Developing a Safety Management System for Fatigue Related Risks in easyJet

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September 30, 2009

EARLY DRAFT of HILAS Book Chapter

“An FRMS represents a “paradigm shift” in the way we manage the risks of fatigue. Such a system would be part of an airline’s Safety Management System, requiring a “just culture” environment and the full commitment of management.”

Curt Graeber, Chairman ICAO FRMS Task Force

“Measure what is important; don’t make important what you can measure”

Robert McNamara, US Secretary of State for Defence during the Vietnam War, advising his air force chiefs, when he discovered that they were using the number of buildings destroyed by bombs as a critical success factor

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Definitions

Accident	An unintended event or sequence of events that cause death, injury, environmental or material damage.
Fatigue Risk Management System	A data-driven flexible alternative to prescriptive flight and duty time limitations which is based upon scientifically valid principles and measurements and which involves a continuous process of monitoring and managing fatigue risk within the context of an operator's Safety Management System.
Fatigue	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**.**
Fatigue Countermeasures Training	A competency based training program designed to develop the awareness of all stakeholders about how the interaction of operational, rest, sleep, circadian and lifestyle factors impacts on the potential fatigue and resulting crew alertness and performance during flight operations.
Duty	Any task that flight crew or cabin crew personnel are required by the operator to perform, including, for example, flight duty, administrative work, training, and positioning
Crewmember	A person assigned by an operator to duty on an aircraft during a flight duty period.
Duty period	A period which starts when flight crew or cabin crew personnel are required by an operator to report for or to commence a duty and ends when that person is free from all duties.
Rest period	A continuous and defined period of time, subsequent to and/or prior to duty, during which flight or cabin crew personnel are free of all duties
Roster	A list provided by the operator of the times when a crew member is required to undertake duties.
FDM Event/Exceedence	Circumstances detected by an algorithm looking at FDR data.
FDM Parameter Analysis	Measurements taken from every flight e.g. maximum g at landing
Hazard	A physical situation, often following from some initiating event that can lead to an accident.
HILAS	EU Commission funded HILAS project (Human Integration into the Lifecycle of Aviation Systems) to introduce new scalable methodologies and technology to satisfy future regulatory requirements for SMS as well as introducing resilience principles into the easyJet operation to improve safety effectiveness and operational integrity based on organisational process knowledge and mapping, lean enterprise initiatives, technological innovation, risk based decision making and organisational learning.

Incident	An occurrence, other than an accident, associated with the operation of an aircraft that affects or could affect the safety of operation.
Level of Safety	A level of how far safety is to be pursued in a given context, assessed with reference to an acceptable risk, based on the current values of society.
Qualitative	Application of subjective, non-numerical methods to assess system and aeroplane safety
Quantitative	Application of mathematical methods to assess system and aeroplane safety.
Risk	Is the combination of the probability, or frequency of occurrence of a defined potentially harmful event and the magnitude of the consequences of the occurrence.
Risk Assessment	Assessment of the system or component to establish if the achieved risk level is lower than or equal to the tolerable risk level.
Safety	Freedom from unacceptable risk of harm.
Safety Management	The systematic management of the operational risks associated with flight, engineering and ground activities in order to achieve as high a level of safety performance as is reasonably practicable.
Safety Management System	A systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures
Safety Assessment	A systematic, comprehensive evaluation of an implemented system to show that the safety requirements are met.
Safety Objective	A safety objective is a planned and considered goal that has been set by a design or project authority.
Safety Policy	Defines the fundamental approach to managing safety and that is to be adopted within an organisation and its commitment to achieving safety.
Safety Performance	The level of safety achieved in a risk controlled environment measured against a safety level deemed as low as reasonably practicable**.**
Severity	The magnitude of the impact of a particular hazard as a function of the attendant potential consequences.
System	A combination of physical components, procedures and human resources organised to achieve a function.
Transient Fatigue	Transient fatigue may be described as fatigue that is dispelled by a single sufficient period of sleep.
Cumulative Fatigue	Cumulative fatigue occurs after incomplete recovery from transient fatigue over multiple days and nights and recovery occurs only after sufficient restorative sleep over multiple days.
Validation	The process of determining that the requirements are the correct requirements and that they are complete.
Verification	The evaluation of the results of a process to ensure correctness and consistency with respect to the inputs and standards provided to that process.

Abbreviations

ACARS	Aircraft Communication Addressing Reporting System
ADS	Air Data System - computer interface between aircraft systems and instrumentation/FDR
AGL	Above Ground Level - measured by aircraft's radio altimeter
ALARP	As Low as Reasonably Practical
AM	Accountable Manager
AME	Aero Medical Examiner
ANC	Air Navigation Commission
ANO	Air Navigation Order - Primary UK aviation legislation
AOC	Air Operator Certificate
APMS	Aviation Performance Measuring System - NASA's advanced FDR analysis tool set
APP	Accident Prevention Plan
AQP	Advanced Qualification Programme – relates training to operational experience
ASR	Air Safety Report – report submitted by aircrew regarding safety incident.
BALPA	British Airline Pilots Association
BASIS	British Airways Safety Information System - PC system for recording Safety Reports
BCAR	British Civil Airworthiness Requirements - civil code being replaced by JAR145
CAADRP	Civil Airworthiness Data Recording Programme - CAA-SRG's flight recorder analysis research programme
CAP	Civil Aviation Publication (UK)
C of A	Certificate of Airworthiness
CEO	Chief Executive Officer
CPSM	Crew Performance Safety Manager
CRPG	Crew Resource Planning Group
CSR	Cabin Safety Report
DAP	Dynamic Auditing Program
DFDR	Digital Flight Data Recorder - normally the crash recorder
DPA	Data Protection Act (UK)
EASA	European Aviation Safety Authority
EFIS	Electronic Flight Instrument System
EGT	Exhaust Gas Temperature
ETSC	European Transport Safety Council
FCLO	Flight Crew Liaison Officer
FDM	Flight Data Monitoring
FDR	Flight Data Recorder - normally the crash recorder
FLIDRAS	Teledyne FDM analysis software
FMC	Flight Management Computer - aircraft system control computer
FMS	Flight Management System - aircraft control system
FOI	Flight Operations Inspector
FOQA	Flight Operational Quality Assurance - FAA's term for flight data monitoring and its systematic use as a quality and safety monitor.

FRM	Fatigue Risk Model
FRMS	Fatigue Risk Management System
FTL	Flight Time Limitations
FTT	Fatigue Tolerance Threshold
GSR	Ground Safety Report
HFMP	Human Factors Monitoring Program
HFSO	Human Factors Safety Officer
HoW	Hours of Work
ICAO	International Civil Aviation Organisation
LOSA	Line Operations Safety Audit
MEL	Minimum Equipment List
MORS	Mandatory Occurrence Reporting System (UK)
NMC	Network Management Control
NPA	Notice of Proposed Amendment
NTSB	National Transport Safety Board
OQAR	Optical Quick Access Recorder
ORG	Operations Risk Group
ORM	Operations Risk Manager
PSWM	Prior Sleep Wake Model
QA	Quality Assurance
QAR	Quick Access Recorder - secondary recorder with a removable recording medium - traditionally tape, now moving towards Optical Disk or solid state
QSM	Quality and Safety Manager
SAG	Safety Action Group
SID	Standard Instrument Departure
SIDD	Safety Investigation & Data Department- UK CAA Department responsible for Mandatory Occurrence reporting System
SIRA	System Integrated Risk Assessment
SME	Subject Matter Expert
SOP	Standard Operating Procedure
SRG	Safety Regulation Group - part of UK CAA responsible for all safety matters
SSDFDR	Solid State Digital Flight Data Recorder
SSN	System Sensory Network
TCAS	Traffic Alert & Collision Avoidance System
TEM	Threat and Error Management
TSB	Transport Safety Board

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Foreword

The evolution of a system for the management of fatigue-related risk in airline and maintenance operations is at present a contentious issue (ETSC Fatigue seminar, 2009). The aspirations for the integration of fatigue management processes into existing SMS guidelines need to be placed in the realities of the present economic and commercial environment - they therefore need to exhibit relevance and demonstrate cost effectiveness if they are to survive the commercial scrutiny of operators worldwide. That scrutiny presupposes the operational and safety case is robust and coherent.

Detailed guidance material needs to be developed at the ICAO and NAA levels to support a graded approach reflective of operator size and complexity and place that into the guidance material along side the means of compliance. This has to work for the business, the end user and the regulator, so the approach must deal with all those areas. However, it is yet to be defined what formal advantages, or derogation from NAA regulation, an FRMS will confer on an operator.

At present, the fact remains that the practical implementation of FRMS is an immature science and the industry is at risk of repeating the mistakes of the early Australian implementation with an over-reliance on predictive models that are not based on operation airline research (Dawson, 2009).

easyJet has spent the last six years developing an operational practical capability in FRMS embodying the principles of ICAO Annex 6 and the EASA NPA 2009-02 (inclusive of the HILAS innovation from the SMS working group) while simultaneously reflecting the need for commercial relevance. easyJet has already faced the task of making FRMS relevant to the operation against the regressive desire of the practitioners for binary guidance as to what is deemed "safe" and "unsafe". This desire has arisen from the complexity of a maturing FRMS that produces a range of data and indicators that require informed interpretation. Among these indicators is the output from predictive modelling which nevertheless remains one element of the assessment toolbox. The collated output should be a fatigue index that allows an appropriate assessment of relative risk specific to the individual and their assigned duty in the context of the pertaining operational conditions. The legal responsibility for owning that risk should be part of the AOC approval process. However "good rostering" practice guidance will minimise the need for arbitration.

This is key to defining the relationship between prescriptive FTL and FRMS. For an operator to invest in FRMS it has to show benefits over adherence in whole or part to prescriptive FTL. Therefore some degree of FTL harmonisation remains an issue otherwise opting for a relatively loose set of prescription is a more attractive option that developing a comprehensive FRMS. The principle should be that the rigidity and scope of an operator’s prescriptive FTL requirement are proportionate to the credibility of their FRMS. A recognised and accredited FRMS conversely allows an operator the flexibility to introduce safe and commercially beneficial rostering solutions. Hence the need to focus on a regulator audit programme upon which graded accreditation will be based and which will define the minimum standard that must be attained for AOC approval.

While one would not pretend that FRMS implementation within easyJet has been without its challenges it has to be acknowledged that the discipline required to ensure relevance and applicability has provided the impetus and motivation to focus and progress. Our learning and knowledge has arisen from practical exposure to operational issues. There is a difference to being ‘paper safe’ as opposed to quantifiable ‘actual safety’.

1.1 Introduction

This document details an implemented Fatigue Risk Management System (FRMS) incorporating HILAS SMS concepts (Stewart et at, 2009a, HILAS, book 3, Ch 4) and models that have been developed to enable fatigue risk to be managed in an evidence-based, dynamic and comprehensive manner. A more detailed background on fatigue theory has been presented in HILAS Book 3, Ch 5 (Loukopoulos, 2009).

The relationship between fatigue and performance has been established where fatigue impacts on crew safety performance by impairing a range of cognitive skills including reaction-time, memory, decision making and communication (Durmer & Dinges, 2005). A Fatigue Risk Management System's function is to ensure that employees (e.g. flight crew, ground and engineering staff) are sufficiently alert so that they can operate to a satisfactory level of performance and safety (EASA, 2009). The same principle applies to the management staff, inclusive of rostering managers and day to day crewing staff who are responsible for decisions that may have fatigue performance implications for crew based on network disruption changes. The FRMS is a system of processes based on scientific principles, including methods for data collection and analysis and sequences effectively into an operators SMS framework. Among other benefits, the system enables easyJet to monitor and understand relationships between rostering, operational variables, crew fatigue and workload. The system also supports identifying where controls need to be implemented or strengthened.

The concept of an FRMS is a system that complements the application of, rather than replacing prescriptive limits "An FRMS should be used in conjunction with certification specifications or individual flight time specification schemes to meet flight and duty time limitations and rest requirements" (EASA, 2009). The FRMS permits operational flexibility through the ability to provide an alternative acceptable means of compliance. This allows for stylized FTL (Flight Time Limitation) schemes, as evidenced based prescriptive limits are more adaptive to the business model requirements of an operator.

1.2 Background to fatigue and operational safety

Fatigue and Safety in Commercial Aviation

"I agree that fatigue is an issue, and I hope that scientific evidence will eventually get the FTLs changed but bearing in mind that when JAA rules came in they were not as limiting as the CAA rules in most cases, there is little hope. There is no evidence. No one calls in fatigued. The only evidence the authorities have to work on is anecdotal or occasionally when it is obvious in an accident that human error was caused by fatigue. But then that pilot would be to blame for flying whilst fatigued" (www.pprune.org/rumours-news/196539-aircrew-fatigue-2.html, 10 December 2005).

"Out of curiosity, have there been any air accidents where the final cause determined was that the flight crew had fallen asleep?

I'm sure you just penned the question quickly and didn't give it much thought. Had you given it more thought you have realised that "falling asleep" is a symptom of chronic fatigue. We are just talking about plain old moderate fatigue. The kind which causes you to make "errors" as opposed to "falling asleep". The kind of errors that make you miss-set altimeters and fly into the ground a few miles before the runway" (www.pprune.org/rumours-news/196539-aircrew-fatigue-2.html, 18 December 2005).

1.2.1 EasyJet and operational fatigue issues

EasyJet is the second largest low-cost, short-haul carrier in Europe with over 180 jets flying 40 million passengers per year on 400 routes. easyJet has attained significant market share within the competitive air transport industry through being dynamic, innovative and attaining maximum aircraft and crew utilisation. easyJet operates out of 18 bases in Western Europe each presenting its own unique operational rostering challenges and employs flight crews representing 26 nationalities, with inherent cultural differences that need to be managed within company safety culture. The airlines' success depends on the training, professionalism, and health of flight-crew to deliver a safe standard of operation for their customer base. easyJet recognises that intensive scheduling practices, including high duty hours and multiple flights per day are a necessary element of Low Cost Carrier (LCC) operations. These factors reflect specific challenges for safety management with regard to human factors considerations and crew fatigue alleviation. These scheduling practices, where they are not managed in an informed manner, can have detrimental consequences for crew alertness and performance (e.g. Caldwell, 1997; Bourgeois-Bougrine et al, 2003; Cabon et al, 2003) and potentially lead to an unacceptable level of fatigue risk exposure.

Research suggests that there is a relationship between detection and management of crew fatigue and risk of incidents and accidents (Batelle Memorial Report, 1998). However, fatigue is a controversial issue that remains difficult to quantify within an airline operational environment. The UK Civil Aviation Authority (CAA) introduced the first comprehensive regulation in the form of an advisory document CAP 371 (The Avoidance of Fatigue in Aircrews) based on the provisions of the Bader report (Bader, 1973). The fourth edition of this document was released in January 2004 however the guidance limits given by Hours of Service frameworks are largely unsupported by scientific field based research (Dawson & McCulloch, 2005; Cabon et al, 2002). The purpose of regulations, as proposed by the EU through the European Aviation Safety Agency (EASA) and UK Civil Aviation Authority, is to provide a fatigue-alleviating framework (Flight Time Limitations, FTL) for airlines. These FTL guidelines (Civil Aeronautical Publication, CAP 371, 2004) allow an airline rostering department to conduct rostering practices that minimise flight-crew operational fatigue. Current regulations have been principally designed around long-haul commercial flight operations and do not reflect the high aircraft and crew utilisation practices that characterise LCC operations (BALPA log, 2004; IATA Research Study, 2001).

An IATA Research Study (IATA, 2001) found that crew fatigue may be affected by the following contributing factors:

- *Increased flying hours;*
- *Unsympathetic rostering practices; and*
- *Absence of adequate JAA/EU rules on FTL.*

The above factors in turn may be influenced by:

- *Shortage of experienced pilots;*
- *High utilisation rates of crews; and*
- *Lack of operations/ administration support.*

and further compounded by:

- *The company organisational or corporate culture; and*
- *The crew professional culture*

1.2.2 Definitions of Fatigue

This section will present some of the more common definitions of Fatigue in the literature and will then review the new ICAO FRMS sub committee draft definition that will become standard for aviation FRMS.

Fatigue is defined by Stokes et al, (1994) as a "general construct of physical fatigue, mental fatigue and emotional fatigue with indistinct boundaries separating each of these elements and that there exists considerable variability amongst the general population". Instead of defining fatigue by this general taxonomy they advised classifying fatigue by criteria through which fatigue is recognised. This was achieved through subjective and quantifiable criteria such as surveys, observational data and accident/incident investigation.

The Fatigue Expert Group (2001) from the Australian Transport Safety Bureau (ATSB) define fatigue as: "A combination of symptoms including: impaired performance (loss of attentiveness, slower reaction times, impaired judgment, poorer performance on skilled control tasks and increased probability of falling asleep) and subjective feelings of drowsiness or tiredness." This definition states fatigue risk performance decrements but does not make the link to precursors and acceptable safety performance.

Caldwell (2003) defined fatigue as a state of tiredness that is associated with long hours of work, prolonged periods without sleep, or the requirement to work at times that are out of synch with the body's biological or circadian rhythms. This definition states the link between fatigue risk precursors, circadian rhythm and performance but falls short of associating fatigue performance to an acceptable level of safety.

Fatigue has also been defined as a "change in body physiology, associated with continuous activity, causing a decrease in work performance and characteristic subjective feelings of tiredness" (Perry, 2000) or "those changes that affect an individual maintaining continued activity" (Jensen, 1995). It is considered to have the status of a "hypothetical construct, an entity whose existence and dimensions are inferred from antecedent and consequent events or variables" (Maher and McPhee, 1994 as cited in the Batelle Memorial Report, 1998).

The ICAO Fatigue Risk Management subgroup comprising leading fatigue research academics from across the industry cite a definition of 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" (ICAO FRMS sub group 2007 and EASA Draft regulations EASA Ops AMC 1 to MS.OPS.8.205(a)-2008).

The last definition includes fatigue risk precursors and links them to crew performance in the context of alertness and satisfactory performance of safety related duties at all times. The definition states that fatigue risk precursors (mental and physiological) can interact with operational processes to manifest fatigue performance decrements. Such performance changes need to be detected and assessed (safety reports, surveys, domain sleep deprivation studies, observational field studies) as operational risk implications and reported and managed to maintain an acceptable safe level of operation. Fatigue management requires both proactive and reactive capability within the risk management process. This definition of fatigue is used as the template for design of a Fatigue Risk Management System at easyJet and the basis for the development and application of a fatigue risk assessment methodology (Human Factors Monitoring Program, HFMP) (Stewart et al, 2008) supporting evaluation of Flight Time Limitations as a control and derogation from certification standard. Fatigue causes in operations can be largely categorised within three main domains (ASLEF, 2003; Baker & Ferguson, 2004) 1. Individual differences, 2. Schedule related factors and 3. Working environment, The consequences of fatigue-related risk needs to be managed whatever the cause. This definition of fatigue has subsequently been incorporated into EASA NPA 2009 provisional regulations.

1.3 Fatigue related risk and operational safety

Low-cost carrier high intensity operations are conducive to degradation of crew performance and an increased risk of fatigue-related incidents and accidents. Causal factors of fatigue-related risk include individual and cultural differences in a flight-crew, operational experience levels, route operational hassle factors, and operating within a schedule design that maximizes crew block hour utilization resulting in physical, cognitive, and behavioural manifestations of fatigue, incident occurrence, and degraded threat- and error-management (Caldwell, 1997; Thomas et al, 2006). A study conducted at easyJet (Stewart & Abboud, 2005) has documented flight-crew specific decrements in performance associated with fatigue. easyJet has recognized that continued success, particularly as the company expands to new market areas, demands that managers have dynamic information on the extent of the fatigue-related risk and a system for managing that risk proactively. They have recognized that emphasis must move away from reacting to recorded events and focus on proactive identification of potential threats, that can compromise safety. This has been given impetus by the advent of Corporate Manslaughter legislation in the UK (Ministry of Justice, 2007) and associated legislation in the EU (e.g. Corporate Manslaughter and Corporate Homicide Act) that states that not knowing or being unaware of the risk does not relieve a corporation of accountability. The first step in the development of a management system for fatigue-related risk is to establish the basis of a performance model that represents fatigue risk precursors and consequences within a safety management system.

Caldwell (2003) means that everyone carries a level of fatigue in their system at all times (transient and cumulative). Transient related fatigue can be mitigated effectively by a single period of sufficient sleep (post a duty period) and prior to undertaking a consecutive duty. Cumulative fatigue occurs due to an incomplete recovery from transient-related fatigue over consecutive or multiple duty periods. Cumulative sleep debt will require a recovery period of consecutive days off free from tasking (and fatigue inducing social influences) to undertake restorative sleep. The point at which this level of fatigue affects operational performance, quality and safety standard of delivered product is where the management of fatigue as a hazard is necessary within a safety management system.

When the fatigue hazard interacts with operational process over a period of time (exposure) it can be represented as a system risk. This risk is managed through a Fatigue Risk Management System (FRMS), which incorporates tools and processes designed to detect, classify, analyse, prioritise and act to mitigate and/or control fatigue risk to a tolerable level both reactively and proactively.

Figure 1 explains how fatigue risk is generated within an airline. It is often assumed that the roster is the primary source of fatigue (circadian disruption). Thus for understanding the true source(s) we need to consider the factors that influence roster design. Business model requirements, external influences, company safety limits and the relevant FTL scheme all come together to determine how a roster is structured. In aviation it is inevitable that rosters designed with the commercial requirements of the business model may need to include features that promote fatigue, for example long duties, early duties, transitions and flights that cross multiple time zones.

The next step in the generation of fatigue risk considers the crew that work the roster, the environment that they work it in and any operational influences. The level of fatigue that different crew members encounter when working a roster varies greatly. Some of this variability is due to individual differences such as age, sleep need, the ability to sleep at irregular times and health. How hours of work interact with an individual’s lifestyle will also influence fatigue. Lifestyle factors which can influence fatigue include having young children at home, second jobs, social engagements and domestic disharmony. In addition to work hours, the level of fatigue crew experience depends on operational influences, such as hassle factors (delays, technical failures, airspace complexities, ramp congestion), adequacy of training, and environmental variables including noise and temperature.

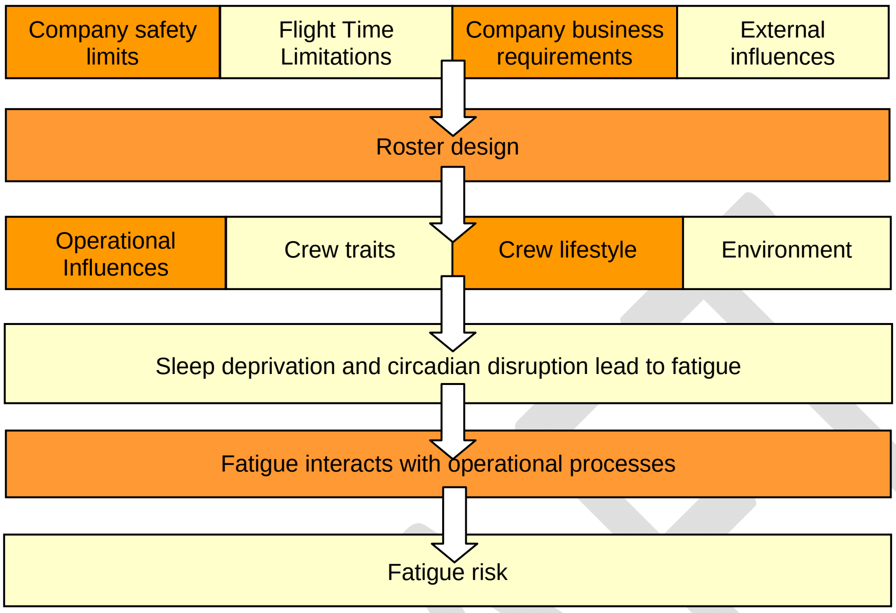


Figure 1. The generation of fatigue risk within an airline (Stewart et al, 2008)

Crew differences, operational influences and the environment influence fatigue primarily by reducing sleep or disrupting the body's 24 hour rhythms, known as circadian rhythms. There is a direct relationship between the human physiological requirement for sleep and human performance. The consequence of operational fatigue-related risk depends on how crew fatigue interacts with operational processes. For example, crew fatigue may be elevated by increased continuous crew cognitive demand due to an aircraft technical problem or adverse weather. Fatigue risk is not a simple reflection of how fatigued crew are, but depends on whether the level of fatigue crew are experiencing, threatens the integrity of the operation.

This is evidenced where fatigue has been identified as a contributor to aviation accidents including the DC-8 at Guantanamo Bay and Korean Airlines Flight 801 accidents (e.g. Rosekind et al, 1996). The DC-8 Guantanamo freighter accident (NTSB, 1994; Rosekind et al, 1996) is a particularly interesting case as the investigation report cited the presence and interaction of three principle fatigue antecedent factors: transient sleep loss, elongated duty period (continuous wakefulness) and operations in the afternoon window of sleepiness. The official investigation was conducted by the NTSB (as an independent agency) to determine the root cause and contributory factors and the data collection was supported by cockpit voice recorder and the Captain's testimony. The crew performance effects cited in the report due to fatigue related risk included: 1) degraded decision-making, 2) visual/cognitive fixation, 3) poor communication/coordination, and 4) slowed reaction time. This was the first time in a major U.S. aviation accident that the NTSB cited fatigue as the probable root cause.

Fatigue increases the risk of an incident or accident occurring by degrading human performance (Folkard, 2003 & 2004). easyJet research has identified fatiguing performance decrements such as increased rates of error commission, decreased error detection and increased threat mismanagement (Stewart & Abboud, 2005). Aviation is not unique in its exposure to fatigue risk. Research in the medical fraternity suggests that extended duty shifts commonly worked by interns elevate the incidence of medical errors and risk of adverse events (Barger at al, 2006). Fatigue impacts on our ability to work safely. It does so by impairing a range of cognitive skills including reaction time, memory, decision making and communication.

It is evident that fatigue within an airline must be managed at many levels and that detection capability for fatigue risk requires a proactive element not simply focusing on active failures and retrospective investigation of events. Within such events the capability must extend to the ability to determine and evidence the influence of fatigue on safe operation as a root cause or contributory factor.

1.4 Towards Fatigue Risk Management

Airlines have limited room to manoeuvre against rising fuel costs, airport charges and aircraft costs/fleet renewal so emphasis is placed on maximising crew and aircraft utilisation to maintain financial performance targets. Crew utilisation is currently regulated by FTL schemes such as CAP 371 (UK CAA) that specify crew flight duty hour limits (900 hours for flight crew). Duty hours by themselves do not effectively consider circadian disruption, task workload or individual differences that can affect crew fatigue levels.

Left unchecked, high crew utilisation can lead to decrements in crew alertness and performance, increased absenteeism and attrition and an unacceptable risk of fatigue-related accidents (Stewart et al, 2006). Therefore, the long-term success of the easyJet business model demands that managers have dynamic information on the extent to which the company is exposed to fatigue risk and a system for managing this risk to as low as is reasonably practical.

In such a complex operating environment focussing on simple compliance with FTL requirements (i.e. 900 hours productivity per year) cannot be justified or assumed to provide adequate legal protection against safety risks for the easyJet business model as has been demonstrated through previous experience at easyJet. Operators are responsible and are accountable for their own risk with the overall requirement of achieving a level of risk as low as reasonably practicable.

The UK CAA has expressed this concern in FODCOM 10/2009 as follows: “The high levels of crew utilisation now being achieved has led to concerns that the degree of protection against fatigue offered by basic compliance with those quantitative FTL provisions specified in CAP 371 Annex A is no longer sufficient for larger companies”

1.5 Fatigue and Regulation

1.5.1 Adequacy of current fatigue controls: Flight Time Limitations (FTL)

Flight Time Limitations (FTL) or Hours of Service (HOS) guidance are the traditional regulatory approach for addressing the fatigue risk of flightcrew. They are applied at the schedule development stage to provide proactive compliance criteria to the rostering team in the design of optimal commercial schedules. FTL function is to limit duty and provide guidance on minimum rest breaks between shifts (recovery time). FTL's thus provide guidance to rostering staff on maximum duty and block hours operated per week, month and annual rolling limits.

The UK CAA introduced an FTL scheme based on the available scientific knowledge at the time (Bader, 1973) to provide operators with guidelines for the avoidance of fatigue in aircrews in Civil Aviation Publication (CAP) 371 (UK CAA, 2004, 4th edition). The Bader report however, duly acknowledges the lack of available objective scientific and operational studies to support the development of the FTL scheme. The document was periodically reviewed in light of industry experience and advances in aeromedical knowledge (CAA, 1982, 1990 and 2004). The committee report states that "no psychological or physiological test were available at the time to provide positive evidence of the presence of fatigue. The tests of performance cannot yet be correlated with established standards of fatigue" (Bader report, 1973: p55, § 3.4).

Across the EU the flight / duty time, and rest time permitted under national regulations can vary considerably (Cabon et al, 2002) and this issue has been addressed by EASA rulemaking directorate and the EU commission through the establishment of one EU FTL standard scheme (FTL Sub-part Q). However EASA has acknowledged that there is still a significant lack of operational studies to support the established guidelines. This fact was highlighted at the recent EU Commission European Transport Safety Council (ETSC) Seminar on FTL and FRMS in Brussels (EU Parliament, March, 2009). EASA and the UK CAA (FODCOM 10/2009) have stated that compliance with different prescriptive regulations alone, does not automatically equate to satisfactory level of safety under all circumstances and the following reasons support this position.

The most common control for fatigue risk utilized in aviation and other safety-critical industries is compliance with FTL, or other limitations on hours of service (HOS). The effectiveness of FTL as a control for fatigue risk has been criticized on the basis that limitations tend to be used as a rostering target, rather than guidance. In this context, there are a number of reservations regarding FTL. It has been argued that HoW limitations are not scientifically defensible, do not enable actual workforce fatigue to be measured or predicted and can inadvertently encourage rostering practices that increase fatigue (Fatigue Expert Group, 2001). In addition, FTL have been criticized because there is significant variability between prescriptive rule sets offered by different aviation regulation authorities (Cabon et al, 2002).

FTL schemes by their nature are a form of static safety management and do not consider:

- Sleep opportunity and quality associated with roster design - circadian influence
- The awareness of risk associated with the flight from a rostering perspective e.g. weather, ATC, Terrain, crew experience; aircraft serviceability
- Crew individual and cultural differences
- Sector workload (number of block/duty hours programmed) and operational hassle factors (delays, aircraft AOG, complex and congested airspace

Secondly, FTL schemes can also restrict commercial and safety flexibility as they:

- Limit scope for effective crew utilisation
- Provide limited feedback on safety threats
- Do not effectively consider circadian disruption, task workload or individual differences that can affect crew fatigue levels.
- Give the assumed protection of being “legal”

FTL compliance does not involve the measurement or knowledge of the level of fatigue-related risk to which employees and the operation are actually exposed. This concern is now shared by the UK Civil Aviation Authority who in a Flight Operations Directive (FODCOM 10/2009) stated: “The high levels of crew utilisation now being achieved has led to concerns that the degree of protection against fatigue offered by basic compliance with those quantitative FTL provisions specified in CAP 371 Annex A is no longer sufficient for larger companies”. Also, that “Appropriate mitigations for (fatigue) risk include an approved FTL Scheme with provision for good rostering practice.” This is in accordance with EASA NPA 2009-02c (EASA, 2009), which similarly gives notice that just compliance with basic legality rule sets is no longer to be considered adequate.

1.6 Development of the safety case

In April 2005, easyJet became the first major airline to be granted alleviation or derogation from Flight Time Limitations (FTL) (as a certification standard). The UK CAA agreed the alleviation based on the results of a safety case report of a 6 month roster trial. The trialled roster was a 5/2/5/4 roster (5 early duties, 2 days off, 5 late duties, 4 days off), which exceeds the FTL (CAP 371) limit of 3 consecutive early duties. easyJet presented a safety case based on the principles of six sigma which demonstrated that, compared to the 6/3 roster (3 early duties, 3 late duties, 3 days off) in operation at the time, the 5/2/5/4 roster was associated with a significant reduction in fatigue risk and flight deck errors.

A requirement for the CAA alleviation was that easyJet implement a risk management system to monitor and mitigate fatigue related risk with the implementation of the new roster pattern. This ‘Fatigue Risk Management’ System (FRMS) is as an evidence-based system for the measurement, analysis and mitigation of fatigue-related risk to as low as reasonably practicable (Australian Safety Transport Bureau, Fatigue Expert Group, 2001). A FRMS is a ‘toolset’ of processes that are employed within an existing Safety

Management System (SMS) framework, thereby enabling fatigue risk to be managed much like any other risk. Fatigue risk management is a recent development and initial reviews of its application in the aviation industry in Australia and New Zealand have been generally positive (Signal et al, 2006).

1.7 A method for investigating operational fatigue risk inairline rosters

Six-Sigma is a philosophy and methodology that places an emphasis on data-driven, analysis through the use of a diverse collection of tools to identify and address the sources of risk within the process. (Pande et al, 2001)

Six Sigma's keystone methodology is made up five elements: Define, Measure, Analyze, Improve and Control (DMAIC). As each step is actioned scientific methods are applied as appropriate (tools context people task, Frei et al, 2003) in order to determine the root cause of a systemic problem and support risk reduction activity. The process is enabled by first clearly defining the problem, deliverables, measures, and measurement system, and then, ensuring that the measurement system in place and working effectively within prescribed criteria. Overall, the DMAIC approach employs problem orientated statistical and analytical tools to identify the issues and collect, and analyze the data. The DMAIC applies a project orientated approach to a systemic problem and focuses on improving the functioning of the overall system (from risk management to safety assurance e.g. holding the gains achieved). The results of the projects are incorporated into running the day-to-day business" (Harry & Schroeder, 1999)

In recognition of the potential fatigue risk associated with low cost carrier operations and the potential weaknesses of controlling fatigue risk via simple adherence to FTL, easyJet developed a Human Factors Monitoring Programme, HFMP (Stewart and Abboud, 2005) based on the principles of six sigma to support evaluation of an airline rostering schedule The HFMP was designed to assess flight crew fatigue, rostering practices and human error, and the interactions between these variables (by applying statistical analysis). The HFMP is a multi-layered programme that mines data from existing Safety Management System (SMS) data bases, for example Flight Data Monitoring (FDM), and includes additional measurements, such as predictive modelling of the fatigue associated with work hours and the objective measurement of sleep. HFMP was developed to investigate contributing factors to crew fatigue / performance by determining correlations between data mined from multiple safety management systems databases. The HFMP represents a proactive (exploratory) risk methodology (McDonald, 2009) and is applied to investigate fatigue safety trigger signals where there is little direct evidence (knowledge of domain safety experts) where new processes are to be implemented (such as rostering rulesets and guidelines). The HFMP is also triggered for application due to the limitations of existing hazard detection tools (such as FTL) and where risk signals have been received from a review of external data sources such as IATA STEADES or ASIAS programs.

1.7.1 5/2/5/4 roster trial

The Six Sigma approach was applied to detect operational risk areas and rostering inefficiencies under current schedule process at easyJet. The aim was to improve the quality of the roster ‘process’ outputs by identifying and removing fatigue related risk factors and where practicable improving crew productivity and lifestyle within a safe rostering framework. An evaluation of the current 6&3 schedule was conducted (6 duty days on followed by 3 days off, after the 3rd duty day the crew transitioned from early morning duties to late evening duties). Post evaluation of this schedule (Stewart & Abboud 2005a) risk reduction activity proposed an amended schedule design (5/2/5/4) roster which was predicted to reduce fatigue by decreasing the number of days worked consecutively and increasing the amount of time off provided for the changeover from early to late duties. The study was managed as a company project tracked by the project board. This study resulted in the design, testing (at two operational bases) and implementation of an alternative pattern at 14 network bases

The performance of the new proposed 5/2/5/4 roster pattern was monitored by the HFMP that included:

- A company network Line Operations Safety Audit (LOSA, incorporating Performance Shaping Factors and Fatigue Behavioural Markers);

- Predictive fatigue modelling;

- Demographic, CRM and Attitude surveys of the pilot population;

- Activity watches and Sleep diaries study;

- PC based cognitive performance testing;

- Rostering and scheduling information;

- Archive data in the form of Air Safety Report’s (ASR) utilising British Airways Safety Information System (WinBASIS);

- Flight Data Monitoring (FDM) and safety data analysis;

- Archive Crew Duty hours; Archive Crew Sickness rates; Archive crew turnover rates;

- Roster stability data.

It was hypothesized that a significant improvement in crew threat and error management would be recorded as a function of a ‘slow wave’ duty pattern designed to minimize circadian disruption throughout the roster period, duty days one to five (‘early’ and ‘late’ duty period), as recorded by the LOSA University of Texas Threat and Error Model. Further, it was predicted that a higher rate of threat and error mis-management would be observed on the duty days on which circadian disruption is expected to manifest.

It was also hypothesized that cumulative fatigue effects through the ‘5254’ pattern would be less prevalent as a function of threat and error management -mediated by the number of sectors operated in a given day and the number of days operated in a given roster period. The study reviews crew performance on selected schedule days to investigate if any measured performance degradation is attributable to circadian disruption of flight crew. This allows evaluation of crew performance throughout a regular shift pattern under the ‘5254’ roster. The study collected data to ascertain if a correlation exists between crew fatigue levels, as a function of rostered duty day; ‘early’ slow wave duty pattern; ‘late’ slow wave duty pattern; sector number and crew performance, as measured using the University of Texas Threat and Error Management (UTTEM) Model. Dependent variables are Threat Detection and Management and Error Detection and Management.

The weight of evidence collected in the HFMP indicated that, compared to the 6/3 roster, fatigue risk was reduced during the trial of the 5/2/5/4 roster (at two trial bases – a regional base and the main base). A summary of the HFMP findings (Stewart & Abboud, 2005b), which formed the basis of the safety case that was presented to the CAA to petition for derogation from the FTL certification standard, are listed below:

Circadian Disruption (sleep/wake cycle disruption) & Cumulative Fatigue

It was hypothesized that the transition to a ‘slow wave‘ shift schedule reflecting minimal circadian disruption to crew would manifest as a reduction in errors of commission and omission and an increase in threat management performance across the schedule. Support for the hypothesis was found in the recording of total crew errors against duty day represented as error per sector. One-Way ANOVA, sig. at 5% level, $p<0.05$)). The ‘5254’ pattern showed no significant difference in performance between the ‘early’ and ‘late’ shift weeks and no significant difference between the duty days (One-Way ANOVA, $p>0.05$). Mean error rates per sector reduced from 5.2 on the ‘6&3’ pattern down to of 2.6 on the ‘5254’ pattern, representing a 50% improvement in crew performance. The pattern reflects less impact on crew circadian rhythms with consistent performance throughout the schedule. Cumulative fatigue effects on performance were not apparent with consistent crew error management across the pattern.

Threat management by crews under the ‘6&3’ pattern reflected the same circadian disruption trend of poor performance on the first duty day (67%) followed by improvement by the third ‘early’ duty (sig. at 5% level, $p<0.05$). Uncharacteristically, managed threats remained high on duty day four across the forward phase shift and then decreased significantly again by duty day six to 78%. Threat management by crews was found to be consistently superior under the ‘5254’ pattern compared to the ‘6&3’. This remained at an average of 96% with no evidence of cumulative fatigue effects on performance (One-Way ANOVA, $p>0.05$, not significant between duty days and not significant between ‘early’ and ‘late’ duties). This indicates that crews are alert and managing event risks consistently well throughout the schedule, lending support to the second hypothesis, namely that minimizing circadian disruption in the shift schedule manifests as a reduction in crew cumulative fatigue performance decrements.

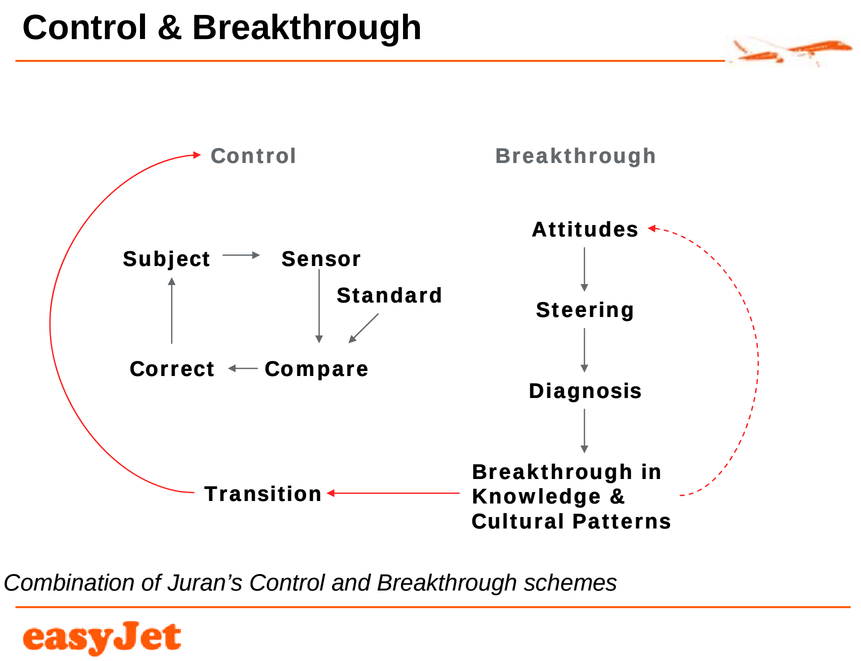
The British Airline Pilots Association (BALPA) was the recognized union through which company management could negotiate any changes to crew terms and conditions of service. The ‘5254’-roster pattern had to be subject to a vote, after approval by the regulating authority, by membership before the pattern could be implemented across the company network. 65% of the BALPA membership contingent voted on the new pattern, with a 93% approval rating. A series of 7 lifestyle questions were directed to crew regarding their experiences of the ‘6&3’ and ‘5254’ patterns. These questions are set out below with ‘5254’ approval ratings reported in parentheses:
Q1. Which pattern enables a better work/life balance? (77%)
Q2. Which pattern enables you to get more sleep? (74%)
Q3. Which pattern do you feel less tired/fatigued on? (91%)
Q5. Which pattern do you feel more alert on? (84%) Q6. Which pattern enables a more regular sleep pattern? (91%)
Q7. Which pattern enables you to perform more safely at work? (84%)

1.8 Breakthrough in knowledge and culture surrounding fatigue-related risk

The FRMS research work conducted at easyJet on the 6&3 roster study (Stewart & Abboud, 2005) represented a breakthrough to the current company understanding of fatigue-related risks. The study resulted in a change of corporate attitude and the establishment of the elements of a management system for the oversight of fatigue risk supported by a just safety culture. This required process development to support the amalgamation and analysis of multiple safety data sources and also implementation of new controls around roster related fatigue (beyond the static safety management capability of FTL). New safety data protocols had to be developed to support confidentiality and non-jeopardy reporting and to facilitate large scale data capture and analysis with the results presented to risk stakeholders who were responsible for enacting change management to the operation. This can be effectively represented by Juran’s Breakthrough and Control schemes (Figure 2, Kingston, 2008). The 6&3 study represented a trigger response by the operator (concern over the adequacy of the normative control) to multiple fatigue-related signals into the management group including an adverse fatigue risk incident. The first study results around the 6&3 pattern form a system snapshot of crew performance and historical analysis of incident and performance databases using the HFMP methodology. This process embodied the concept of improvement breakthrough (Juran, 1964; Juran & Godfrey, 1995). The results of the initial study caused the company management to review the adequacy of current Fatigue codified controls in relation to the risk oversight requirements of the LCC business model. The next step was to employ a managerial approach to fatigue related risk manifestation and this lead to the development of process redesign as a new method of an ‘acceptable means of compliance’ for the oversight regulator. This required easyJet to establish a control process to monitor fatigue-related risk on the company network that steps beyond a systemic Breakthrough to Control scheme. The standard here represented is not necessarily that of regulatory or codified compliance but can represent internal company standards (self-regulatory) where the control process establishes a managerial systems approach to the identified risk.

The new proposed Rostering schedule (5/2/5/4) was designed to mitigate the process limitations of the 6&3 schedule and was to evaluated through a trial implementation of the improved roster (5254) pattern prior to seeking management signoff (and regulator derogation approval) for network application (Stewart & Abboud, 2005b). This follow on methodology led to the application and approval of an FTL alleviation from the UK Civil Aviation Authority which represented a systemic change within easyJet. This was a step change from a normative (compliance) process and is in line with Juran's Breakthrough to management system concept as a form of fatigue risk control. The new implemented roster pattern can be defined as a `strategic change, a dynamic, decisive movement to new, higher levels of performance' (Juran, 1994) as crew error rates were effectively halved, FDM recorded events reduced by 70% and crew attrition levels dropped by 50%. The limitation of the early easyJet work was that the methodology employed could not be implemented as a continuous cycle due to the cost and manpower requirements. Therefore, the airline needed to look at applying a 'continuous six sigma process' as a form of safety risk management within the SMS to monitor fatigue related risk.(this will be addressed in a later section).

The step from Breakthrough to Control represents identifying and developing hazard detection and management controls to support a continuing cycle of events. In the case of the FRMS this was initiated by the development of a SMS managerial approach to operational fatigue risk inclusive of the development of a corporate safety policy with an integral fatigue risk management policy based on a just framework. This safety culture policy supports a safety data and crew performance management protocol agreed with the company pilot union. The development of an evidenced based data driven Fatigue Risk Management System has elicited support from the highest levels of management. This highlights the importance, as Juran states, of easyJet managers' understanding of the attitudes, the organisation and the methodology used to achieve breakthrough, and for airline management to establish the fundamental difference between large scale snapshot field studies and the application of a control or management system cycle.



Control & Breakthrough

Combination of Juran's Control and Breakthrough schemes

Figure 2. Juran's Control and Breakthrough Cycle (Kingston, 2008)

1.9 From a Six Sigma based Study to Implementation of a Managerial or control cycle for fatigue-related risk

1.9.1 The role of ICAO and EASA

The previous section demonstrated a proactive step by an operator to effect systemic change based on identified rostering process inefficiencies and safety risk. We have also reviewed the limitations of current controls in the form of FTL as a static form of safety management. easyJet, recognizing the limitation of the current regulatory fatigue controls and based on the proactive operational research it conducted was included on an ICAO Fatigue Risk Management subcommittee. This committee's remit was to develop new guidance and regulatory framework for the control of operator fatigue related risk and promulgate this guidance as ICAO Standards and Recommended Practices (SARP). This next section takes the reader through the proposed new regulatory controls from the ICAO committee from which an operator can develop a managerial system for the monitoring and mitigation of fatigue-related risk. This process completes the breakthrough to a control cycle for the evolution of an airline fatigue risk management system of processes.

ICAO formed a Fatigue Risk Management subcommittee in March 2006 (inclusive of easyJet) after completion of the Flight Time Limitations Standards and Recommended Practices (SARP). The purpose of the sub committee was to introduce Fatigue Risk Management Systems (FRMS) as the next step following the update to the prescriptive flight time, flight duty time, duty time and rest periods amendment proposals for the amendment of Annex 6 —Operation of Aircraft Part I — International Commercial Air Transport — Aeroplanes.

The FRMS Subcommittee was comprised of experts in the field of fatigue research and operational fatigue management inclusive of Regulators (United States (FAA), United Kingdom (CAA), Transport Canada (TC) and France (DGAC)), the International Air Transport Association (IATA), easyJet Airline and Scientists (US, Sweden, New Zealand and France).

Draft guidance was submitted from the committee as changes to the Standards and Recommended Practices (SARPs) of Annex 6, Part I in November 2008. It offered a new Appendix that provides guidance on FRMS.

The guidance developed was in structure based on the FRM conceptual framework by Gander (2005) as shown in Figure 3 and included:

- Guidance for the development of Fatigue Risk Management Systems
- Flight time, flight duty periods and rest periods for fatigue management
- Fatigue Risk Management Concepts and definitions
- Essential components of an FRMS
- Roles and Responsibilities of operators, employees and regulators
- Guidance for development of fatigue risk management regulation
- Guidance on FRMS education and awareness training

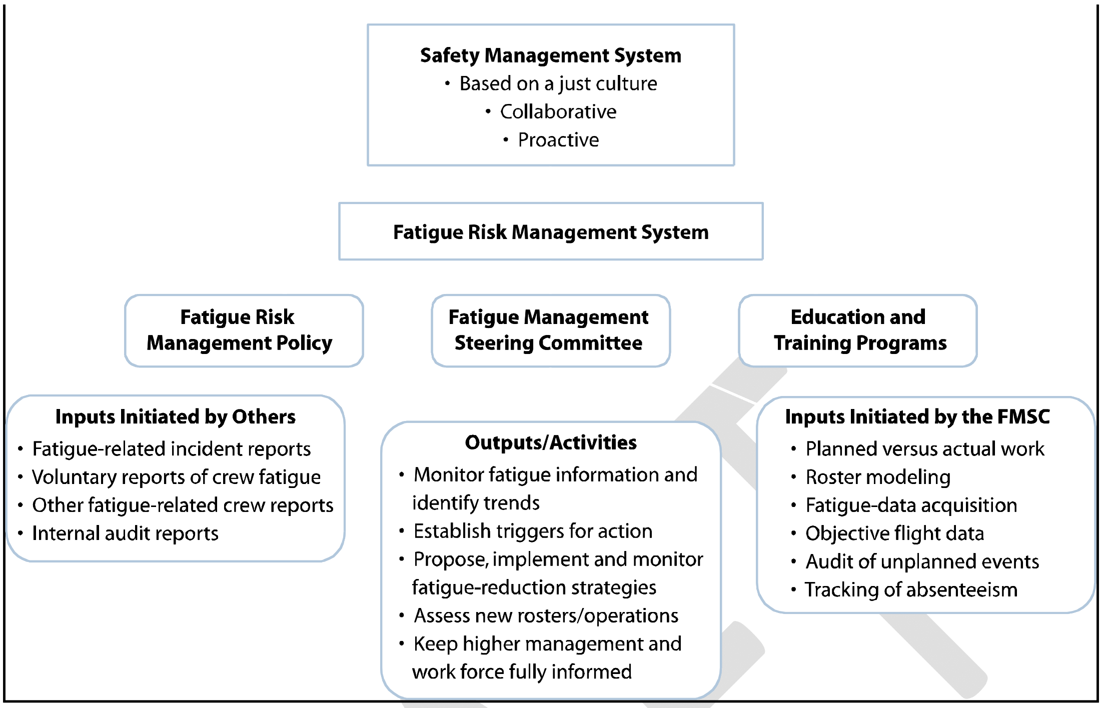


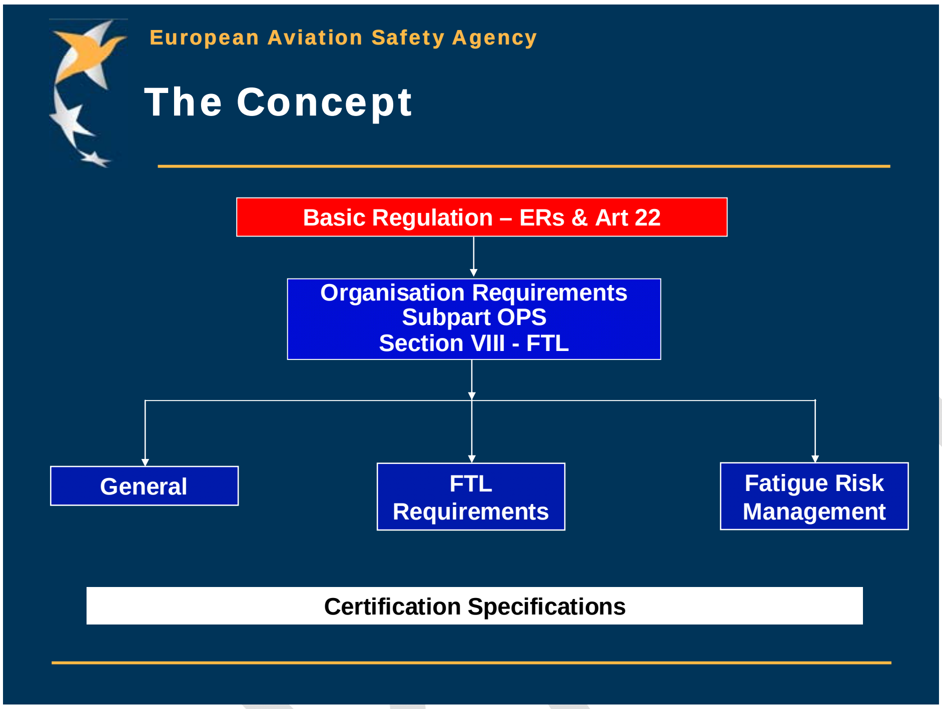
Figure 3. FRMS Structural components by Gander (2005).

The ICAO draft document outlined the principle characteristics of an FRMS and the relationship to SMS inclusive of:

- Should be an integral part of an established SMS.
- Applies SMS principles and processes to proactively identify and continuously manage fatigue safety risk.
  - Data driven systems designed to identify risks.
  - Multi-layered defences to manage risk.
  - Shared responsibility among management & employees.
- Functions within a regulatory oversight framework.
- Can enhance safety <u>within</u> the envelope of prescriptive flight/duty time limits or as an <u>alternative</u> to prescriptive rules that provides at least an equivalent level of safety.

This ICAO draft document was used by EASA as the basis for new draft regulation due to come into effect in April 2012, pertaining to FTL and fatigue management (Figure 4) and outlined by EASA at the inaugural meeting of the International FRMS Forum (Valentukevicius, 2009).

Valentukevicius stated that EASA currently has no remit for issues relating to FTL and has recently released a Notice of Proposed Amendment (NPA) EASA NPA 2009c that sets the proposed framework for the FTL requirements (when EASA assumes competence for FTL in April 2012). He went on further to state that this framework is subject to the EASA rulemaking process including review and Regulatory Impact Assessment (RIA). The NPA contains Draft Opinion together with Certification Standards, Acceptable Means of Compliance and Guidance Material for operators. A significant addition in the proposed requirement for an FRMS was that it must be appropriate to the size and nature of the airlines operation (assumed basic compliance to the FRMS elements would not be sufficient for all operators).


European Aviation Safety Agency

The Concept

Basic Regulation – ERs & Art 22

Organisation Requirements
Subpart OPS
Section VIII - FTL

General

FTL Requirements

Fatigue Risk Management

Certification Specifications

Figure 4. FRM and FTL draft regulatory concept (Valentukevicius, 2009)

The new draft regulation as outlined in GM OR.OPS 025/325. FTL: FRMS states the following operator responsibilities with regard to system development and processes:

- Develop, document and implement a comprehensive FRMS.
- FRMS needs to be monitored by internal audit. Operator should provide FRMS education and awareness training. .
- Provide adequate resources for the continuing effectiveness of the FRMS
- Provide mechanisms for ongoing consultation with stakeholders, the competent authority and crew representatives. Should include a Fatigue Management Steering Group to coordinate all fatigue management activities. e) "A commercial operator should work cooperatively with the competent authority."

What however is of note is that there is no guidance from ICAO or EASA on how to meet these requirements and to what standard. Also the operator must develop the components tools and processes for the management of fatigue-related risk and integrate these effectively into an operator's SMS. The starting point before we address these other issues is to place the components of the FRMS, as outlined, into an ICAO SMS (9859 version 2, 2008) format that is readily understood by airlines.

1.10 ICAO SMS main components

ICAO has formulated a body of work (ICAO Safety Management Manual (SMM) Document 9859) that provides guidance for the development, training, documentation and communication of a Safety Management System into an Airline's business model.

ICAO defines an SMS as:

> *"a systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures."*

ICAO requires that member States shall require an SMS implementation and that the SMS shall be accepted by the state. The SMS shall, as a minimum (ICAO, 2008):

- identify safety hazards;
- ensure the implementation of remedial action necessary to maintain agreed safety performance;
- provide for continuous monitoring and regular assessment of the safety performance; and
- aim at a continuous improvement of the overall performance of the safety management system.

The ICAO SMS framework consists of four main components and twelve sub-elements. The four components are designed to support two core operational processes underlying an SMS, safety risk management and safety assurance.

The four components of an SMS are:

1. Safety Policy and Objectives;
2. Safety Risk Management;
3. Safety Assurance; and
4. Safety Promotion

Each component is subdivided into elements, which encompass the specific sub-processes, specific tasks or specific tools that the actual management system must engage or utilise in order to conduct the management of safety as just any other core business function or organisational process.

The FRMS functions according to SMS principles to maintain an acceptable level of safety, through the application of scientific principles based on human physiology and knowledge, determined from data collection, risk investigation and analysis. In doing so it allows greater operational flexibility of crew scheduling, in comparison with prescriptive limitations of flight and duty time. The FRMS thus forms an integral part of easyJet's established Safety Management System (SMS).

The FRMS has been adapted to manage the operational risk(s) of easyJets flight time specification scheme(s) for flight and duty time limitations and rest requirements.

Fatigue Risk Management applies standard management control principles in order to mitigate fatigue risk in airline operations, through processes based on shared responsibility amongst management and crew members acting within a just culture. The component elements of FRMS from EASA NPA 2009c can now be represented against the SMS structural components (Table 1).

1.11 Management Framework for fatigue related risk based on ICAO

The essential elements of an FRMS based on the ICAO draft guidance and EASA NPA 2009c can be presented against the ICAO SMS framework (adapted from EASA NPA 2009c and ICAO 9859 (2008)) as in Table 1.

ICAO's components of SMS	Essential FRMS Elements
Safety Policy and Objectives Management commitment and responsibilities Safety accountabilities Appointment of key safety personnel Coordination of emergency response planning SMS documentation	• Written & approved Fatigue Risk Management Policy • Non-punitive "Just Culture" • Fatigue Management Steering Group • Documented Processes and Procedures for FRMS Implementation • Strategic, Scientifically Driven Crew Scheduling • Validated, Timely Fatigue Mitigation Strategies
Safety Risk Management Hazard Identification Risk assessment and mitigation and **Safety Assurance** Safety performance monitoring and measurements The management of change Continuous improvement of the SMS	• Fatigue risk assessment and mitigation • Crew Fatigue Reporting • Data Driven Processes Monitoring Alertness • Recording and investigating Fatigue Related Incidents • Operator Internal Auditing • FRMS Validation Programme • Safety Performance Measurements • Data Collection and Assessment
Safety Promotion Training and education Safety communication	• Education and Awareness Training • Employee communication using channels for feedback

Table 1. FRMS Elements linked to an adapted ICAO SMS structure.

The implementation of an FRMS capability requires the development of capability around the SMS structure for fatigue related risk.

This structure links the core operational activities of a Safety Management System as defined by ICAO; namely safety risk management and safety assurance to processes for the detection, monitoring and mitigation of fatigue related risk. The next step is to focus on the precursors and consequences of fatigue related risk and develop a system model based on risk management process that can be used as a basis for an FRM system implementation.

1.12 Development of a Fatigue safety performance model

1.12.1 Relational Models of Fatigue

In aviation, high workload (route complexity, airspace and airport congestion) associated with intensive short-haul scheduling, is considered in combination with sleep deprivation, as causal factors to fatigue (Bourgeois-Bougrine et al, 2003) and CAA Paper 2005/04: Aircrew Fatigue, (2005). Cognitive fatigue can also result from continuous high stress and a requirement for long periods of vigilance. From literature there is a well established and documented relationship between fatigue associated with sleep deprivation and human performance (cognitive, physiological and behavioural)(Caldwell et al, 2009). Aircrew fatigue has been cited as a combination of scheduling factors and workload (Samel et al, 1997). Caldwell (2005) states that scheduling factors, circadian disruption, sleep deprivation and extended duty periods can affect crew alertness and performance. Crew alertness after a period of rest has been positively correlated to sleep duration and quality (Pascoe et al, 1994). Length of duty, number of operated sectors have been positively with fatigue performance (Powell, 2008). Baker & Fergusson (2004) cite fatigue as consequence of inadequate restorative sleep due to precursors inclusive of time of day, environment, commute time, individual factors, work factors, and family obligations. They define fatigue as a "state of impaired physical and/or mental performance and a lowered alertness arising from inadequate restorative sleep, inclusive of mediators such as time of day and time since awake" (Baker & Fergusson, 2004). The relational model identifies principle antecedents to fatigue but does not identify the fatigue performance consequences or relate fatigue performance to safety risk. Further the antecedents of fatigue are linked only to sleep deprivation but sleep deprivation is both a cause and consequence of fatigue.

The performance effects of fatigue include: decreased short term memory, slowed reaction time, increased errors of omission and commission and increasing lapse rate in both number and duration (Dinges, 1995). "Fatigue has a direct and well-established influence on human performance, namely a higher frequency of errors committed by operating pilots" (Gander et al, 1996). Flight-crew have also displayed poor judgement when assessing intrinsic levels of alertness and fatigue (Dinges, 1995). Some individuals have stated that they were alert when in-fact they were in the process of falling asleep (Roth et al, 1994). There is also a trend to underestimate the level of one's sleepiness (Rosekind and Schwartz, 1988, Ingre et al, 2006). A decrease in flight-crew alertness and performance reduces safety margins and this increases the risk of an incident or accident occurring being attributed to fatigue (Folkard, 2003).

The consequences and effects of fatigue on performance have been published and include (Summarised from Hawkins et al, 1983; Neri et al 1992; Caldwell et al, 1997; Dinges et al, 1995, Batelle Memorial Report, 1998; Rosekind et al, 1996 & Lawford, 2005):

- Degraded judgement and decision making of crew
- Deterioration in the accuracy and timing of actions, reduced reaction time
- A change in perception of risk and risk tolerance
- Crew involuntary lapses into sleep (microsleep events)
- Crew unconsciously accepting lower standards of performance
- A reduction in situational awareness (ability to integrate information into a system model)
- Crew performance becomes increasingly erratic and inconsistent
- Crew attention range narrows and some tasks are forgotten or ignored; cognitive fixation
- An increased number of errors of omission, which increase to commission, when time pressure becomes a factor
- An increase in both number and duration of lapses (forgetting) with increasing fatigue
- Reduced visual perception
- A decline in CRM behaviours (effective communication and inter-personal interactions; poor communication and coordination).

The relationship between fatigue causes and consequences has been captured diagrammatically in Figure 5.

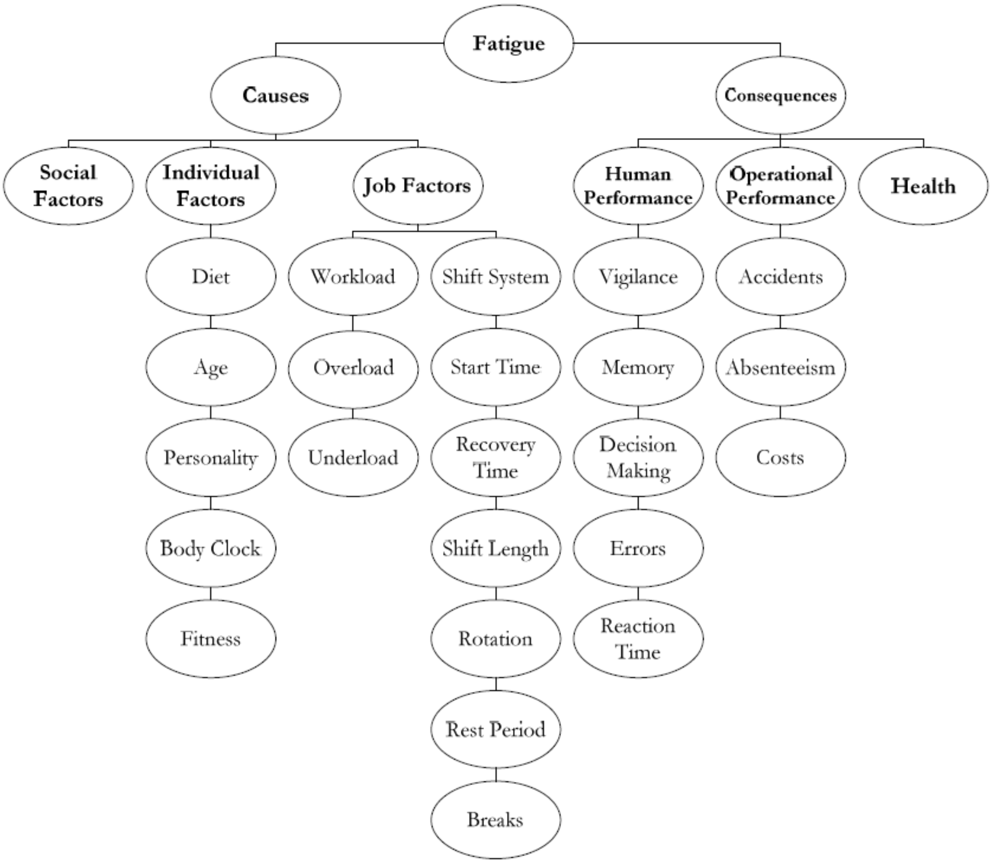


Figure 5. Fatigue causes and Consequences relational diagram (ASLEF, 2003)

Sutton et al (2003) in their relational model (Figure 6) group the antecedents of fatigue under two main headings Job factors and Individual factors (Individual factors (trait and social) and Job Factors inclusive of Work factors (inclusive of environment, job design and workload) and Schedule related factors (time of day, shift system design, rest breaks).

The model includes and extends on the antecedents considered by ASLEF (2003) and Baker and Fergusson (2004) by showing diagrammatically inter-relationships between the causes and consequences of fatigue. Whilst these relational models show the causes and consequences of fatigue in an influence diagram, they fall short of establishing fatigue as a risk that must be managed through a safety management system. Also again, sleep deprivation is both a consequence and causal factor of fatigue that should be represented in such an influence diagram. Of note is that there is no arrow from Health to Human performance. That said, it is the first true model to effectively group the precursors and consequences of fatigue to performance (system and individual).

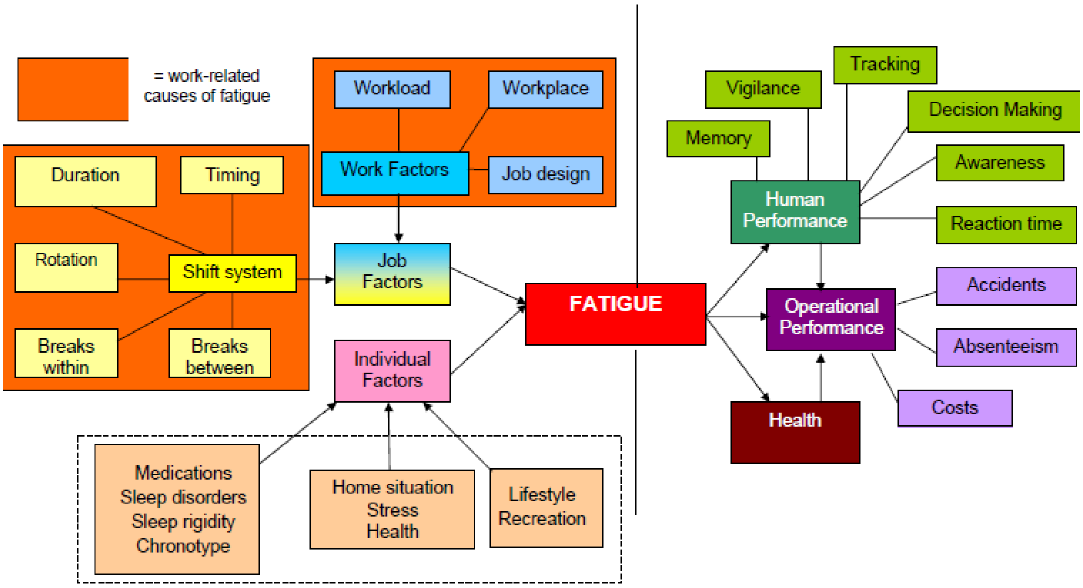


Figure 6. Fatigue Influence Diagram (adapted after Sutton et al, 2003)

1.12.2 Dawson & McCulloch Trajectory Model (2005)

The Dawson & McCulloch (2005) make the first attempt to link the relationship between fatigue antecedents and performance to a trajectory model of accident causation (Reason 1997). The model associates four levels of antecedent as precursors to a fatigue related incident/accident. The fatigue incident being the final point of an ‘error’ trajectory or causal chain of events. The approach relates organisational latent failures or conditions to the commission of fatigue related errors (slips, lapses, mistakes and violations - intentional deviation from SOPs) or unsafe acts at the sharp end of the operation.

The Dawson & McCulloch model (Figure 7) proposes an error trajectory rather than a performance trajectory. The left side of the model, termed hazard assessment, steps from the fatigue antecedent, in the form of sleep opportunity (as a hazard) to performance decrements such as fatigue-related crew behaviours and error commission. The trajectory ends in incident and/or accident occurrence. The opposing side of the model proposes the hazard-detection tools in trajectory sequence against the identified hazards. The hazard-detection tools proposed, tend to rely heavily on predictive fatigue models and subjective crew assessments on fatigue symptoms and sleep. Objective data sources such as physiological measures and SMS data, inclusive of roster quality indices and Flight Data Monitoring, are not considered. The model offers no guidance on the detection, investigation, risk assessment, and management process for fatigue events within the Safety Management System (the model defaults to management through an airline Safety Management System (SMS).

The model also assumes there is an investigation process that is integrated into the SMS that can detect fatigue influence, causal and/or contributory, to event occurrence. Current fatigue risk investigative capability within literature only extends to the application of directed scientific methodology and application of predictive fatigue models (models that predict sleep opportunity and alertness that don’t consider individual differences and work environment). Neither process has the sufficient diagnostic capability to support the investigation of fatigue-related incidents. The question is what level of fatigue is contributory and linked to unacceptable performance relative to operational standards. Dawson & McCulloch acknowledge the lack of field performance studies from which to draw performance data to better define operational fatigue controls. The model proposes proactive and reactive controls for fatigue, but suffers from the limitations of the Reason trajectory model of causation. Crew may not manifest fatigue-related symptoms and/or behaviours, yet commit errors (easyJet HFMP study presented to NASA Ames - Intelligent Systems Division Seminar, 2007). Further, fatigue symptoms, behaviours, and error commission may occur simultaneously and not follow a trajectory. The model also does not account for transient fatigue (fatigue that can be overcome by a single restorative sleep period) linked to high workload as a fatigue hazard. That said, it is the first model to propose fatigue management with a proactive and retroactive capability and link the management of fatigue to a Safety Management System.

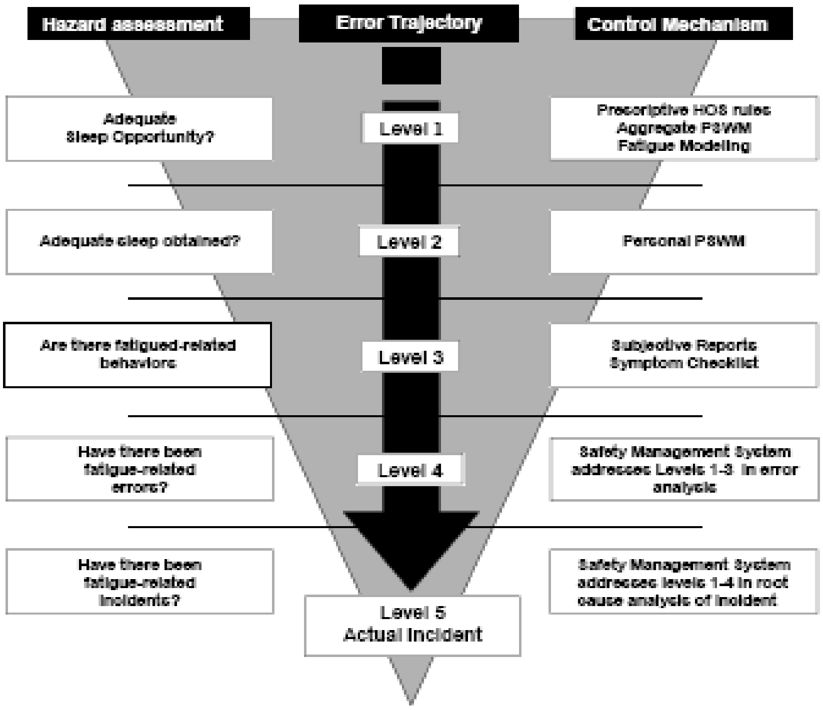


Figure 7. Fatigue Risk Trajectory (Dawson & McCulloch, 2005)

1.12.3 Safety Risk Management and fatigue-related risk

The relational models of Sutton et al (2003), ASLEF (2003) and Baker & Fergusson (2004) describe the relationship between fatigue causes and consequences. Dawson and McCulloch (2005) evolve this concept by describing ‘fatigue as a hazard’ linked to Reason’s accident causation model (Reason, 1997). The Dawson & McCulloch model describes a fatigue ‘error’ trajectory and outlines controls appropriate to the four levels of the model (sleep opportunity to fatigue related incident/accident). The level one hazard is stated as 'sleep opportunity' as the starting point of the trajectory however sleep opportunity in itself does not constitute a hazard, lack of sleep opportunity however does. However, Sutton et al group the antecedents to fatigue (hazard sources) as work factors, shift system and individual factors. Caldwell (2004) cites the principle antecedents as schedule factors, sleep deprivation, circadian factors and individual differences. The model further states that the first three levels of the trajectory are then addressed within the SMS as 'error analysis' representing a control mechanism. This would imply that some sort of risk assessment and management process is enabled from this analysis. The following quote from the Australian New Zealand Risk Standard 4360 refers to the process as:

"Risk management involves establishing an appropriate infrastructure and culture and applying a logical and systematic method of establishing the context, identifying, analyzing, evaluating, treating, monitoring and communicating risks associated with any activity, function or process in a way that will enable organizations to minimize losses and maximize gains" (AS/NZS 4360-2004)

The system safeguard (control mechanism) linked to the level one trajectory trigger hazard include predictive models, FTL and self assessment of sleep (e.g. Prior Sleep Wake Model (PSWM)(Dawson & McCulloch, 2005). System safeguards (controls and barriers) function to prevent contact between 'system energies and environments and people and objects' (DOE/SSDC 76 45/27 p3, 1986). Controls set against fatigue antecedents are inclusive of roster optimisation tools with evidenced based rulesets, fatigue countermeasure training of crew and rostering staff, recruitment protocols, Standard Operating Procedures in addition to those cited by Dawson and McCulloch.

These consequences must be considered against the context that crew are not good at assessing their own level of fatigue effectively (Dinges, 1995). These effects are also not straight forward - fatigued crew do alter their behaviour and implement countermeasures to promote the safe passage of flight (Thomas et al, 2006) (Caldwell et al, 2009).
When considering a performance model of fatigue that has application to aviation a framework needs to capture the principle elements. These involve fatigue antecedents, organisational controls, measure fatigue related performance, detect and assess operational fatigue risk and fatigue countermeasure application and manage tactical and strategic change (organisational learning and memory) as part of a continuous improvement cycle within an SMS framework.
To compete effectively easyJet as a low cost airline seeks safe optimisation and efficiencies within its rostering practices and, therefore have to know the boundaries within which they can operate safely (operating close to the limits set by the regulatory authorities -in flight time limitations for example). Prompted by a serious fatigue-related incident, a study was undertaken to establish the parameters of fatigue within the existing roster system (Stewart & Abboud, 2005).

1.13 System Integrated Risk Assessment (SIRA)

System Integrated Risk Assessment (SIRA) (Figure 8) is easyJet's risk management framework (Stewart et al, 2006; HILAS SMS Book 3, Ch 4: Stewart et al, 2009). It is driven by a clear commercial requirement to manage the operational risks the airline faces in a proactive manner. Starting with a range of event inputs (from individual errors to commercial threats), a 'system sensory net' gathers a wide range of technical, human performance and system data which is then fed into an intelligence process, classifying and analysing causal patterns. In turn this drives decision-making, intervention design, risk mitigation and monitoring. The cycle then continues.

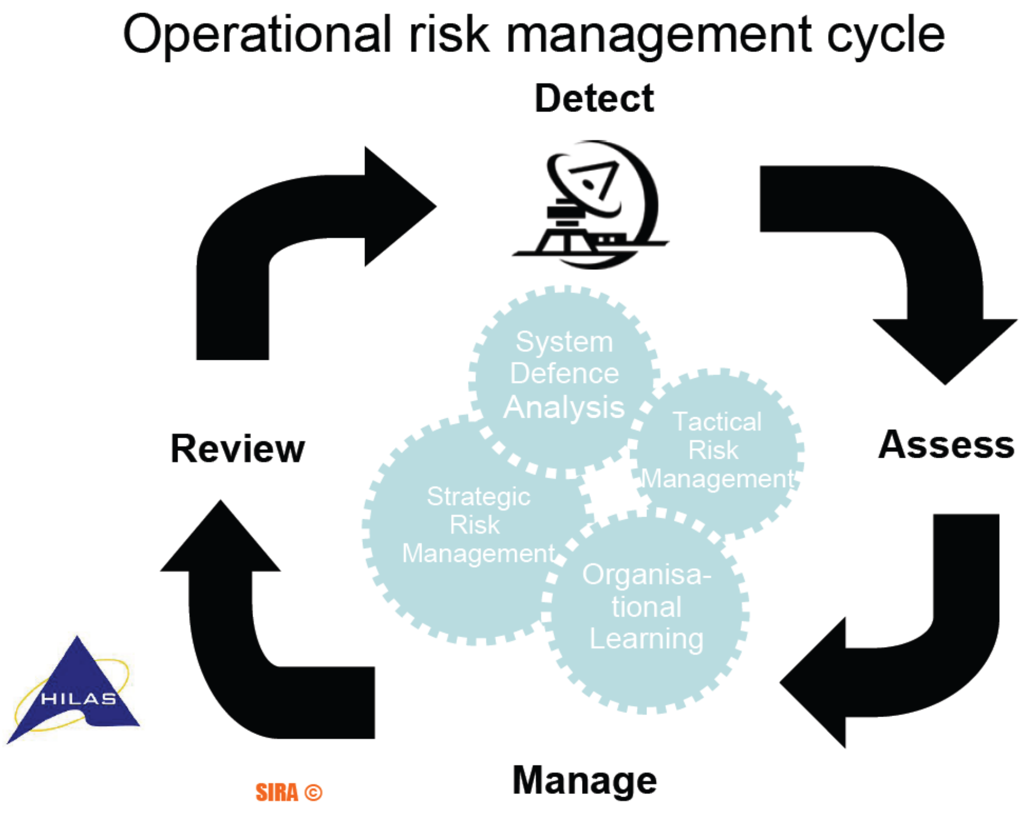


Figure 8. SIRA Risk Management Model

This model was applied to the easyJet fatigue related risk problem. A very wide range of evidence was collected over an extended period – not only routine technical and human performance data, but also specific surveys and additional in-flight performance measures were sampled (Stewart & Abboud, 2005a&b). All this data was then analysed with the benefit of a fatigue and rostering model (Fatigue Audit Interdyne: FAID, Fletcher & Dawson, 1998) which helped identify areas of vulnerability due to human circadian periodicity. This evidence clearly identified high-risk areas (e.g., transitions from early to late shifts and insufficient post duty rest and recovery). This then enabled the redesign to the rostering system to eliminate these problems. This required a special derogation from the Civil Aviation Authority's Flight-time Limitations regulations. The new rostering system was justified and approved in the light of the evidence presented. The revised rostering schedule was implemented and the monitoring continued. The evidence then demonstrated a significant improvement on all safety related indices. Also important from the point of view of implementation and acceptance of the new roster system was that the new system was both more popular with the pilots and delivered greater operability to the company. Section 1.9 discussed this from the perspective of the evolution from a single roster study to a strategic change process of monitoring and continuous improvement with an increasing focus in the background and contextual factors which influence the operational outcome. From an SMS orientation this work also illustrates how having a good system model facilitates joint optimisation between different stakeholders in the process.

Operational fatigue manifestation requires a multilayer capability of fatigue detection tools (subjective and objective) that have sufficient resolution and sensitivity to detect operational fatigue (tools-context-people-task: Frei et al, 2003). Fatigue is heterogenous in nature and objective measurement tools can capture only a limited aspect (Shen et al, 2006). Application of fatigue countermeasures strategies by crew that recognise fatigue symptoms through performance insight (may not be reported) can limit safety signals received by the FRMS/SMS and mask operational risk issues. This is a form of recovery measure post manifestation and assessment (Caldwell et al, 2009). Crew implemented control and recovery strategies to maintain a satisfactory level of safe performance masks true potential operational risk. Investigations are difficult to progress, as there is in effect 'no smoking gun' adverse outcome, from which to apply sequencing and analytical techniques to assess operational risk exposure linked to the severity of the outcome. Potential consequences mitigated through proactive risk management activity are not often reported and are less convincing to management post investigation than adverse outcomes.

The safety trigger signals (detection followed by inquiry) on a system level are received through the FRMS/SMS sensory network of hazard-detection tools (intra and inter organisational). The FRMS/SMS receives these trigger signals from both safety-risk management and safety-assurance sources. The process is based on a risk radar approach acting as a system-sensory net scanning the risk environment. The data is managed within the company Aviation Quality Database (AQD) and an intelligence process classifies and analyses causal patterns. These signals can be from reactive, proactive, evaluatory and exploratory fatigue hazard-identification tools (e.g. fatigue reports, safety reports, FOQA events, fatigue surveys, threat & error management, safety performance metrics, safety target thresholds, roster quality indices), which are transmitted, documented, and classified (method classification model). Identified hazards are initially risk assessed triggering system recovery strategies where appropriate. Tactical and strategic investigations are conducted with resultant change management activity implemented. Risk monitoring and mitigation activity adjusts the system to maintain operational risk within an acceptable safety region in accordance with ICAO SMM 9859 (ICAO, 2008).

The model proposed recognises that fatigue risk to the operation occurs when a fatigued crew interacts with the operational process. Every flight carries a measure of fatigue-related risk, but the role of the FRMS is to determine where crews can adequately perform satisfactorily, all their safety-related duties. Individual and system countermeasures can assist to mitigate the effect of this manifestation. Identified fatigue-related risk areas are investigated and, where evidence supports policy or rule-sets changes, then a larger scope strategic investigation and management process is enacted. The HFMP for example, forms part of a strategic proactive and exploratory risk-assessment activity. The tactical and strategic investigation processes drive decision-making, intervention design, and monitoring against the operational system. The cycle then continues utilising feedback-loop processes as a function of risk management from both strategic and tactical interventions. The tactical and strategic cycles of the model are interdependent represented by the larger strategic cog driving (and driven by) the smaller tactical cog dealing with day-to-day risk activity. The strategic cycle represented by the larger cog encodes organizational change whilst the tactical cycle deals with day-to-day risk activity with corresponding response speeds. The model proposed steps beyond the approach adopted by Dawson and McCulloch by recognising that fatigue antecedents that need system safeguards extend beyond sleep opportunity and that fatigue countermeasures employed by operating crew can limit system safety trigger signals. Further the model incorporates the principles of the HILAS risk management process (Stewart et al, 2009a,HILAS Chapter 4, Book 3) as the basis for Fatigue Risk Management process (integrated into the airline SMS).

The SIRA process model has been redesigned and enhanced by applying principles of Organisational Learning resulting in a realignment of existing bodies and closing learning loops. The key functions in Organisational Learning (detect, notify, inquire and adjust) are embodied by 'learning agencies' and 'organisational memory' interconnected with operations and management (Koornneef and Hale, 2004, Koornneef et al, 2008).

Organisational Learning (OL)(HILAS Chapter 4, Book 2, Koornneef et al. 2009) is the capacity of an organisation to learn from experiences and from its changing environment in order to maintain its viability, meaning, for instance, to stay in business in a competitive market. Learning is a process of finding a solution to a problem situation and implement it to resolve the problem. In order not to learn twice the same lesson, memories in which the lessons learned are stored are essential. They need to be accessed when a problem situation is recognised, so that lessons learned earlier can be retrieved and reused. For organisations, it is vital to develop a clear view of *what* there is to learn *when*, *where*, and by *whom*. In this respect, the concept of 'operational readiness' (Nertney, 1987) within a tactical goal of doing the intended activity right and with a strategic objective of maintaining viability of the organisation provides a productive starting point.

A Learning Agency consists of persons who take on the role to learn on behalf of the organisation and bring in their collective expertise, including tacit knowledge, about daily practice as far as relevant to the operational problem in operational context. The core function is 'inquiry' resulting in a preferred set of measures that are communicated with line management for implementation, or in identified problems that need to be solved by other stakeholders. Typically, members of a learning agency are very busy and are scarce resources. This stresses the need to store problems and outcomes from the inquiry in organisational memory that can be accessed for reuse of solutions.

Organisational Memory exists in different forms, including external regulation (EASA NPA 2009; CAP 371), fatigue policy, evidenced based rostering rulesets, best practice protocols, FRMS manual, fatigue awareness and education training programs, IT storage & retrieval systems, dedicated meetings, such as Fatigue SAG and Roster Evaluation Group meetings, and group behaviour that can be observed to read out this form of memory. Much knowledge that operators has about daily practice is tacit in nature and can be mobilised for organisational learning in the setting of a more or less formal designed 'learning agency' function.

Fatigue-related risk precursors and consequences can now be effectively represented within a Risk Management framework (Figure 9) that provides a performance trajectory from risk precursor to system risk management activity and feedback processes. This is a step beyond the influence diagrams of the past and facilitates how fatigue factors are risk managed within an FRMS.

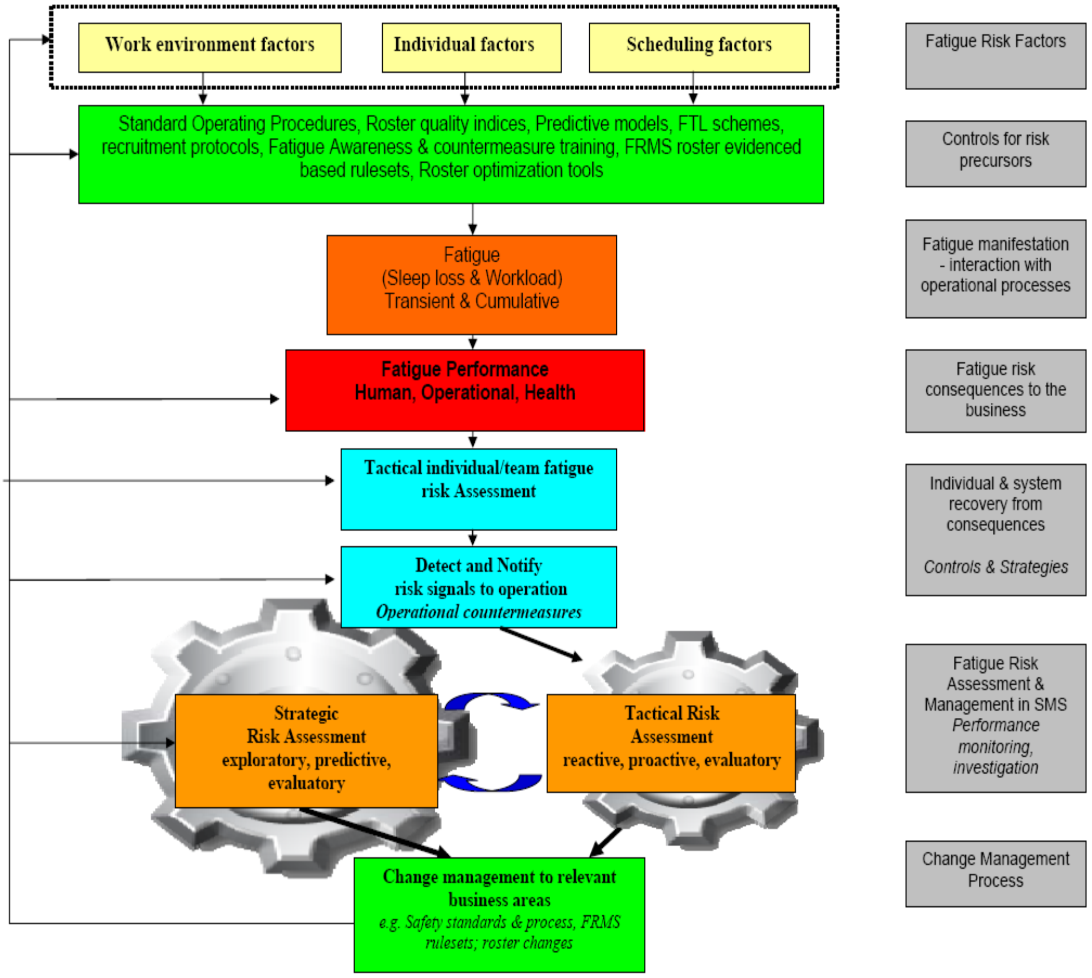


Figure 9. easyJet Fatigue Risk Management model

This model facilitates the core functioning criteria for fatigue management based on the ICAO SMS framework inclusive of:

1. Detecting, measuring, categorising, investigating and analysing operational fatigue hazards in order to provide the interface between safety risk assessment and rostering processes.
2. Prioritising strategic and tactical fatigue risks so as to develop and implement appropriate controls and evidenced based rostering rulesets.
3. Communicating change and risk management activity to the organisation
4. Tracking and monitoring the performance of implemented controls thereby assessing any residual risk.

5. Providing feedback to stakeholders and the regulator as part of a continuous improvement cycle

1.14 EasyJet Management system for Fatigue related risk including a Fatigue risk management model

In summary then, the establishment of a Fatigue related risk management system requires an SMS construct inclusive of policies, risk assessment tools and processes to manage operational hazards arising from fatigue.

The risk generation and management flowchart in Figure 9 states that fatigue-related risk interaction with operational processes, beyond affecting the performance of individuals or teams, can threaten the integrity of the operation as a whole. It represents a trajectory from fatigue causal factors to fatigue interaction with operational process and establishes the link to risk management activity.

The model shows that fatigue causes of individual, schedule and work environment factors are systematically managed through a series of operational controls and that the risk of fatigue comes about as the result of shortcomings and deficiencies in these safeguards (Reason, 1997). It also acknowledges that controls and safeguards can be applied where necessary at the many levels in this flowchart. A single deficiency may not lead to an incident however a combination of factors can align the holes in the Reason Swiss Cheese model and lead to a fatigue related incident or where fatigue contributory factors are linked to a number of incidents raising operational risk levels.

The flowchart demonstrates that fatigue-related risk needs to be managed by a system of processes ranging from a fatigue policy, education and training for management and line staff and risk tools for the detection, investigation and analysis of fatigue safety triggers and also processes for tactical and strategic management of risk. It presupposes that the controls and management processes for an FRMS are harmonised into an airline SMS and operational management infrastructure. This harmonisation of an FRMS detection toolbox within the SMS sensory network increases the SMS depth of focus and resolution as fatigue related contributory factors may be prevalent within a number of safety related incidents.

This Risk Management Model for fatigue related risk recognizes that:

- *Inter-individual differences exist between operating crew and how they perform when fatigued, their ability to assess their fatigue state linked to performance assessment and their intrinsic sleep ability, quantity and quality* (Graeber, 2009),
- Sleep deprivation (transient and/or cumulative) and workload can lead to performance decrements manifested by crew which in turn can impact on crew performing operationally to a satisfactory level of safety under all circumstances

- FTL rulesets, as a principle fatigue control within the operation cannot be written for every rostering contingency, represent a static form of safety management and often are unsupported by scientific evidence
- Application of fatigue countermeasures can provide strategies that partially mitigate operational fatigue related risk and fatigue-related signals received by the FRMS but not the underlying physiological factors; and
- Fatigue related risk can manifest as a root cause or contributory factor behind the occurrence of safety incidents and that risk mitigation and monitoring is a necessary (both tactical and strategic) SMS function to support evidenced based rostering rulesets (that govern crew scheduling and can impact on crew alertness and performance)

1.14.1 Implementation of a Fatigue Risk Management System at easyJet

In 2006 easyJet became the first European airline to implement an FRMS. The key benefit of managing fatigue risk is obviously the prevention of accidents, however it is simplistic to view fatigue risk management as merely a safety initiative. It is in the commercial interests of managers to understand the nature of fatigue risk and easyJet have incorporated the FRMS into its core business model. Knowing operational risk exposure enables managers to ensure that the short-term profitability is simultaneously considered with brand protection in mind.

easyJet have also implemented the FRMS in preparation for the ICAO SMS legislation that is due to become effective in 2012. ICAO Annex 6 guidance and the draft EASA NPA 2009c regulations will require airlines to implement a continuous safety monitoring program with management accountability for operational risk.

In a similar vein, in the EU the strengthening of the European Aviation Safety Agency (EASA) means that national regulatory bodies are going to have less oversight in the future and airlines will need to implement internal governance, or in other words risk awareness and ownership and a strong internal audit process (Hampton Report, 2005). In the UK, the CAA is already under pressure to cut resources and place more emphasis on internal self governance. Furthermore, the Corporate Manslaughter and Corporate Homicide Act (c19) (2007) states that being unaware of a risk does not mean that managers are not culpable or accountable.

Insurers and underwriters are also promoting the application of proactive risk management strategies that demonstrate safety awareness and capability (Airline Business Risk Management Survey, 2007). Insurers recognise that compliance to regulatory baselines cannot ensure safety operation under all circumstances and look to see how organisations manage safety performance including how the SMS integrated into wider enterprise risk management processes. Insurers have stated that they will link airline premiums against organisational risk signature (AeroSafety world, 2007).

1.14.2 Reasons supporting FRMS implementation

The benefits of managing fatigue like any other risk, i.e. within an SMS, are significant. Reasons for investing in an FRMS include (Graeber, 2009):

1) Knowledge of fatigue risk exposure is a fundamental element of business model – FRMS gives a measure of risk exposure. It is in the commercial interests of operators to understand the nature of fatigue risk and manage it effectively for continued safe operation and viability in the commercial environment. Safety links to commercial interest via brand protection.
    - Provides equivalent safety with greater operational flexibility than prescriptive Flight/Duty Time Limitations.
    - Is based upon the latest scientific knowledge about sleep, circadian rhythms, alertness levels, and performance.
    - Takes into account known variables that affect sleep and alertness which prescriptive flight/duty limits cannot address.
    - Is data driven to reflect unique and changing airline factors.
    - Incorporates the management of operational fatigue risk into a proactive and accountable SMS framework.
    - Enables an enhanced level of safety based upon identifying and managing fatigue risk relevant to specific circumstances
    - Reduction in frequency of medium and high risk events
    - Reduction in oversight from the regulating authority
    - Reduction in attrition
    - Reduction in fatigue lost duty days and sickness incidence due fatigue related factors
    - Increased crew morale and CRM performance

The quantification of the benefits a reduction in fatigue associated with altered work schedules has been demonstrated in the nuclear industry by Fleishman et al (2006) with the following benefits:

- Reduction in frequency of severe accidents
- Reduction in plant shutdown risk
- Improved security
- Reduction in frequency of lost and restricted work days

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