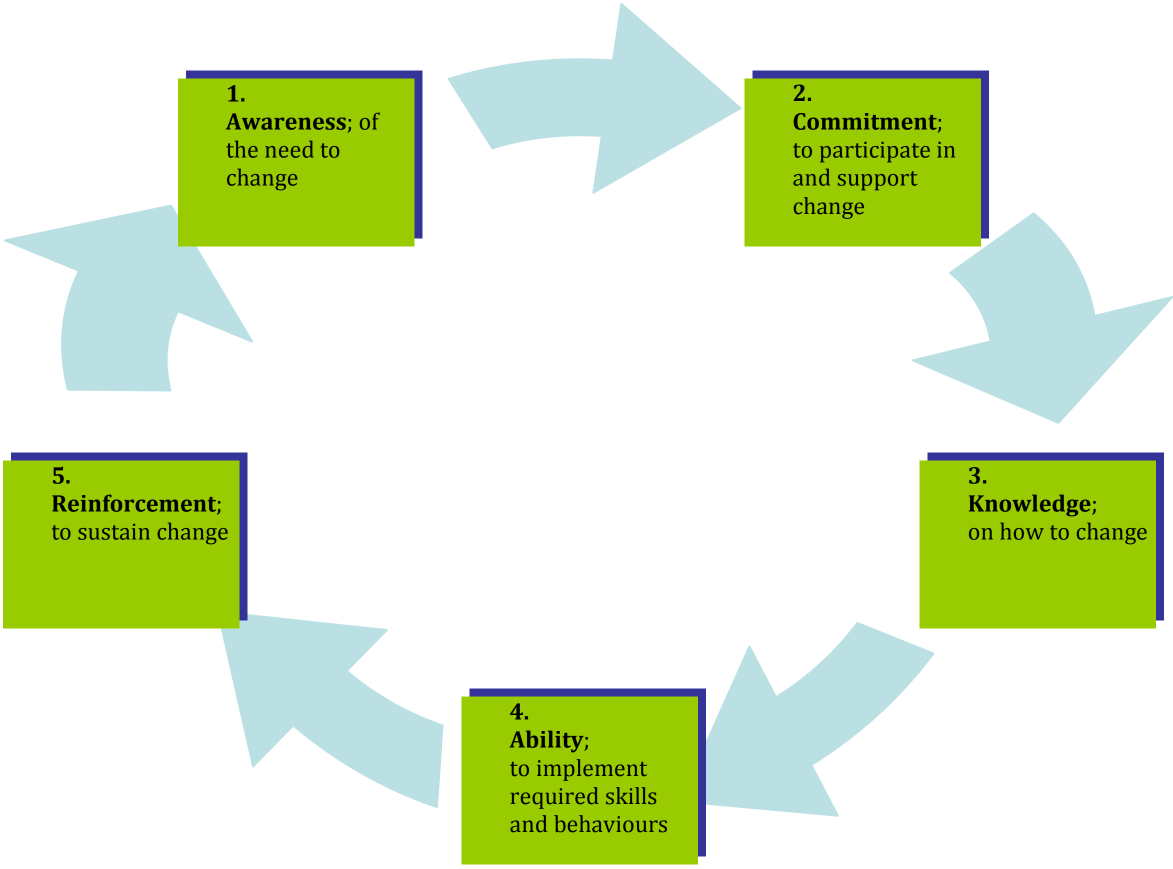

Figure 13. FRMS Change Management Process

(Stewart, 2009)

Awareness of a need to change must be created within the organization, starting with a diagnosis of the prevailing situation and then identification and evaluation of methods to address it.

Management, Union and the FMSC need to show strong leadership in "selling" FRMS so that it is a process that is "owned" and potential benefits recognized company wide. To encourage workforce engagement, a strong signal of senior management commitment to the FRMS philosophy is the policy statement a generic example of which is found at Appendix D.

Courses on policies and procedures training are required for managers and employees alike to understand the behavioral and cultural traits of FRMS so that the relevant skill sets can be deployed to create, develop and maintain such a system.

An organisational framework must be established, within the structure of the SMS, and informed by an open and transparent company FRMS policy which should include the following elements:

- commitment from the highest levels of the organization;
- a specified line of accountability for fatigue risk management;
- definition of company management and employee responsibilities;
- identification of work groups covered by the FRMS;
- FMSC terms of reference;
- identification of fatigue reporting mechanisms;
- policies for the identification and managing of fatigue risk;
- FRMS training and resources commitment;
- Responsibility to act on FRMS internal audit recommendations.

(FSF, 2005)

Through a process of human factors monitoring programme (HFMP) reports, internal and external FRMS audits and reviews of the reactive reporting elements of the fatigue "risk radar" a running assessment of the efficiency of the system can be maintained and a variety of tactical or strategic modifications can be introduced to reinforce the process. Figure 13, summarises the stages of the FRMS change management process.

Figure 14 describes how the change management process might translate into a company's organisational process chart.

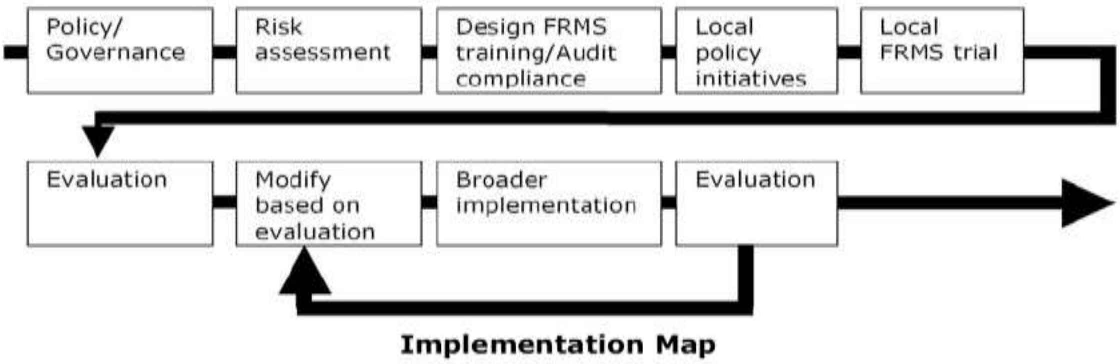

Figure 14. FRMS Organisational Implementation Map

(Transport Canada, 2007a)

6.2.5 Operational Benefits

The overarching benefit of FRMS is enhanced flight safety. In some quarters this is perceived as being achieved at the expense of commercial viability as many of the FRMS "levers" of change represent increased direct operating costs. This assumes that current operations are safe enough i.e. if FTLs are complied with, then as well as being legal, the operation must be safe; and that FRMS is a handicap in terms of commercial competitiveness. The first assumption has already been addressed, the second is dealt with here.

The derived advantages of FRMS implementation can be categorised as accruing in 4 distinct areas; the individual employee, the flight operations department, the company and the regulator.

For the pilot employee every duty, planned or otherwise, will be assessed by the FRMS and the sometimes highly contentious decision of whether or not a flying duty can be safely carried out with respect to fatigue is left to the integrity of the system, removing from the pilot a weight of responsibility and releasing intellectual resources that can be focused on other areas of the operation. Other advantages include better welfare and lifestyles less blighted by continuous fatigue leading to possible long term health benefits.

For flight operations, although some aspects of the roster may be more restricted, FRMS will quite possibly open up opportunities where traditional FTLs have been unnecessarily punitive on the programme. Safety cases based on FRMS principles may be made for increasing absolute monthly and yearly limits of flying duty. More physiologically sympathetic rostering will result in lower absenteeism with a better balance of work and time off; a feature that will play out well as a recruitment incentive and benefit employee retention. Fewer incidents as a consequence of FRMS policies will mean less disruption to the flying programme and a reduced engineering and administrative task. The computerised rostering tools required of an FRMS system will lead to a much simpler and transparent roster production process and also increased flexibility and efficiency.

The company, beyond the flight operations department, can capitalise on the cache of operating FRMS as an enhanced safety feature that contributes to commercial interests via brand protection. Furthermore the reduction in frequency of medium and high risk events will result in a lower risk signature that will qualify for lower insurance premiums (Stewart, 2009). Data from other transport sectors indicate that companies with accredited FRMS/SMS suffer 50 to 75% less crashes (Jackson, 2008). Crucially it might be the case that duty limitations will no longer be decided by typically protracted management/union negotiation but rather on purely scientific grounds.

From a regulator's point of view an organisation running an FRMS, as an integral part of an SMS, will be much easier to oversee as the built in reporting and operational control functions of the system will endow the operation with far greater transparency. As FRMS/SMS is intended to apply to every operational aspect of an airlines activity, then an external audit of FRMS/SMS should reveal a complete operational assessment of the organisation.

6.3 FRMS in Operation

The first application of an FRMS philosophy to an aviation environment was in 1995 when the CAA of New Zealand (CAANZ) introduced an "alternative compliance scheme" to their existing FTL scheme. Following on from this the

Australian Civil Aviation Safety Authority (CASA) began trialling FRMS in 2001. Both of these initiatives were prompted by the geographical remoteness of these 2 countries and particular demands on their aviation industry leading to a realisation by the NAAs that the conventional FTL schemes in place were not sufficiently broad enough in their scope to regulate all aviation activities.

With the arrival of the Airbus A340-500 extended range aircraft airlines were able to introduce scheduled ULR services of 16 hours and over. In 2004 Singapore Airlines (SIA) started services from Changi to Los Angeles and New York whilst Emirates began flying directly to Sydney and New York from Dubai. These operations could not be catered for within these organisations' normal FTLs so special, dedicated ULR procedures were devised for these flights based on FRMS principles which are now a universally accepted reference for long-haul FRMS operations.

Elsewhere, in the intensive, short haul environment of the low cost carrier, easyJet found that the roster routine allowed by their existing FTL scheme was contributing to undesirable levels of fatigue risk and incidences of flight deck errors. After conducting a trail of an FRMS designed roster, easyJet was able to present to the regulator, a safety case for alleviation from their FTLs by virtue of employing FRMS techniques which ensured an equivalent or better level of safety. This was accepted and easyJet rolled out their FRMS programme in April 2005.

Also in Europe, to date, Jetairfly (TUI) and DHL Air have begun development of their own FRMS systems (Jackson, 2008).

A review of FRMS introduction into the regulatory regimes of the CAANZ and CASA together with a description of FRMS in operation with ANZ, SIA and easyJet is contained in Appendix E.

7.0 Introduction of FRMS into Long-haul Operations

As the Australian regulator CASA discovered, the introduction of FRMS involves such a cultural shift in thinking about how fatigue is managed that the ground has to be thoroughly prepared before institutional change is initiated.

In the first instance the impetus has to come from the regulator as no established commercial operator is going to change such a fundamental aspect of its operation without an element of regulatory coercion. This, however, must represent the least of the reasons for change. The rationale for FRMS adoption must rest firmly on the merits of the argument for moving towards a dynamic, safety driven, risk management system. Everyone involved in the operational activity of an organisation has to "buy in" to the philosophy. General acceptance of the idea is the first major hurdle and this has to be achieved through a company wide campaign of education at all levels through studies of theory, industry best practice and company FRMS safety case analysis.

Management and unions alike will have important roles to play in comprehensively endorsing the new thinking and showing leadership in adapting to a new safety management culture. With the aim of casting the system's safety net over a much broader reach as its primary focus, the FRMS should transcend the old industrial "tug-of-wars" contests fought over flight duty times. The cultural philosophy of the system recognises that by catering to work group safety/welfare needs the overall safety/commercial requirements of the operation are also fulfilled. Fundamental to its unimpeded working will be management/union agreement to wholeheartedly support and participate in the programme.

Establishment changes to accommodate FRMS will be minor as the company's existing SMS will provide the appropriate organisational framework with common system data and communication network requirements already in place. However, the change management task will call for extensive and thorough training as would befit the major cultural realignment exercise involved with moving from a static fatigue limitation scheme to a dynamic, risk focused scheme. Training will be an ongoing commitment, reinforcing the realignment process through periodic refresher courses.

As is demonstrated by the easyJet experience, the operational heart of FRMS is the Risk Assessment/Management process. This has to be uniquely designed to meet with the specific characteristics of the airline's activity and deliver appropriate solutions that fit the airline's operation to mitigate recognised risk. Part of the function of this process is a feedback loop that will act to monitor the working of the system and validate its effectiveness for internal/external audits and regulatory oversight.

Responsibility for implementing, coordinating and supervising all aspects of the company FRMS will rest with the FMSC, made up of representatives from all operational areas of the organisation including, scheduling/rostering, as well as commercial/marketing staff and establishment planners, and external medical/scientific advisers. Their primary function will be to set out company FRMS policy.

Event	Organisation	Notes
Regulatory Requirement	ICAO, EASA, CAA	FRMS as enhancement to FTLs.
Policy Statement	Company Management	Union agreement.
FMSC establishment	Company Management/Union	Representation from all Operational areas of Business. - Policy Document - Organisational Structure - Education -Risk Assessment/Management
Educational campaign	Company/FMSC	“Sell” FRMS to company staff.
Safety Case	FMSC/Safety Services/Operations	Specific Fatigue Survey/Study of Problem Trips with FRMS proposed solution as change/approval justification. General Company wide Fatigue Survey to act as reference baseline pre FRMS introduction.
FRMS Approval	CAA/Company	FRMS Regulator Audit requirements established.
FRMS establishment	FMSC/Safety Services/Operations/Training Department/HF Department	- Responsibilities - Training - Reporting Chains/Nets -Risk Assessment/Management goes live.
Transition from FTLs to FRMS	FMSC/Safety Services/Operations/Training Department/HF Department	Initially on a trip by trip basis starting with problem trips rolling out to other trips as experience gained of process. General FRMS Principles, not associated with organisational change can be applied immediately.

Table 6. Sequence of Events – FRMS Introduction

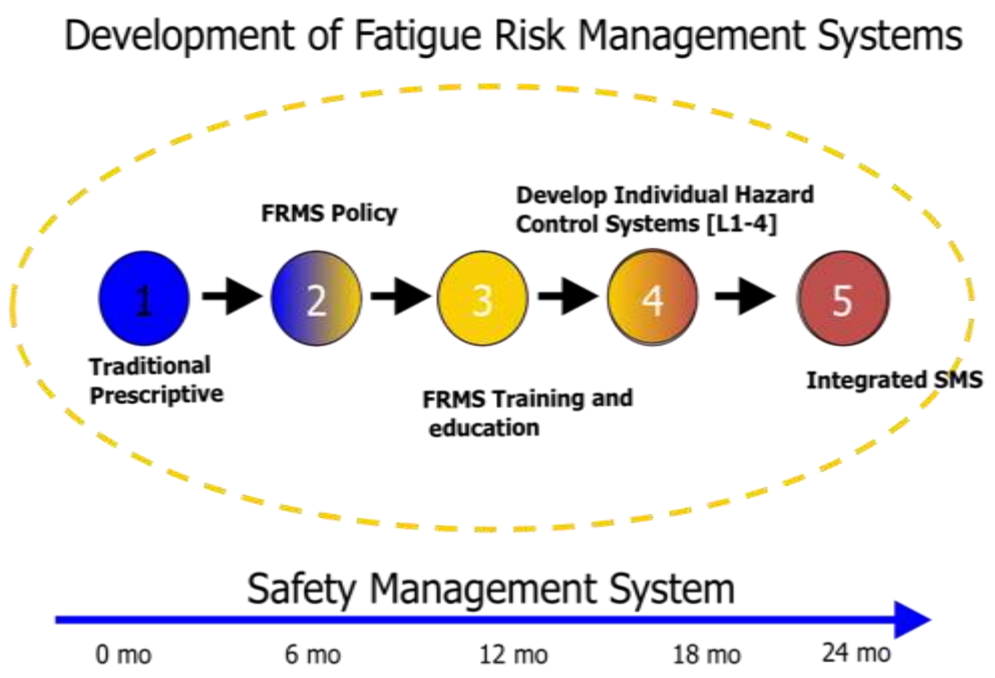

Figure 16. Overview of FRMS Introduction and Time Line

(Dawson, 2004)

7.1 Regulatory Background

The International Civil Aviation Organisation (ICAO) sets out in its Standards and Recommended Practices (SARP) document guidance for aviation authorities to follow in formulating regulations. In the draft Annex 6, Part I of the SARP proposed for issue in 2011, ICAO recommends that:

> *"Operators shall establish flight time and duty period limitations and a rest scheme….. to manage fatigue."* and that these *"Shall be based upon scientific principles and knowledge where available…".*

(CAA, 2009c)

In response to this ICAO guidance EASA have signalled in a notice of proposed amendment to EU.OPS proposed to be mandated in April 2012 (postponed from October 2010), when EASA takes control of FTL regulation, that OR.OPS.025.FTL will state (Learmount, 2009b):

> *"An operator shall establish and maintain an FRMS as an integral part of its management system."* that *"shall correspond to the roster system or flight time specification scheme used by the operator…"* and that the *"Operator shall take mitigating safety measures when the FRMS process shows that the required safety performance is not maintained."*
>
> (EASA, 2009)

7.2 Safety Case

The purpose of the safety case exercise is to verify the need for FRMS incorporation, collect a baseline of fatigue risk data as a pre-FRMS implementation reference, establish and refine the process for risk assessment and management, trial "levers" for fatigue risk mitigation (to prove the system and effectiveness of "levers") and gain regulator approval.

The 2 trip rotations indicated by the VAA pilot fatigue survey to be the most fatiguing should be the primary focus for an FRMS safety case i.e. for the Airbus fleet, the LHR-HKG-SYD pattern and for the Boeing fleet, the LHR-LGW-MCO pattern.

A comprehensive HFMP should be planned for at least 6 months to account for seasonal changes in length of daylight and effects of weather. A campaign of objective testing using Actiwatches and carrying out PVT and Palm Pilot alertness tests together with subjective data achieved through sleep diaries and fatigue report forms, completed at specified points, should be conducted.

The performance outcome of these surveyed trips could be analysed through assessment of the various sources of data, listed in section 6.2.1, and already collated by the SMS, filtered for those reported outcomes, the occurrences of which, pilots had some influence over. By emulating easyJets methodology (Appendix E), it should be possible to establish a linkage between rostering practice and given working environment, measured flight crew alertness (and by inference, fatigue) and the performance/safety outcome.

With the inclusion of a computer fatigue modelling programme such as QinetiQ's SAFE, tuned to the particular operating characteristics of the airline, validated by the HFMP, areas of fatigue risk could be predicted and a proactive risk assessment/management function could be employed for these safety case trips and applied in future to all trips in the airline's route structure.

FRMS strategies deployed by SIA for their ULR operations could be trialled to gauge their effectiveness and reinforce the case for regulator approval. Organisational "levers" to mitigate fatigue risk could be manipulations of the schedule by changing departure times, or roster pattern by varying layover and recovery times, or crewing establishment by increasing crew compliments. Further measures might include studies into the best arrangement for crew in-flight rest and the effects of cumulative fatigue built up over a series of rotations (QinetiQ, 2008).

Appendix F shows an example of a SAFE analysis for both the LHR-HKG-SYD and LHR-LGW-MCO trip rotations for the current schedules, as planned, and in each case after the operation of a fatigue risk mitigating "lever".

7.3 FRMS Integration into Airline SMS

Organisational establishment changes to accommodate FRMS can be minimised as the FRMS Organisational Chart, depicted in Figure 10 (Section 6.2), can overlay the SMS structure. The "just culture", holistic, shared ownership and safety performance driven features are closely mirrored in both the related systems which compliment each other's purpose. Table 9 demonstrates how the essential elements of FRMS are related to the 10 organisational functions of SMS identified by ICAO.

ICAO's 10 Steps to SMS	Essential FRMS Elements
1. Planning	- Non-punitive Fatigue Risk Management Policy - "Just Culture"
2. Senior Management Commitment	
3. Organisation	- Fatigue Management Steering Group
4. Hazard Identification	- Fatigue Risk Assessment Tools - Crew Fatigue Reporting - Employee Communication Channels for Feedback
5. Risk Management	- Strategic, Scientifically-Driven Crew Scheduling - Validated, Timely Fatigue Mitigation Strategies -Data driven processes for monitoring alertness
6. Investigation Capability	- Procedures to Investigate and Record Fatigue-Related Incidents
7. Safety Analysis Capability	- Data Collection & Assessment
8. Safety Promotion & Training	- Education and Awareness Training Programmes
9. Safety Management Documentation	- Documented SOPs for FRMS Implementation
10.Oversight and Performance Monitoring	- Operator Internal Audit Programme - FRMS Validation Programme - Safety Performance Measurement

Table 9. SMS Principles Embedded in FRMS (Powell, 2009)

7.4 System Ownership

A core principle of FRMS philosophy is system ownership. All operational stakeholders have a part to play in and are responsible and accountable for FRMS implementation, operation, equitable administration, maintenance and improvement of the system (CASA, 2004).

7.5 Education and Training

Compelling, comprehensive, coherent and credible education will be the key to the success of introducing FRMS into an airline SMS. The ideas of shared ownership, "just culture", and collaborative and proactive safety management, central pillars of the FRMS philosophy must be accepted into the lexicon of the corporate culture for the theory to transform into efficient and productive practice.

For such a cultural shift in fatigue management thinking, from prescriptive hours of work limitations to safety/performance outcome influenced limits, and very much dependant on company personnel active acceptance, the education process needs to take place right at the beginning of the change management phase reaching as many people in the airline as possible, from top management down. The topics should cover:

- FRMS theory;
- Legal (Corporate) and Regulatory (NAA) requirement;
- Human Factors justification;
- Company FRMS Policy;
- Company Risk Assessment/Management Process;
- Company FRMS Organisational Structure;
- Individual FRMS Responsibilities
- FRMS Implementation Plan and
- Benefits of FRMS adoption.

After the FRMS education campaign has completed, then training of all staff associated with flight operations should begin based on the curricula that the FSF recommended for SIA ULR operations i.e.:

- Causes of fatigue in the airline environment
- Consequences of fatigue on aviation safety;
- Requirement for confidential feedback from incidents;
- Recognition of signs of fatigue and decreased alertness in self and others;
- Physiology of sleep and understanding of one's own sleep physiology and how it should influence preferential bidding;
- Circadian rhythms and homeostatic process;
- Sleep and alertness strategies including "sleep hygiene";
- Diet and hydration including effects of alcohol and caffeine;
- Prescription and non-prescription medication and rules;
- In-flight environment and its effects;
- Work scheduling and,
- Crew coordination to address sleep inertia after in-flight rest.

(FSF, 2005b)

This training should be reinforced through the normal routine of recurrent training.

7.6 Risk Assessment/Management

The complexity of a long-haul operation with world wide destinations, round the clock activity, and a variety of trip and layover lengths requires a modified risk assessment/management process to that explained earlier (6.2.1).

By comparing the analysed output of the "risk radar" element of the reactive component of the process with predicted fatigue levels from the SAFE programme, the proactive component, a relationship can be established between safety of the operation in terms of reported fatigue risk events and expected fatigue. This relationship, which may be unique to each rotation, can be used to aid trip planning with respect to schedule timings, number of pilots, length of layover etc..

The starting point for this process would be a defined level of safety stipulated by the regulator as an acceptable rate of fatigue risk event reporting which would correspond (via the relationship) to a limit on the decrement to SAFE predicted alertness. This limit would then inform the trip design process, using SAFE, and continue to be a dynamic, systematic fatigue risk governing function. True to FRMS principles, safety performance outcome would drive the process.

The transparency of the process could be ensured by publishing the latest alertness level limits calculated for each trip. By making the SAFE programme available to pilots it could be verified that predicted alertness levels for a prospective trip rotation did not diminish below the limit promulgated. In setting the limit, factors could be introduced to allow for individual physiological differences in tolerances to fatigue and for variations in fatigue inducing aspects of the operation such as coping with weather and technical problems. Delays and diversions would necessitate a fresh SAFE evaluation with the facility to specify a cut off time for creeping delays.

FRMS system ownership would be satisfied by pilots' ability to directly monitor and influence, by tactical fatigue risk mitigating measures, the risk assessment/management process. The process's working metrics would meet the data needs of the regulator/operator for auditing/oversight requirements.

7.7 Company FRMS Policy

As a FRMS is a closely integrated feature of a company's SMS much of the documentary requirements of both systems will be common and therefore a degree of FRMS policy can be referenced to the SMS policy manual.

Features that FRMS policy must define are:

- The level of senior management commitment;
- Responsibilities and accountability of the accountable executive, managers, committees, and employees;
- The purpose and goals of the FRMS;
- How the organisation will achieve its safety objectives;
- Resources allocated to FRMS
- The responsibility of all employees to manage fatigue risk;
- Fatigue related safety outcomes expected of managers, employees and contractors;
- Training requirements;
- Reporting procedures for fatigue related hazards;
- The fatigue reporting policy ("just culture");
- A procedure for evaluation and continuous improvement of the FRMS.

(Transport Canada, 2007b)

Further expressions of FRMS policy will require statements on the characteristics of FRMS integration within the company's SMS, and means of communication and consultation on policy. As FRMS is intended to be a dynamic, constantly developing entity, explanation of how and when policy changes are going to be promulgated will be crucial for the coordinated propagation of procedures. It is envisaged that specific policy guidance will be formulated for operational departments as indicated in Table 10.

Department	Policy Guidance covering:
Rostering	Trip pairing, roster build and juxtaposition of trip rotations do not compromise FRMS principles.
Crewing	FRMS principles preserved with operational changes.
Operations	Rescheduling conducted according to FRMS criteria.
Engineering	Understanding how technical unserviceabilities effect fatigue levels. Minimum Equipment Lists amended to reflect FRMS requirements.
Airport Services	Influence of delays on fatigue and importance of OTP
Fleet Management	Evaluation of FRMS effectiveness on pilot workforce
Training	Ensuring FRMS policy understood and being followed.
Safety Services	Monitoring and auditing of FRMS processes.
Crew Logistics	Layover hotel arrangements respect FRMS requirement for uninterrupted sleep opportunity (during daytime if necessary).

Table 10. FRMS Departmental Policy Guidance

7.8 Regulator Oversight

It is anticipated that FRMS implementation into a long-haul operation will be a stepped process on a trip by trip basis. Many of the oversight requirements of the prescriptive FTL scheme will remain as FRMS is initially operated as an enhancement to the present scheme of fatigue management. Regulator supervision of company SMS will include functions of the FRMS.

The metrics of the risk assessment/management process output will facilitate the regulator's auditing task. However, to gain company wide confidence and acceptance of the new fatigue management system, to ensure that poor or incorrect practices do not become entrenched and enshrined in company procedure a strict regulator oversight commitment will be required in the early stages of implementation. Moreover, as every airline's FRMS will be different, tailored to their particular operating circumstances, the regulator will have to learn and understand each organisation's system in order to validate and monitor it. Bench marking and establishment of safety goals will be needed by which the system can be assessed. The robustness of the system and company's management ability to oversee the correct functioning of the programme will be the major issues to be considered.

The oversight task will be demanding and, indeed, involve a change management process requiring new organisational structures for the regulator as well.

Once the FRMS/SMS are established the relationship envisaged between regulator and airline is illustrated by the diagram in Figure 17.

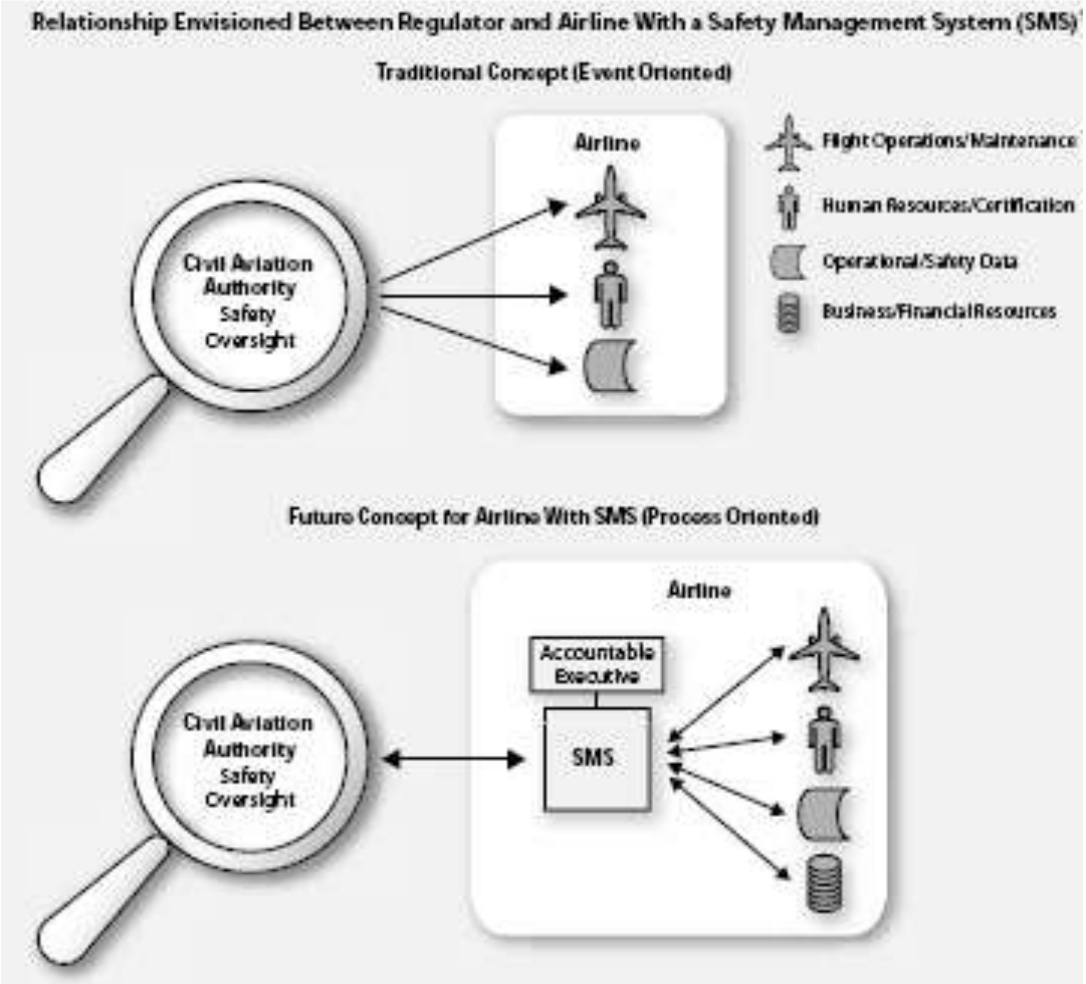

Figure 17. Relationship Envisioned Between Regulator and Airline with SMS

(FSF, 2005c)

7.9 Pros and Cons of FRMS Adoption

Some of the advantages and disadvantages listed by a 2004 Australian Government discussion paper particularly applicable to a long-haul operation are:

Advantages;

- Improved flexibility with operation not restricted by sometimes inappropriate prescriptive FTLs;
- Increased safety through better awareness and understanding of fatigue;
- Improved rostering efficiency through deployment of more capable rostering tools and procedures required for FRMS;
- Clearer sharing of responsibilities for fatigue management;
- Credible, scientific basis for fatigue management;
- System not polluted by industrial issues;
- FRMS closely aligns with corporate governance and duty of care legislation;
- Transparency, understanding and faith in method of operation; and
- Shared ownership, "a problem shared is a problem halved".

Disadvantages;

- Resource hungry implementation costs for cash strapped business;
- Temptation to over rely on the sexy fatigue management software to the detriment of other FRMS components and strategies;
- Some fatigue management software can be cumbersome and difficult to apply;
- Potential for FRMS abuse by either management or employees;
- High establish workload, particularly in implementation phase.

(CASA, 2004)

Previously mentioned benefits of a more engaged work force due better lifestyle, lower rates of operational exceedances and incident/accident occurrences resulting in lower insurance premiums and airline brand protection all combine to make a strong corporate case for FRMS adoption beyond just complying with forthcoming regulation.

7.10 Acceptance Issues – Union/Employer

FRMS has to be universally accepted within an organisation if it is to properly function as an effective fatigue management system. Contest over prescriptive FTLs has traditionally been the modus operandi of union and employer engagement and removal of this industrial minefield of issues into the realms of scientifically decreed best practice will present huge challenges for both sides of the labour relations divide.

The union scepticism echoes natural pilot cautiousness which is characterised by a deep seated suspicion of the additional role of FRMS in modifying hard won prescriptive FTL rules and the potential for its exploitation by airlines to gain increased productivity at the expense of fatigue risk. As a former British Airline Pilots' Association (BALPA) official commented:

> *"The culture of the company is crucial to the success of FRMS, which creates one of the biggest challenges to its effective use."*
>
> (Jones, 2007)

Similarly employer groups are wary that FRMS may be a charter for disaffected employees to abuse the system by falsifying fatigue issues for their own ends and prejudicing the airline's operation. Other concerns focus on the difficulty of implementing and regulating such an amorphous system which appears to set ill defined boundaries that may have dubious legitimacy, to limit operations.

Substitution of the "hard rules" of FTL schemes, drawn up right at the outset of FTL design to protect the lifestyle aspirations of flight crew, would be fiercely opposed. Only through recognition of the underlying tenet of FRMS philosophy which promotes a work/lifestyle balance that relies on equally satisfying both the needs of the operational task and the employee, one reliant on the other, will the change in culture occur.

Successful FRMS adoption requires a holistic company safety culture that is complimented by a corporate culture of universal, mutual trust and respect.

8.0 Future Applications of FRMS

Complete objective recording of circadian rhythms and sleep profiles of the whole flight crew workforce of an airline could be facilitated by technological development of a combined mini Biorhythm and Actiwatch physiological monitoring device that was made unobtrusive to wear. This would allow a continuous monitoring process and be an integral part of the company's FRMS.

The data from such a monitoring programme could enhance the "risk radar" of the risk assessment/management process, contribute to a much more thorough database of fatigue risk which could guide future research into the area, improve computer fatigue modelling, and be a valuable aid for fatigue risk mitigation.

Benefits for the individual pilot might include; assessment of their personal tolerance to fatigue, advice on lifestyle options to address areas where monitoring identified fatigue susceptibility and informing the roster production process to allocate trips that suited their physiological routine.

For crews on standby duty, continuous monitoring matched to computer fatigue modelling could protect them from the excesses of dynamic, operational crewing decisions and be a valuable tool for crewing staff to make best use of their available standby crews.

9.0 Conclusions

The very nature of long-haul flying exposes pilots to fatigue risk through:

- Working long duty periods;
- Routinely operating over the WOCL period; and
- Accumulating sleep debt due to sleep pattern disturbance owing to circadian rhythm disruption.

Traditional prescriptive FTLs as a means of fatigue management were originally designed:

- Largely according to industry best practice;
- With little medical or scientific foundation;
- With minimal alleviation for effects of circadian disruption due to trans meridian shift;
- To limit hours of duty rather than maximise opportunities for sleep;
- Being better suited to aid recovery from physical rather than mental fatigue; and,
- As a static form of regulation not able to adapt to a dynamic environment.

Although modified over the years in reaction to changing industry conditions, FTLs have:

- Suffered from poor interpretation and/or abuse;
- Been exercised to unintended degrees due to intense commercial competition;
- Required extra allowances "bolted on" such as variations, dispensations and exemptions to permit the extremes of airline activity i.e. ULR flights;
- Insufficiently adapted to regulate 2 pilot long-haul and short-haul LCC operations and other advances in the industry; and,
- Allowed "in seat napping", to compensate for FTL shortcomings.

The lack of effectiveness of FTLs to regulate fatigue has been masked by:

- An accident reporting regime that was reluctant to assign fatigue as a cause;
- "Macho" industry culture that considered fatigue management as a threat to commercial competitiveness resulting in underreporting of fatigue issues;
- Labour negotiations that traded FTL issues for employment compensations;
- Perception that if the operation was "legal" then it must be safe: and,
- Difficulty in measuring and assessing effects of fatigue.

More recent “enlightened” accident/incident reports, confidential reporting and a subjective pilot survey suggest unacceptable levels of fatigue do occur under prescriptive FTL schemes.

With increasing evidence of FTL deficiencies and the uncertainty over the future of the European FTL regulatory environment the case for FRMS adoption becomes ever stronger.

FRMS is a holistic, scientifically based, data driven fatigue management system that can be an integral part of an airline’s SMS. The philosophy of the system is based on:

- Multiple defensive layers to protect against fatigue;
- Shared ownership and responsibilities;
- “just” culture reporting;
- A risk assessment/management process that continuously, and dynamically adapts the system to mitigate risks;
- Consultation and communication;
- Reactive and proactive risk mitigation; and,
- Open and transparent policy.

For a long-haul operation the SAFE, computer fatigue modelling programme can play a key role as the proactive component in the FRMS risk assessment/management process.

Early experience has shown that implementation of FRMS involves a major change management task that must include:

- Comprehensive education to promote cultural shift in safety thinking;
- Top Management (and union) commitment;
- Initial and recurrent training to reinforce knowledge;
- Establishment of organisational framework within SMS;
- Thorough planning of transition from FTLs to FRMS; and,
- Safety case “trials” with an HFMP.

Despite high start up costs and high establishment workload during implementation phase, FRMS can bring about the following benefits:

- Improved safety leading to lower administration /engineering/insurance costs;
- Increased operational flexibility and adaptability;
- Compliance with corporate governance and duty of care legislation;
- Isolation of industrial issues from fatigue management:
- Corporate brand protection;
- Better regulator oversight;
- Engaged workforce due to:
    - Improved rostering;
    - Better lifestyles;
    - Lower levels of fatigue;
    - Transparent, scientifically credible system; and,
    - Shared ownership.

The best outcome for FRMS introduction will only be achieved through a partnership between management and union to promote a company culture that fosters universal mutual trust and respect and is open to the "shared ownership" and "just culture" doctrines.

During the implementation phase of FRMS it will be important that regulator oversight is increased to ensure that the system is properly adopted. This process may take 2 years or more.

With advances in physiological monitoring equipment, universal workforce sleep and body clock data could be gathered contributing to a comprehensive database of fatigue risk.

10.0 Recommendations

In light of proposed changes to European fatigue management regulations, the best option for a UK long-haul airline is to implement an "alternative scheme" governed by FRMS principles.

As part of their drive to mandate FRMS, regulators should be encouraging the aviation industry to:

- Share fatigue management knowledge in a central database;
- Understand the philosophy and case for FRMS;
- Adopt FRMS best practice;
- Network with regulator and other organisations for rapid dissemination of:
    - New ideas;
    - Guidance;
    - Proposed regulation;
    - Case studies;
    - Presentations; and,
    - Problem areas and solutions.

Regulators should also publish guidance documentation to educate organisations about FRMS and aid them in implementing policy, procedures and practice. Such guidance should take the form of:

- An FRMS toolset;
- Generic examples of FRMS policy and procedure to fit common cases;
- Advice on regulation requirements;
- A manual authoring and assessment tool; and,
- Guidance on internal monitoring and audit of FRMS.

Regulator oversight commitment during an airline's FRMS implementation phase should be enhanced.

11.0 Future Potential Areas of Study

In the context of the aviation industry there is, as yet, no detailed understanding of the relationship between fatigue and levels of safety (Dawson et al, 2005).

With widespread aviation industry implementation of FRMS resulting in greater quantities of alertness testing data, physiological monitoring data and fatigue related safety outcome data becoming available, studies could be undertaken to establish the relationship of fatigue to safety; a relationship that would fundamentally underpin the justification for FRMS.

Other studies might look into how task loads associated with specific trip patterns effect fatigue, using the NASA Task Load Index (NASA, 1988) and the effects of cumulative fatigue acquired over months and, indeed, years of long-haul flying on general health.

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Appendix A

The Mechanism of Sleep

The mechanism of sleep itself comprises of several stages that are sequenced in cycles lasting around 90 minutes throughout the period of sleep. The stages' descriptions are laid out in Table 1 and the structure of sleep shown in Figure 3:

Stage	Description	Time of Occurrence	Function
1	"drowsy sleep", some awareness of surroundings, microlapses ,microsleeps	Transition from waking to sleep, usually 10 minutes	Part of "sleep onset latency"
2	Accounts for 50% of sleep, irregular brain wave pattern, "spindles"	Between Stages 1 and 3, usually 15 minutes	"True onset of sleep"
3	Slow wave sleep (SWS) – "deep sleep", slower brain activity	Between Stages 2 and 4 usually lasting 15 minutes	Body restoration and immune system regeneration.
4	Slow wave sleep –"deep sleep", slow brain activity	Most Stage 4 sleep occurs early in night	Decrease in metabolism
REM	Rapid eye movement, desynchronous brain activity, "paradoxical sleep"	90 minutes after sleep onset in cycles of increasing amounts	Strengthening and organising of memory

Table 1. Mechanism of Sleep (Green et al, 1991 and Caldwell et al, 2003)

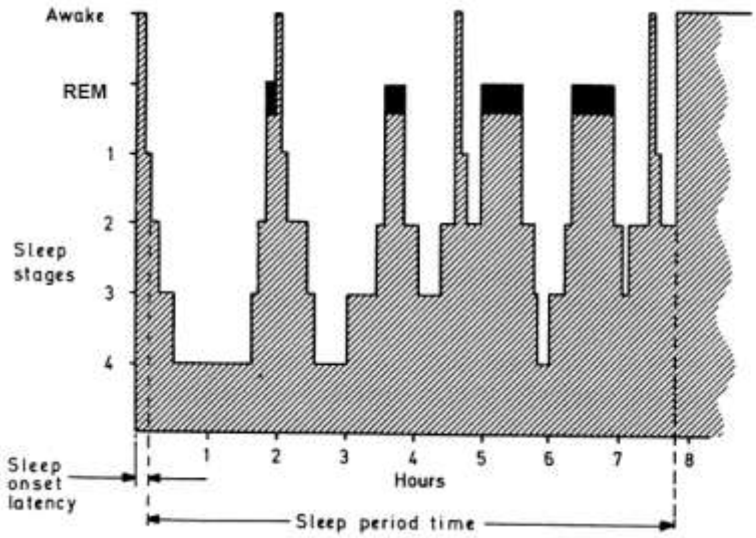


Figure 3. Typical Nocturnal Pattern of Sleep of Young Adult as indicated by Electroencephalogram (EEG) Recording (CAA, 2005b)

Appendix B

UK Flight Time Limitations Schemes' History and Development

History

The first time any means of flight time limitation was exercised in the UK was in 1927 when the authorities decreed that flight crew should undergo a complete medical examination if they exceeded 125 flying hours in any 30 consecutive days.

The first Standards and Recommended Practices (SARP) document produced in 1948 by the newly created Council of the International Civil Aviation Organisation (ICAO), that became the basis for Part I of Annex 6 of the ICAO convention, recommended that an operator should *"formulate rules limiting the flight time and flight duty periods of flight crew members."* and also called *"for adequate rest periods and shall be such as to ensure that fatigue, occurring either in a flight or successive flights or accumulated over a period of time due to these or other tasks, does not endanger the safety of a flight."* (Bader, 1973).

This requirement was incorporated as an article into the British Air Navigation Order (ANO) in April 1950.

After the crashes of 2 British aircraft, the first a York aircraft (G-AHFA) into the Andes mountain range of South America on 2 February 1953 and secondly a BOAC Constellation aircraft (G-ALAM) on landing at Kallang Airport Singapore in September 1954, pilot fatigue was cited in both accidents reports (Bader, 1973). These reports prompted an amendment to the ANO, in May 1957, that required operators to establish their own limits on flight time and duty periods within amounts fixed by provisions of the Order. Additionally an absolute limit on crew flying public transport aircraft was imposed of 125 hours in any 30 consecutive days.

In January 1964 the UK Ministry of Aviation further restricted this limit to 115 flying hours in 28 consecutive days and constrained roster schedule planning to one hour shorter than was actually allowed on the day by the ANO.

By January 1968, after earlier proposals for extensive restructuring of the regulations could not be agreed to, a comprehensive guidance to help operators discharge their responsibilities under the ANO was promulgated in Civil Aviation Publication (CAP) 295 and as an appendix to *Air Operators' Certificates; Information on Requirements to be met by Applicant and Holders* (CAP 360). This advised that a multi-pilot, single sector flight duty period should not extend beyond 12 hours and again reduced the absolute limit on flying hours to 100 in 28 consecutive days. Again, the onus was put on operators to follow this guidance material to set their own limits subject to the oversight of the Department's Flight Operations Inspectorate.

When proposed further changes to these guidelines were circulated by the Director of Flight Safety (Department of Trade and Industry) in July 1971 difficulties once more arose in the consultation process with interested parties and the proposals were not implemented.

This, then, was the background to the decision to set up a committee of inquiry into the subject that, under the chairmanship of Douglas Bader, was called the Committee on Flight Time Limitations (FTLs), the report of which, on 4 June 1973, led to the framework that all UK FTLs have since been based on and that has remained largely unchanged to the present day (Bader, 1973).

The Avoidance of Excessive Fatigue in Aircrews

The "Bader Report", as it became known, called for the consolidation of the hitherto fragmented regulation of operators' scheduling arrangements variously contained in ANO 1972, CAPs 360 and 295 into a single, uniform "flight time limitations requirements" document, the provisions of which would be administered by a new, permanent body, the Flight Time Limitations Board. This was constituted to advise the Civil Aviation Authority (CAA) on matters of requirements and legislation but with the overriding remit of ensuring flight safety. Of note here is that amongst the appointees to this board of operators and "*practising airline captains*" there was to be an independent aeromedical specialist (Flight International, 1973).

The prime objective of the report was to make recommendations to ensure *"….. that aircrew are rested at the beginning of each duty period."* For such a technically complex matter it was considered that the emphasis should not be by enforcement through legislation but rather by close supervision of the authority through granting and maintaining of the Air Operators' Certificate.

In producing its report the committee recognised the sensitivity of and effect that their deliberations would have on *"…. the economy of airline operations and on the attractions or otherwise of the aircrews' professions*." and also how contentious a factor fatigue was in industrial negotiations (Bader, 1973). Of the 3 sources of evidence considered; aeromedical, accident reports and opinion based on experience of operators and aircrews neither of the first 2 were thought to "*…provide a basis for establishing fatigue requirements in quantitative terms."* although it did concede that future modification of the regulations should be made "*….in the light of experience and results of aeromedical and other research."* (Bader,1973).

The report introduced the concept of the "duty cycle" as the most appropriate framework for defining measures to prevent fatigue analogous to the normal working patterns of other occupations. "Duty" was reclassified as; flying duty periods (FDPs), positioning, ground training, ground duties and standby duties. This cycle was to be constructed with reference to 4 separate but interrelated operator set controls, limited by constraints of the requirement, on; cumulative duty hours within a duty cycle, individual duty periods, individual rest periods, and length of duty cycles related to time off.

In keeping with the "duty cycle" philosophy and to limit cumulative fatigue a weekly and monthly limit on duty hours (flying plus other duties) was recommended at 50 hours within any consecutive 7 day and 160 hours within any 28 consecutive day period for all types of operation. The existing 100 flying hours limit within 28 consecutive days was to be maintained. A further, annual limit on flying hours was set at 900 hours in any consecutive 12 calendar months. This was based on the assumption of a typical 1680 annual hours for workers in business and industry occupations and relating this to flying hours using a ratio of 1.87:1.

The FDP was redefined to include the post flight duties and was governed, in most cases to values more restrictive than hitherto allowed. The calculation was done according to a set of tables that took into account a number of factors that influenced the duty such as; local start time, number of sectors operated, whether the individual was acclimatised to local time and or the length of the preceding rest period.

The rationale for the new FDP limits was based around an appreciation for the normal human cycle of 16 hours wakefulness and 8 hours rest, reducing available duty for later starts and setting limits for the amount of time spent on standby and following duty. Although acknowledgement of the effects of circadian rhythm disturbance (time zone shifts) were reflected in the proposals it was observed at the time that *"the maximum cutback of an FDP due to time-zone effect is only one hour, and that that only covers morning departures."* (Flight International, 1973). The overarching recommendation in this area was that *"Crews should make a conscious effort to plan their activities in accordance with the requirements of their forthcoming duty period irrespective of local time."* (Bader, 1973).

Other recommendations were made on limits of minimum rest, short breaks, days off, split duties, in-flight relief, positioning, helicopter operations, single pilot operations and, with respect to issues of crew lifestyles, on notification of rostered duties. Notably, following the example of the Australian ANO, the report suggested that the UK ANO should be amended to include the all encompassing requirement *"… that a flight crew member should not fly, and an operator should not require him to fly if the crew member is suffering from fatigue."* (Bader, 1973).

At the time the "Bader Report" was recognised as a sincere attempt to reconcile the various and often opposing views of interested parties, existing complex regulations and the poorly understood study of fatigue into a comprehensive and credible document. It was tacitly acknowledge as a good starting point and a "work in progress" on the matter.

All the recommendations of the report were passed into regulation and came into force as the first edition of CAP 371, "The Avoidance of Excessive Fatigue In Aircrews", on 1 May 1975.

Development

In July 1982 a second edition was published which simplified the details of the regulation, accounted for time spent on standby and balanced increases in permitted duty with increased requirements for time off (Flight International, 1982). A significant change was that FDP was redefined again to end at brakes on and so as to not include the post flight activities.

By the end of the 80's considerable changes to the FTL's were required owing to the greater prevalence of air ambulance operations, markedly increased helicopter activity supporting the North Sea oil industry, the growth of intensive holiday charter flights from the UK to Mediterranean destinations, increases in night freighting flights and the impending introduction of long range, 2 pilot crew aircraft such as the Boeing 747-400, the McDonnell Douglas MD-11 and the Airbus A340.

The CAA were particularly concerned that British airlines were rostering schedules which were technically within the requirements of CAP371 but outside the document's general principles and whilst not breaking existing pilot duty hour regulations had "*not applied the rules in the spirit in which they were drawn up*," (Flight International, 1989).

The third edition of CAP371, that took effect on 1 May 1990, introduced measures to combat disturbed sleep patterns resulting from roster disruptions and uneven duty cycle work rates. Duty hour limits and minimum days off requirements were increased as was the minimum allowed day off rest time. Also introduced was a limit of not more than 3 consecutive night flight operations with a compulsory extended rest period before the first flight.

Other new requirement to schedule not more than 4 early starts or late finishes in any 7 days and rebanding of individual FDPs to limit early evening/late afternoon departures were set. For the first time new limits were imposed specifically on the flight duty periods that 2 pilot aircraft crew could operate to. The maximum crew standby duty period was reduced from 20 hours to FDP plus 6 hours and all time spent positioning was now classed as duty.

Further measures to accommodate the new breed of long-haul aircraft which were now coming into service included rules for augmented crew and revisions to in-flight relief provisions for operations with more than 2 pilots.

Commenting on these changes the British Airline Pilot's Association (BALPA) said at the time that the CAA had *".... decided to accept arguments based on commercial interests which prejudice the safety of pilots and passenger"* (Flight International, 1990). Nevertheless inclusive tour operators were contemplating having to hire 5-10% more pilots to comply with the new regulations highlighting the fundamental relationship between fatigue avoidance regulations and airline commercial competitiveness.

Throughout the 1990's, with the advent of new technology and commercial pressure calling for 2 pilot crewed aircraft to reach increasingly more distant destinations that required FDPs that went outside the template that the existing regulations provided, new mechanisms to accommodate these extended FDPs were devised and were known as variations to the standard FTL scheme. Still in use today, these variations were strictly controlled, awarded after seeking specific approval, recorded in the organisation's operations manual, could not be modified or amended without CAA permission and allowed extensions to normal FDPs of up to one hour balanced by compensatory factors such that the overall safety of the scheme was not compromised. To facilitate the burgeoning low cost carrier airline sector other variations were adopted which included self-drive positioning within an FDP and designation of alternate bases (CAA, 2005a).

In April 2006 the fourth edition of CAP 371 became effective and incorporated the standard variations as annexes to the main body of the document. Importantly the definitions of a week, 2 weeks and a month were tightened up to mean a continuously rolling period of 7, 14 and 28 days respectively as was originally intended but in subsequent interpretations had become open to abuse.

Other significant changes included the removal of the exemption from the "early start" limits if crew were accommodated in a company provided hotel, as scientific research showed that a night in hotel close to the airport did not produce a more effective night's sleep. Also steps were taken to stop the practice of abusing the 18 – 30 hours rest period by inserting a short period of standby to split the time into 2 rest periods of 18 hours or less so as to take benefit from the more advantageous subsequent allowable FDP (CAA, 2003b).

Appendix C

VAA Pilot Fatigue Survey

The survey, in the form of an online questionnaire, sponsored by the author, was run on a voluntary basis with respondents remaining anonymous. Out of a total 789 rostered pilot population at that time, 540 were surveyed with 131 responding, accounting for 17% of all VAA pilots. The responses achieved represented a balanced, indicative cross section of the pilot body in that there was an even spread of age and experience, almost exactly a 50/50 split between captains and first officers, and appropriate distribution of the different annual, contracted hours options. Notably, proportionally more Boeing pilots (53%) took part than did Airbus pilots (47%) where as a more statistically correct sampling would be around a 33/67 split, respectively. This possibly reflects better job satisfaction levels on the Airbus due to more agreeable trip rotations.

In the first part of the survey, to gain an appreciation of general fatigue levels and to investigate if any differences could be discerned between the Airbus and Boeing fleets (and their different trip patterns), pilots were asked to asses their clinical fatigue levels according to the Epworth Sleepiness Scale and record how many days of sickness they had taken in the last year.

Following that, respondents were invited to nominate the trip pattern that they found was the most fatiguing of all the trips that they did and rate their alertness at 5 key points within the cycle of the trip with respect to the Samn-Perelli Seven Point Fatigue Scale (SP). Comments were requested as to the reasons behind why the chosen trip was found to be most tiring and, finally, statements were sought of a more general nature about work related factors influencing fatigue.

It was accepted that, being highly subjective and retrospective in most aspects of its execution, this survey had limited value as a definitive statement of fatigue levels in the VAA pilot workforce. Rather its intended purpose was to point out problem areas of the VAA operation with respect to fatigue that could then be assessed from an FRMS perspective.

Analysis of the results of the Epworth Sleepiness tests indicated completely normal levels of fatigue within the representative sample as a whole with the Airbus pilots' average rating of 7.16 coming out slightly nearer to the bottom end of the "mild sleepiness" range (8-10) than did the Boeing pilots' score of 6.79.

The responses to the sickness question did, however, highlight noticeable differences between the 2 fleets. On the Airbus 28.6% of pilots said that they had not taken any sick leave in the last year whereas for the Boeing the figure was 37.7% suggesting some 9.1% more pilots went sick on the Airbus. Pilots taking over 2 week's sick leave were proportionally more prevalent on the Airbus with 17.5% recording the longer absences to the Boeing's 6.4% and embedded within those results 7.9% of the former having over 6 weeks away with no participating Boeing pilots falling into this category at all (Figure 4).

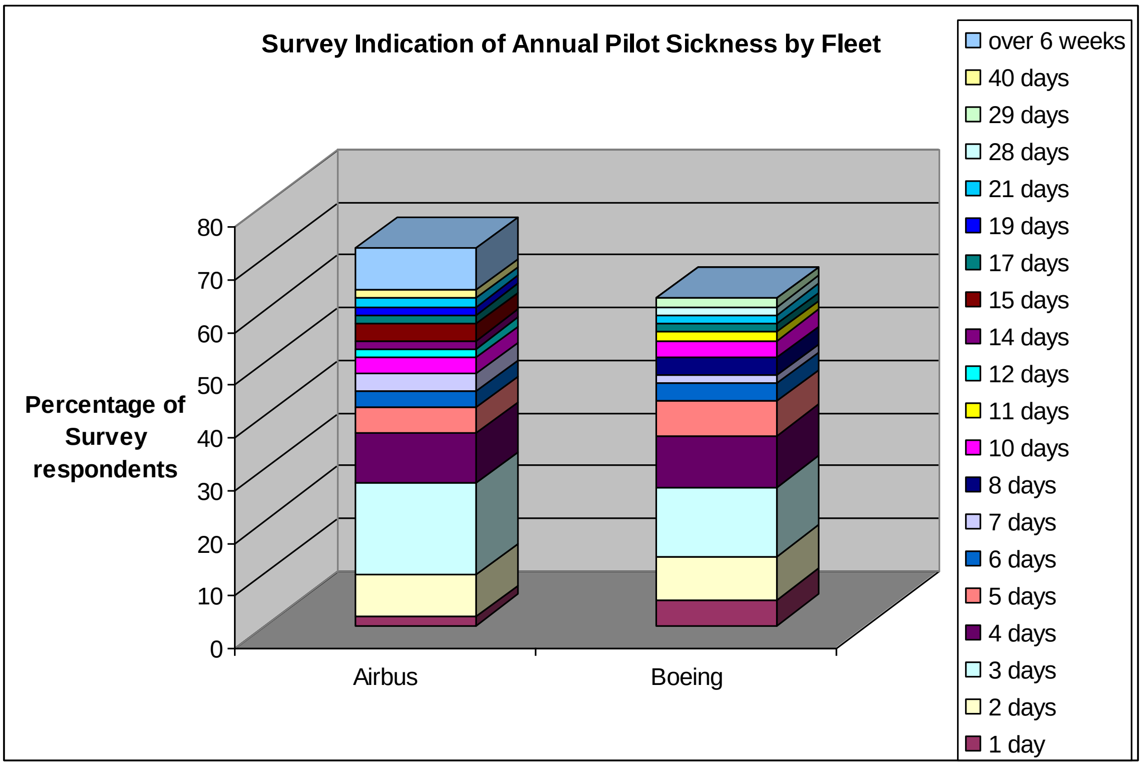


Figure 4

In terms of the number of sick days per pilot per year, according to those who responded but excluding those Airbus pilots who had had over 6 weeks sick leave, the rates were 3.97 for the Boeing fleet compared to 4.86 for the Airbus; a 22.6% higher rate for the Airbus fleet (specific data for sickness over 6 weeks sick was not collected so it was not possible to include this in the calculation however, in this case, its inclusion would have made the difference even more pronounced).

With respect to which trip rotations were found to be most fatiguing it was apparent that each fleet had their respective trip that stood out in this category. On the Airbus 39.1% of pilots nominated the Hong Kong/Sidney (HKG/SYD) rotation as their most tiring duty and 80.8% of Boeing pilots selected one of several flights operating to either Orlando or Miami as their most exhausting trip. This latter trip employed the Florida 2 (FL2) variation to the approved company FTL scheme and, in most cases, required prior surface transport positioning between Heathrow and Gatwick, It is appropriate to note here that the Airbus fleet, that serves all East and South bound destinations as well as all US destinations bar 2, has a far bigger route structure than does the Boeing which only goes to the US, the Caribbean and very occasionally South Africa. This partly explains why, with FL2 flights representing a much bigger proportion of Boeing fleet's overall flying, the FL2 trips were scored, in percentage terms, significantly higher (64.9%) than the HKG-SYD flights on the Airbus (39.1%).

Interpretation of the coalesced SP Fatigue Scale survey results filtered to only show the trips polled as being the most arduous did indeed reveal parts of the trip cycle where the general feeling was of being "*moderately tired; let down*" and in some instances, most notably on the commute home, after duty end, being described as "*extremely tired; very difficult to concentrate*". Interestingly even the results from the non FL2 HKG/SYD trips, plotted for comparison, ranged into the upper reaches of the fatigue scale.

In order to put these findings into some sort of context one of the few yardsticks that is available to compare the results to more commonly held perceptions of degrees of alertness is to relate the SP scale with Blood Alcohol Concentration (BAC) levels. Research into this area suggests that the UK drink driving laws' BAC limit of 0.08 milligrams of alcohol per millilitre of blood is reached at around 4.8 on the SP scale (Dawson et al 1997). Plotted results for the SP scale survey, shown in Figure 5 below, indicated that the HKG/SYD chart line was above this level for a significant proportion of the last sector and that for the FL2, breached the 4.8 level at the top of drop (TOD) point on the inbound UK sector and peaked at a point markedly above this level for the commute home. Interestingly enough the authors of the paper that introduced the SP scale considered that flight crews with scores of 5 or above should not fly (Samn et al, 1982).

Of note for the FL2 line is that the indicated fatigue at check in for the next trip after minimum base turn round (MBTR) was slightly higher than the first reading in the cycle; possibly implying an aspect of accumulative fatigue with this rotation.

Interestingly, these subjective survey results show a reasonable correlation with the SAFE computer fatigue modelling predictions produced in Appendix F.

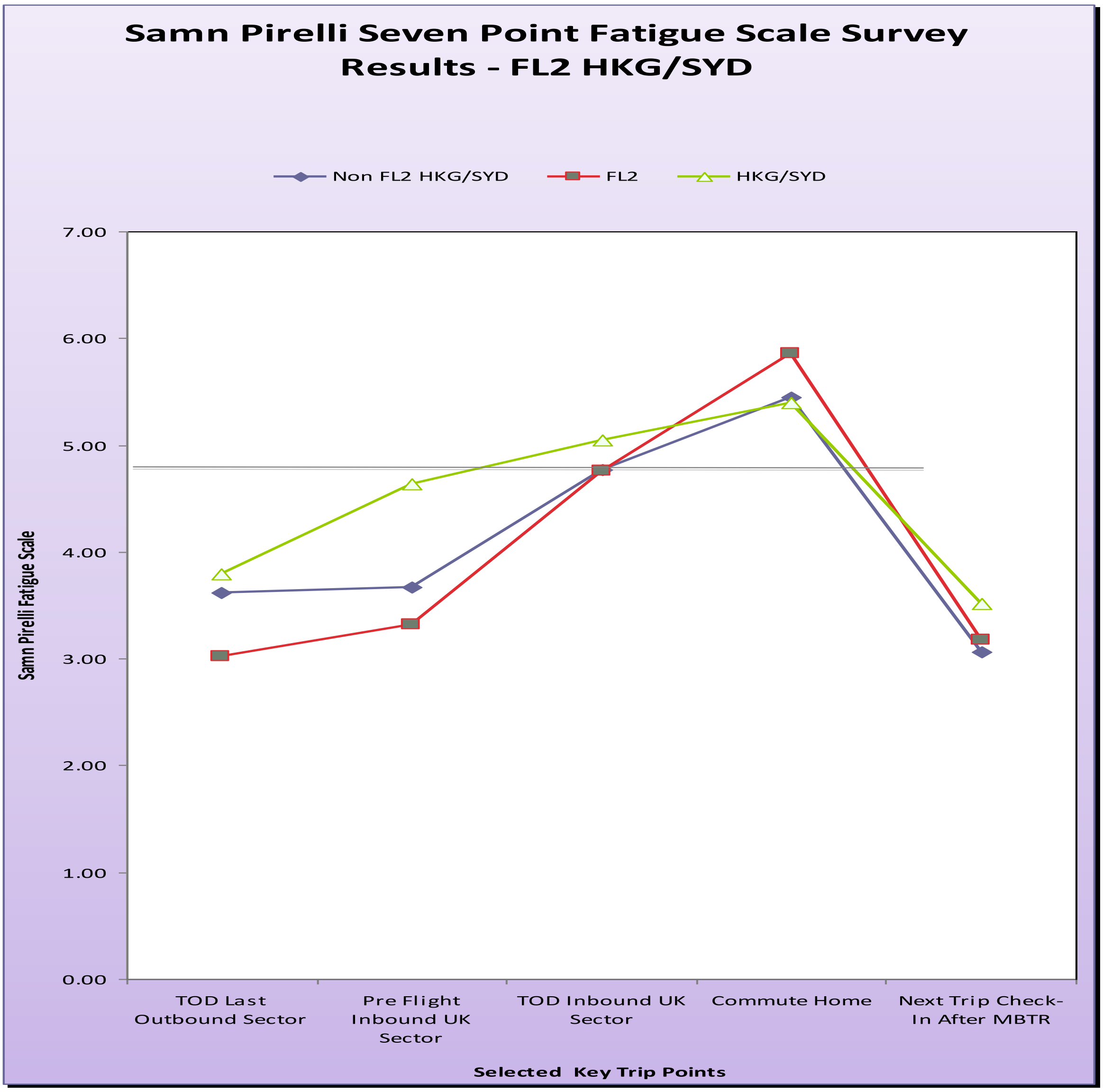
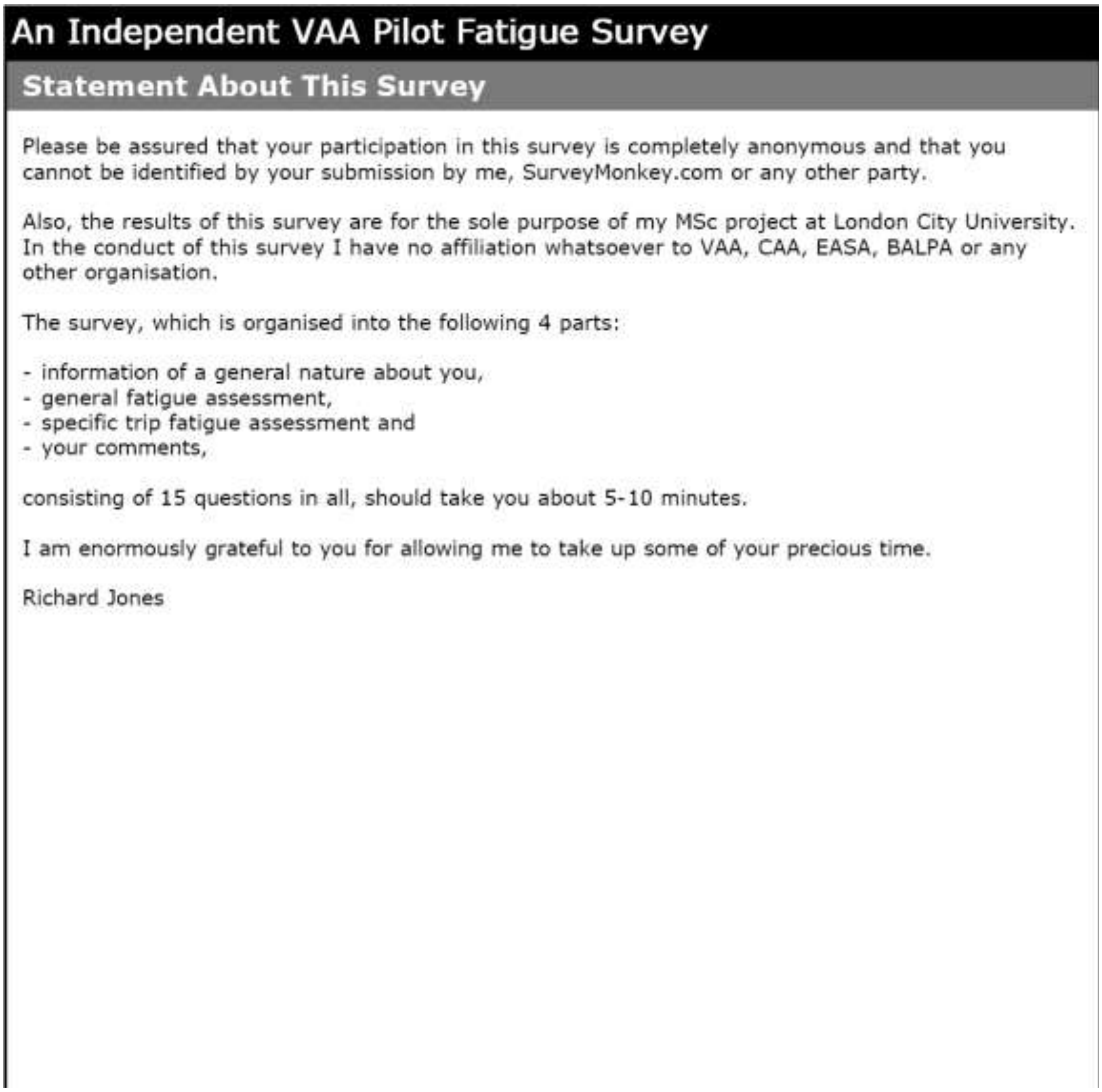


Figure 5

Comments received in the survey broadly backed up the results achieved from the analysed data with many respondents expressing the view that the current FTL scheme was not succeeding in properly regulating the risk of fatigue in the flying programme.

These survey results have to be qualified by reemphasising that respondents to the survey were self selected and could participate without fear of disciplinary retribution and so the pilots who did reply were most likely to be more predisposed to highlighting the more fatiguing aspects of the operational routine.

Fatigue Survey Questionnaire



An Independent VAA Pilot Fatigue Survey

Statement About This Survey

Please be assured that your participation in this survey is completely anonymous and that you cannot be identified by your submission by me, SurveyMonkey.com or any other party.

Also, the results of this survey are for the sole purpose of my MSc project at London City University. In the conduct of this survey I have no affiliation whatsoever to VAA, CAA, EASA, BALPA or any other organisation.

The survey, which is organised into the following 4 parts:

- information of a general nature about you,
- general fatigue assessment,
- specific trip fatigue assessment and
- your comments,

consisting of 15 questions in all, should take you about 5-10 minutes.

I am enormously grateful to you for allowing me to take up some of your precious time.

Richard Jones

An Independent VAA Pilot Fatigue Survey

Part 1

Firstly, I need to know some general information about you.

1. What age are you?

2. Which fleet are you on?

- A343/346
- B744

3. How many years have you been flying long haul?

4. Roughly how many flying hours do you have in total (in all flightdeck roles)?

5. Which seat do you normally fly from?

- Lefthand seat (including trainers)
- Righthand seat

6. For the last scheduling year which annual flying hours target were you on?

- 375
- 750
- Other
- 640
- 850

7. Roughly how many hours did you achieve in the last scheduling year?

An Independent VAA Pilot Fatigue Survey

Part 2

Secondly, I want to gauge your general state of fatigue by using the "Epworth Sleepiness Scale" and assess how different roster patterns associated with our 2 fleets may have a bearing on fleet specific sickness rates by asking you how many days off sick you have taken.

1. How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times. Even if you have not been in some of these situations recently, try to imagine how they would have affected you.

	would never doze	slight chance of dozing	moderate chance of dozing	high chance of dozing
Sitting and reading	○	○	○	○
Sitting, inactive in a public place (e.g. theatre or at a meeting)	○	○	○	○
As a passenger in a car for an hour without a break	○	○	○	○
Lying down to rest in the afternoon when circumstances permit	○	○	○	○
Sitting and talking to someone	○	○	○	○
Sitting quietly after lunch without alcohol	○	○	○	○
In a car, while stopped for a few minutes in traffic	○	○	○	○

2. How many days off sick (for any reason) have you taken in the last scheduling year? (optional)

An Independent VAA Pilot Fatigue Survey

Part 3

Thirdly, I want to identify those trip rotations that the general consensus considers generates the highest levels of fatigue and rate that fatigue at specific points during the rotation according to the "Samn-Pirelli Seven-point Alertness scale". This assessment is necessarily retrospective and subjective but it does have value for future FRMS applications by establishing a baseline of fatigue data for future reference and in validating both objective fatigue measuring methods (which are beyond the resources of this project) and computer fatigue modeling programmes such as that developed by QinetiQ,

1. From your experience over the last scheduling year, excluding those trips where you have had an extraordinary event such as a diversion, select from the list below the normal trip pattern that you would say has been the most fatiguing overall.

For Caribbean trips (other than Havana) please select the "Other - please specify below" option and record the details of the trip rotation in the box below as follows: outbound flt no. (VS....), 2 sectors (2S), dead heading (DH), layover nights (...N), positioning day (PD), inbound flt no. (VS....) etc. according to what applies.
For example: VS37,2S,3N,VS32.

Other (please specify)

An Independent VAA Pilot Fatigue Survey

2. For your selected trip, from your most recent experience, rate your level of alertness at 5 nominated points during that trip as indicated on the left hand side of the table below with reference to the scale along the top:

	Fully alert; wide awake;extremely energetic	Very lively;responsive;but not at peak	Okay;somewhat fresh	A little tired;less than fresh	Moderately tired;let down	Extremely tired;very difficult to concentrate	Completely exhausted; unable to function effectively
Top of descent, outbound sector or last sector of outbound phase (two outbound sectors)	○	○	○	○	○	○	○
Pre-flight, inbound to UK sector	○	○	○	○	○	○	○
Top of descent, inbound to UK sector	○	○	○	○	○	○	○
Commute home	○	○	○	○	○	○	○
Check-in for next trip after MBTR	○	○	○	○	○	○	○

Comments elaborating on any particular factors influencing a rating would be most helpful (optional)

3. For the trip in question were you a relief pilot?

- ○ No, not applicable - two pilot crew trip
- ○ No
- ○ Yes, and the scheduled allowed an equitable distribution of time in seat
- ○ Yes, and the scheduled required me to be "burnt out"

4. Was the trip operated according to the Florida Two Variation?

- ○ No, not applicable
- ○ No
- ○ Yes

5. Was hotac provided for the night prior to the start of the trip?

- ○ Yes
- ○ No

An Independent VAA Pilot Fatigue Survey

Part 4

Your Comments (optional)

1. Please feel free to make any comments on significant, work related factors that you feel affect your level of alertness.

Epworth Sleepiness Scale (Johns, 1991)

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times. Even if you have not been in some of these situations recently, try to imagine how they would have affected you.

0 = would *never* doze
1 = *slight* chance of dozing
2 = *moderate* chance of dozing
3 = *high* chance of dozing

- Sitting and reading	________
- Watching TV	________
- Sitting, inactive in a public place (e.g. a theatre or a meeting)	________
- As a passenger in a car for an hour without a break	________
- Lying down to rest in the afternoon when circumstances permit	________
- Sitting and talking to someone	________
- Sitting quietly after lunch without alcohol	________
- In a car, while stopped for a few minutes in traffic	________
Total Score	________

Scoring:

up to 8	-	normal
8 – 10	-	mild sleepiness
11 – 15	-	moderate sleepiness
16 – 20	-	severe sleepiness
21 – 24	-	excessive sleepiness

Samn-Perelli Seven-point Fatigue Scale (Samn et al, 1982)

Individuals are requested to select one statement that describes how they feel:

1 Fully alert; wide awake; extremely energetic
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

Appendix D

Sample FRMS Policy Statement

SAMPLE TEXT

Section 3.2.1 Senior Management Commitment to Managing Fatigue (Mandatory)

1. [Insert Company Name]'s Fatigue Risk Management System policy represents the strongest commitment at the highest level — signed by the accountable executive.

   [insert Company Name] is committed to protecting all employees, contractors, service providers, clients, visitors, and the general public from fatigue-related risk. There will be no compromise in an employee's well-being in anything we do. Implementing measures to minimize fatigue-related risk and create a safe, healthy, and injury-free environment is a leadership responsibility. Continuing support of this effort is the responsibility of everyone.

2. The purpose of the FRMS is to reduce, as far as practicably reasonable, workplace fatigue and its risks, to ensure a safe and error-free work environment for employees, contractors, and clients. The objectives of this policy are to ensure:

   - Employees are fit for work
   - The company enjoys a safe working environment by minimizing hazards associated with fatigue
   - The fatigue hazards associated with long work hours and shift work are minimized
   - Employees have access to assistance through a range of preventative initiatives, including training
   - Informed decisions are made about work design
   - On-going risk assessment and hazard monitoring takes place
   - Employees unfit for duty as a result of fatigue will be dealt with consistently and fairly in accordance with this policy

Resources for maintenance, development and implementation, updating and reporting of fatigue in the workplace in relation to the FRMS policy and personnel responsible for it will be through the Human Resources Department (or similar).

(Transport Canada, 2007b)

Appendix E.

Analysis of FRMS in Operation

Civil Aviation Authority, New Zealand

Although air transport operators in New Zealand have been allowed to choose between complying with prescriptive flight and duty time (FDT) regulations and applying for approval to operate under a potentially more flexible company specific FDT scheme since 1995, a recent study found that there was no appreciable difference in how fatigue was managed in terms of number and frequency of use of fatigue management strategies between those sets of companies opting for the different schemes. Moreover there was evidence of discrepancies between managers and pilots of the effectiveness of some fatigue strategies suggesting that there was an industry wide deficiency of knowledge of fatigue and fatigue management processes. The report recommended that the regulator and other industry groups should promote a more mature safety culture and greater knowledge base as a prerequisite to support and oversee company specific fatigue management schemes (Signal et al, 2008).

Civil Aviation Safety Authority, Australia

Instructed by a year 2000 Australian Government report entitled "Beyond the Midnight Oil" recommending CASA to implement a FRMS to regulate flight and duty times for aircrew, the Australian regulator commenced a trial of operator developed safety cases based on, initially, 21 operators implementing fatigue management systems (FMS). The impetus for this initiative came from the recognition that the FTL system governed by CAO 48, the CASA equivalent of CAP371, had become largely based on exemptions from the rules (variations in UK CAA terms), was proving difficult to manage and was not science based. It was also acknowledged that CAO48 had more to do with regulating work than managing fatigue.

In 2001, as part of the process of FRMS introduction, CASA cancelled many of the CAO 48 exemptions to encourage organisations to develop and implement FMS comprising policy, training and education, risk management and compliance audit mechanisms. CASA wanted to move the industry away from compliance to an arbitrary rule set and make safety the primary focus through a performance or outcome based model of regulation.

Although CASA's intentions were well founded, the scale and complexity of the task were underestimated. A 2003 CASA commissioned report observed that too few resources had been devoted to educating the industry about the major cultural shift to a safety-case approach to regulation. Many smaller operators, predominant in the Australian aviation industry, did not have the time or funds to invest in understanding the new system and crafting their own bespoke version of it. They simply added the company name to the relevant boxes of the guidance templates provided by Canberra as a means of complying, which effectively, flew in the very face of FRMS philosophy. As well as recommending more effort to be concentrated on education the report called for CASA to develop an FRMS "toolbox" to assist in system development and suggested an interim stage between CAO 48 and full FRMS compliance whereby, particularly for smaller operators, a range of "off the peg" policies were made available that could be "adapted" to the more commonly found, simpler operations (McCulloch, 2003).

Despite a poor implementation phase, CASA's trial has gained acceptance for FRMS and proved that it can be a successful FMS. Recent CASA announcements state that it is preparing to roll out FRMS industry wide and that all of the remaining CAO 48 exemptions will be withdrawn (Jackson, 2008).

Air New Zealand

Despite its, perhaps, uninspiring regulatory backdrop, Air New Zealand (ANZ) has whole heartedly grasped the FRMS initiative and is today considered the pioneer of FRMS adoption. Given its geographical location requiring long sectors with night time departures to get to Northern Hemisphere destinations at commercially appropriate times and with no overseas pilot basings resulting in trip rotations lasting up to 13 days, circadian disruption and fatigue are ever present hazards for ANZ pilots.

The airline's fatigue management programme began with the setting up of the Flight Crew Fatigue Study Group (FCFSG) to initially study the feasibility of introducing a policy for controlled rest recovery (CRR) on the flight deck (in-seat napping) as a means of temporarily enhancing alertness, based on research conducted by NASA. Through a joint management and union initiative the essential philosophy of the programme was that strategies would be "data driven rather than industrially motivated". The de-identified data, accessible to all participants, had to support the recommendations of the FCFSG whose workings were subjected to periodic, external, leading expert review and scrutiny. As a result of this successful initiative ANZ became the first airline in the world to introduce a CRR policy.

ANZ's FCFSG is much the same as a Fatigue Management Steering Committee discussed earlier but with the addition of a scientific advisor. It has set out the model that has informed the generally accepted FRMS structures and practices of today; monitoring, assessing and reporting fatigue risk; recommending mitigating strategies; raising awareness of the subject through education and training and carrying out fatigue surveys to identify problem areas and increasing the knowledge base. One area of the FCFSG's work has been the development of a computerised pilot alertness test (PATANZ) based on a Palm Pilot PDA that can be easily and inexpensively deployed for fatigue survey programmes.

ANZ's FRMS has identified trip rotations where fatigue risk was not immediately obvious due to comparison with similar rotations where there were no fatigue issues. However owing to hotel and airport transfer arrangements prior to one trip in question, the risk did become borderline significant. The finding lead to the pre-positioning of slip crews in order to operate the last sector of the pattern (Powell et al, 1998).

Other validation of subjective experiences of pilots by integrating knowledge obtained from fatigue reports, operational studies and focused studies has led to successful differentiation between effective and ineffective intervention measures. This was so on the Auckland – Los Angeles – Auckland rotation where the addition of a fourth pilot to the crew compliment was found to be more effective at reducing fatigue than an extra 24 hours of layover in Los Angeles. This strategy has now been adopted on other trip patterns (FSF, 2005b).

These examples highlighted some key characteristics of FRMS namely:

- Close correlation between subjective and objective data suggested that subjective means of fatigue assessment can have validity in the absence of objective testing due to impracticalities and/or costs;
- Management/union ownership of the FRMS process can bare fruit in terms of a safer operation;
- A scientific approach pointed up problem areas on trip patterns whereas a purely flight and duty time analysis would have compared these patterns favourably with other similar patterns where no problems existed.

Ultra Long Range Flights, Singapore Airlines

As regulator of one of the first airlines to conduct ULR flights, the Civil Aviation Authority of Singapore prepared for this undertaking by setting up a ULR Task Force which in turn took advice from the ULR Crew Alertness Steering Committee, a global forum sponsored by Boeing, Airbus and the Flight Safety Foundation consisting of representatives from medical research establishments, airlines, aircraft manufacturers, regulators, safety groups and pilot associations.

Informed by earlier experience of FRMS, the steering committee recommended that ULR flights should be approved on a case by case basis based on the assumption that the rotation was an out-and–back flight between an approved city pair using a specific aircraft type with a defined departure window and treated as a variation to an airline's FTL scheme rather than a broad based blanket approval for such operations. In addressing crew alertness and performance issues extensive guidelines were set out as to how a ULR flight procedures and practices should be formulated. These were categorised under the following headings:

- **Crewing**;

  - Flight Crew Compliment
    - Number of flight crew required assessed according to scientific evidence and operational experience
    - Initial FRMS validation of crew compliment
    - Review of crew compliment according to validation results
  - Flight Crew Qualifications
    - Operational experience of long-range flights
    - Minimum of 4 pilots, 2 of which must hold pilot in command qualification, 1 of which should be at the controls at all times

- **Education**;

  - Training of all staff associated with ULR operations; management, pilots, cabin crew, scheduling and rostering staff, dispatchers, operations staff and airline medics to include the following curricula:

    - Consequences of fatigue on aviation safety;
    - Confidential feedback from incidents;
    - Recognition of signs of fatigue and decreased alertness in self and others;
    - Physiology of sleep;
    - Circadian rhythms and homeostatic process;
    - Sleep and alertness strategies;
    - Diet and Hydration;
    - Prescription and non-prescription medication, plus related regulatory policies;
    - In-flight environment;
    - Work scheduling and,
    - Crew coordination to address sleep inertia after in-flight rest.

- **Delays and Disruptions**;

  - Specified maximum allowable departure delay dependant on city pair and whether at home base or outstation to ensure "creeping delay" does not compromise crew alertness
  - Regulator approved delay, disruption and diversion contingency plans
  - Risk assessment of all factors associated with a diversion on a ULR flight including reversion to long range flight FTLs
  - Captain has final authority for the safe conduct of the flight with respect to crew fatigue

- **Standby**;

    - Standby crew must fulfil pre-ULR rest requirements
    - Dedicated ULR standby system
    - Early notification of in-flight rest allocation

- **In-flight Environment;**

    - Rest
        - Crew rest facilities are sufficient to ensure pilot alertness is maintained at an acceptable level. Ideally individual compartments separate from flight deck that allow reclining or horizontal sleep and appropriately designed to cater for the following factors:
            - Noise levels;
            - Changing space
            - Reading lights
            - Ventilation, temperature and humidity controls
            - Alerting and communication systems to flight deck and passenger cabin
            - In-flight entertainment

    - Lavatories
        - Dedicated flight crew lavatory within flight deck secure area

    - Flight deck environment
        - Ergonomic design to reduce stress and fatigue levels such as:
            - Comfortable seating;
            - Suitable lighting and sunshades to limit sunlight and heat;
            - Noise management;
            - Humidification control and
            - Appropriate system alerting mechanisms.

- **Rostering Practices**:

    - Operating patterns for flights and layovers should provide:
        - Adequate pre-flight and layover rest preferably affording 2 major sleep opportunities to ensure crew member fully rested prior to flight departure;
        - Adequate physiological recovery time after trip;
        - Reasonable additional time off for normal social interaction;
        - Recovery time that does not infringe pre-ULR rest requirements, and,
        - Crews acclimatised to local base time before trip start.

- In-flight rest procedures should include:
  - Responsible plan promulgated for in-flight rest planning;
  - In-flight rest planning guidance provided to crew;
  - In-flight rest tailored to flight pattern;
  - Adequate crew notification of in-flight rest period allocation;
  - A degree of flexibility towards rest allocation once flight underway;
  - Change/handover procedures particularly with respect to sleep inertia following a rest period;
  - Cockpit napping procedure advice (used as a complimentary strategy)

- Scheduling of ULR trips:
  - Not to include duty positioning as part of pre-ULR rest period:
  - Must be considered a "stand alone" duty and not combined with any other.

- **Go/No-go**;

  - Guidance material provided on go/no-go decision making with respect to factors affecting crew alertness and performance e.g.:
    - Minimum equipment list (MEL) provisions i.e. for rest facilities, inflight environment, degraded flight automation etc.;
    - Delays, disruptions, diversions, and,
    - Any other aspects that may affect crew alertness.

(FSF, 2005b)

To achieve approval for ULR flights SIA had to show compliance with these procedures and adopt FRMS styled practices such as mathematical computer modelling using QinetiQ's SAFE programme and create a company ULR operational steering committee to validate and monitor these procedures and outcomes in close cooperation with the CAAS.

Experience gained so far has shown that this cautious and consensual approach, complying with FRMS principles, specifically allowing crew members 2 inflight rest periods per sector and guidance on sleep management, has resulted in ULR crew fatigue levels that are favourably comparable to crew fatigue levels of conventional FTL regulated long range flights.

easyJet

In the early 2000s it became clear to easyJet management that, in following their business model of focusing on minimising direct costs and maximising resource utilisation, high flight crew utilisation, although within the boundaries of their FTL scheme, led to decrements in crew alertness and performance, increased absenteeism and attrition and an unacceptable risk of fatigue related accident (Stewart, 2008). At the time they operated a roster pattern of 3 early duties, 3 late duties and 3 days off (6/3 roster) that, given the multi sector minimum crew rest nature of the LCC working environment could, without sympathetic rostering, lead to unacceptable levels of fatigue risk exposure.

To acquire a better understanding of this situation easyJet developed a Human Factors Monitoring Programme (HFMP) that interrogated information from Flight Data Monitoring (FDM), FAID predictive modelling and other data streams from the company SMS to try to establish a link between flight crew fatigue, rostering practices and human error. The programme identified that the short time separating early and late duties on the 6/3 roster pattern presented a fatigue risk and suggested a pattern of 5 early duties, 2 days off, 5 late duties and 4 days off (5/2/5/4 roster). This new pattern was trialled alongside the current one and was found to more than halve the incidences of high to very high fatigue risk duties. Line orientated safety audit (LOSA) results indicated that crew mean error rates were aglso halved.

On the back of these results a safety case was presented to the UK CAA for alleviation from the CAP371 stipulations on consecutive early and late starts to allow implementation of the 5/2/5/4 roster. This was granted on the premise that easyJet introduce an FRMS to actively manage, by way of an evidence based system, fatigue risk (Stewart et al, 2006).

Much of the knowledge base of FRMS had previously come from the long-haul sector of the aviation industry so easyJet has been a front runner in the introduction of FMS into the European short haul arena. Consequently the company have had to develop their own FRMS very much from first principles, the latest human factors theory and other industries' best practice. A key element of the easyJet system is their bespoke risk assessment/management model, System Integrated Risk Assessment (SIRA) (Figure 15) that has been influenced in its design by the International Risk Management Standard 4360, a respected standard in the world of organisational risk management.

In subsequent operation the 5/2/5/4 roster was the subject of 9% of all duty related reports to the UK's Confidential Human Factors Incident Reporting (CHIRP) scheme in 2006 and indeed the roster was referenced in all reports received from easyJet pilots that year. Significantly the following year only one report was received after the roster routine was modified to allow 3 days off between the early and late duties (CHIRP, 2008). This then is perhaps the perfect example of an FRMS process in action; Reacting to a reported fatigue risk by investigation, analysis, assessment, acceptance, evaluation, decision and operational change management.

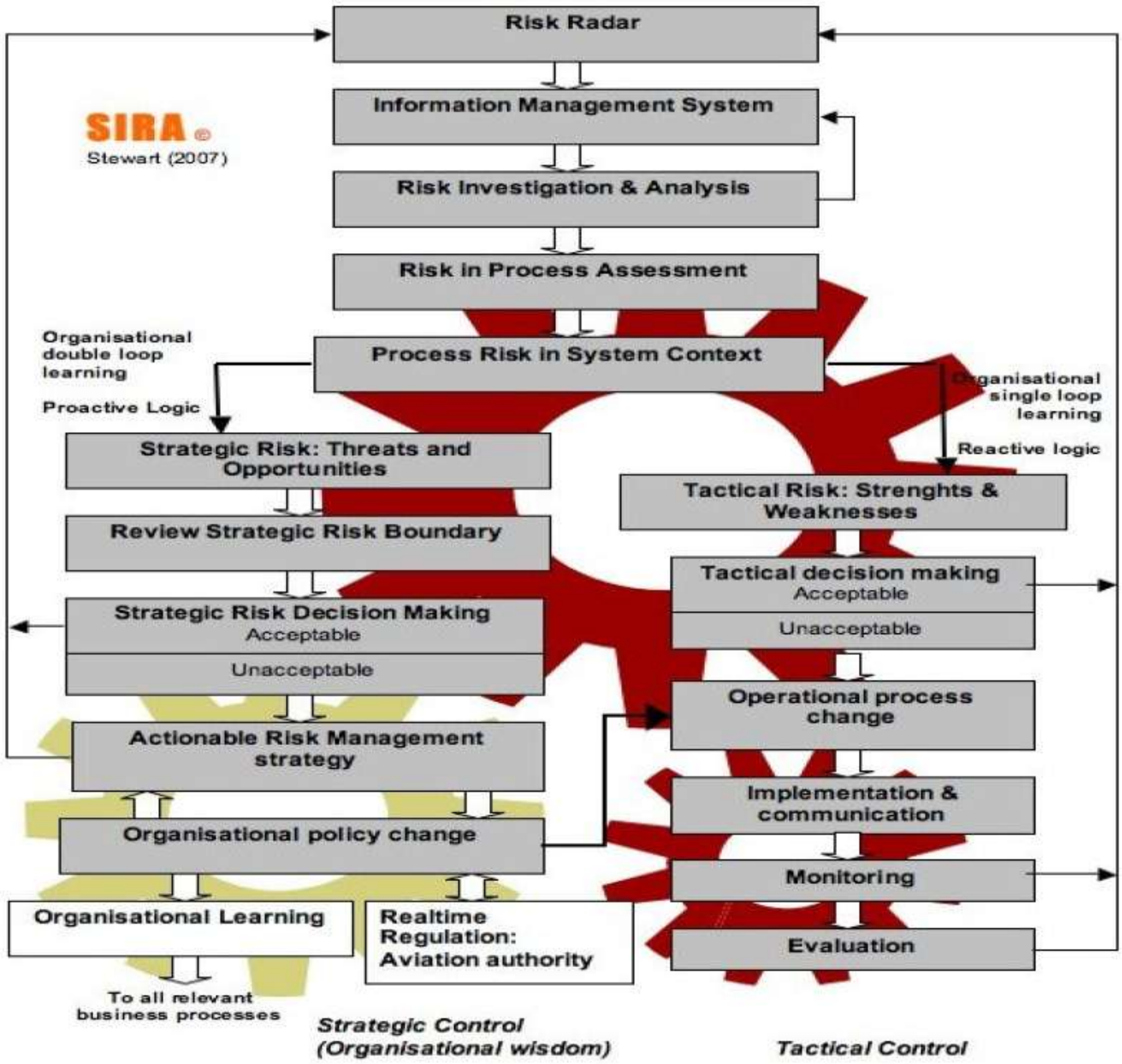


Figure 15. easyJet's Risk Assessment/Management Model – SIRA

(Stewart et al, 2008)

Appendix F

Example of SAFE Analyses of Trip Rotations Before and After Operation of Fatigue Risk Mitigating "Levers."

<u>Trip 1</u>

LHR-HKG-SYD

Current roster schedule, operated by 3 pilot crew all sectors (all times GMT):

Day	Report	Departure	GMT diff	Destination	GMT diff	Duty Finish
2	20:00	LHR	+1			
3				HKG	+8	10:20
4						
5	10:00	HKG	+8	SYD	+11	21:05
6						
7	03:05	SYD	+11	HKG	+8	14:25
8	09:40	HKG	+8	LHR	+1	19:20

Table 7. LHR-HKG-SYD Trip Rotation Schedule

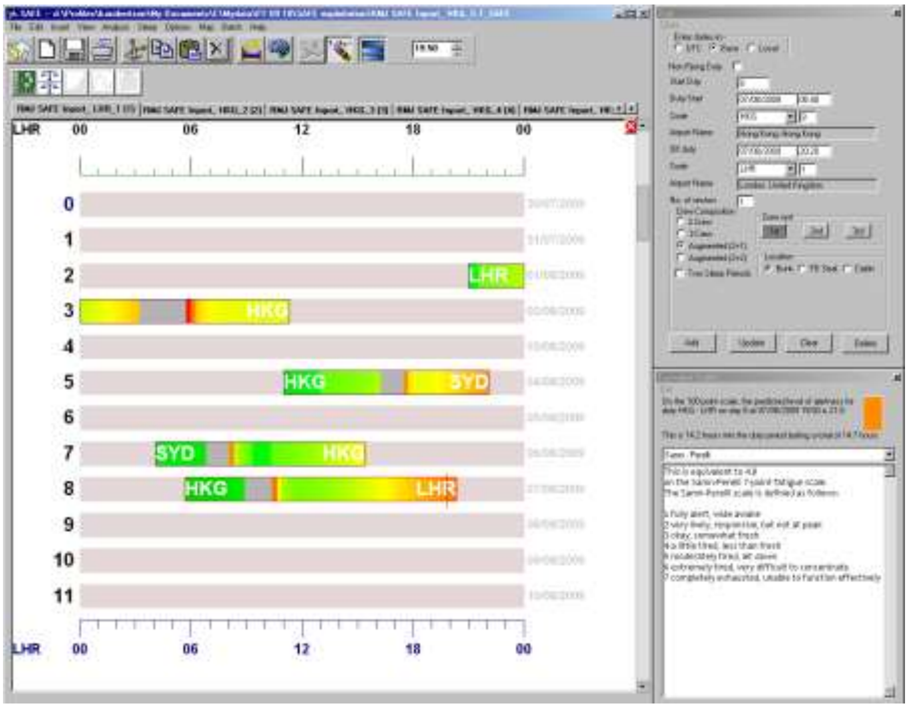


Figure 18. SAFE Analysis of Current LHR-HKG-SYD Schedule (3 pilots all sectors)

Samn Perelli Fatigue Scale prediction (above) for 1850Z on day 8 (time of landing at LHR) is <u>4.8</u>, i.e. equating to "moderately tired; let down".

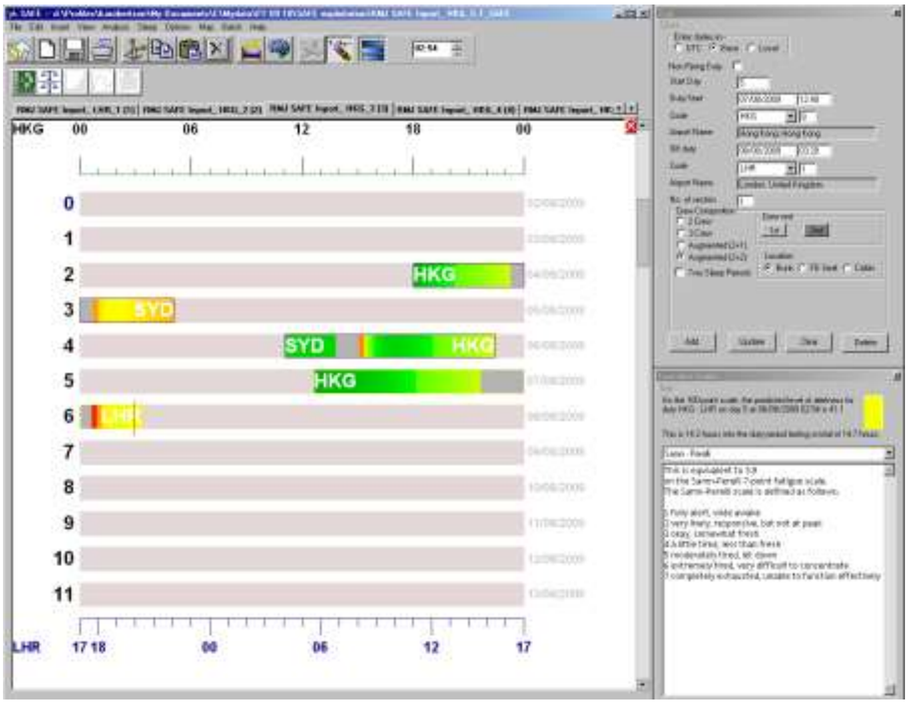


Figure 19. SAFE Analysis of LHR-HKG-SYD Schedule Modified by Inclusion of Fourth Pilot on Last Sector

Samn Perelli Fatigue Scale prediction for 1850Z on day 6 (time of landing at LHR) is 3.9, i.e. equating to "a little tired; less than fresh" – nearly a one point improvement in alertness on the SP scale.

(Due to limitations of the computer programme schedule could only be represented as starting from HKG outbound despite being a faithful analysis of whole trip pattern starting from LHR, hence trip finishes on Day 6 rather than Day 8 as previous analysis. Also LHR time is shown as local rather than as previously, GMT.)

Trip 2

LHR-LGW-MCO

Current roster schedule, operated by 2 pilot crew all sectors (all times GMT):

Day	Report	Departure	GMT diff	Destination	GMT diff	Duty Finish	Notes
2	0920	LHR	+1	MCO	-4	21:30	Surface Positioning LHR-LGW
3	22:10	MCO	-4				
4				LHR	+1	09:15	Surface Positioning LGW-LHR

Table 8. LHR- MCO Trip Rotation Schedule

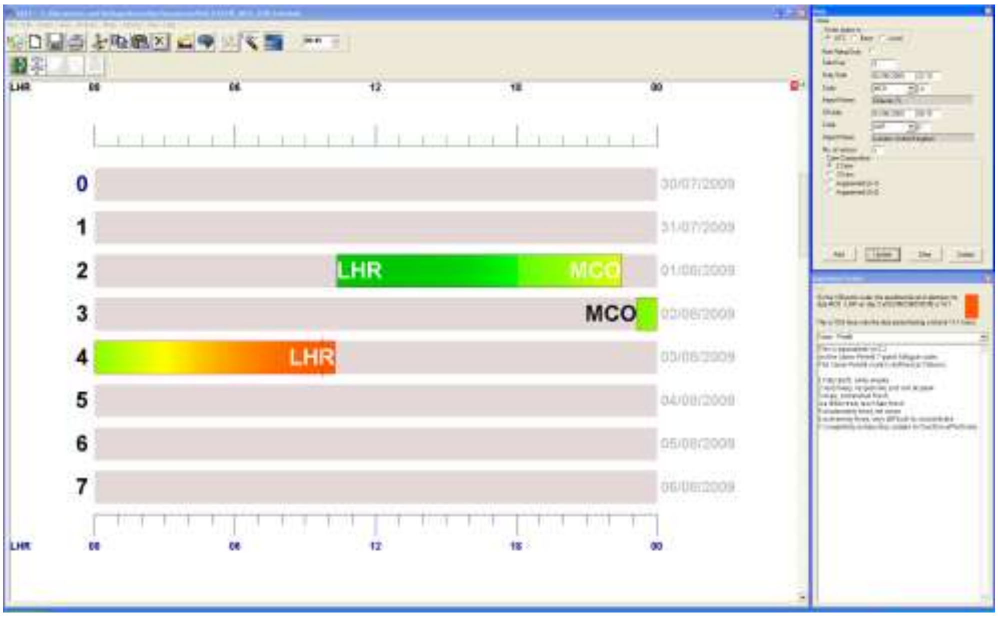


Figure 20. SAFE Analysis of Current LHR-LGW-MCO Schedule (2 pilots)

Samn Perelli Fatigue Scale prediction for 0730Z on day 4 (time of landing at LGW) is 5.2, i.e. equating to “moderately tired; let down”.

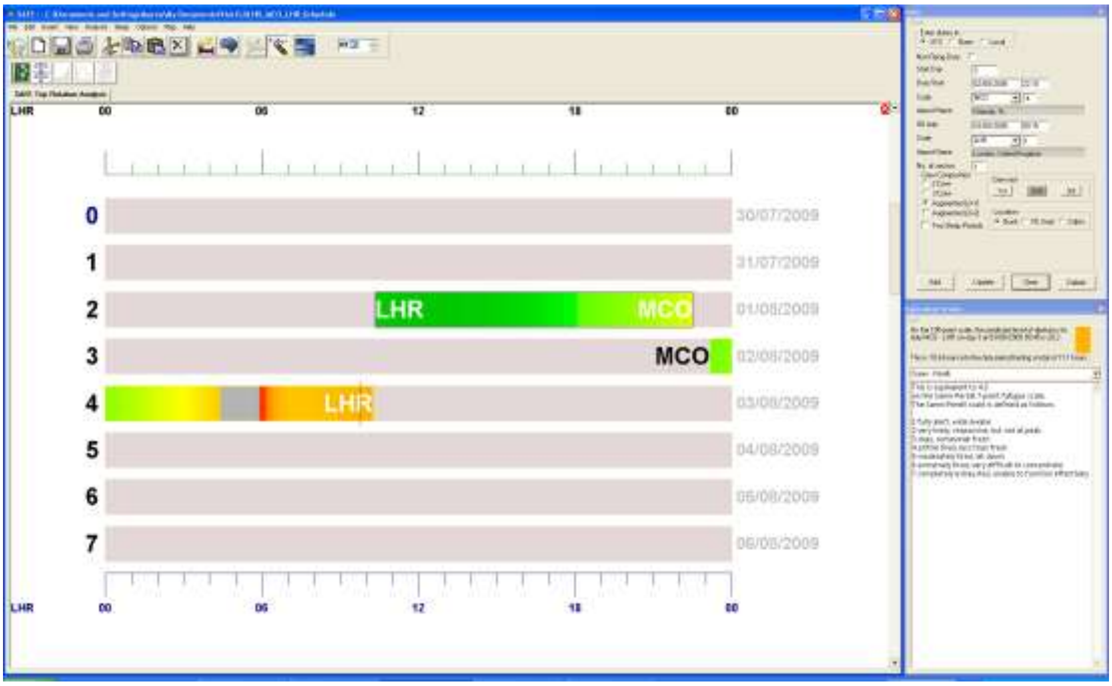


Figure 21. SAFE Analysis of LHR-LGW-MCO Schedule Modified by Inclusion of Third Pilot on All Sectors Allowing In-flight Relief on Return Sector

Samn Perelli Fatigue Scale prediction for 0730Z on day 4 (time of landing at LGW) is 4.3, equating to "a little tired; less than fresh" – nearly a one point improvement in alertness on the SP scale.

Notes:

- In the time line representation of the SAFE programme output the colours indicate:

Mauve/Grey	-	Off Duty
Green/Yellow/Orange/Red	-	Increasing Fatigue Levels during Duty
Grey	-	In-flight Rest taken in Bunk

- All analyses represent the most favourable case of the pilot flying (PF). Other pilots, PNF and relief pilots may record higher associated levels of fatigue.