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FATIGUE RISK MANAGEMENT FOR CABIN CREW

BY
SHILPA SINGH
SAP ID: 500071778

UNDER THE GUIDANCE OF
MR. ATUL GARG
GM (O), SMS
AIR INDIA LIMITED

A DISSERTATION REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

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Shilpa Singh

Signature

Name of the Student : Shilpa Singh
Residential Address : A4D, Rivali Park, Borivali East, Mumbai -400066
Telephone/Mobile : 9920082163
E-mail : shilpa_2k4_singh@yahoo.com
Date : 25 Jan 2020
Place : Mumbai

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FLIGHT SAFETY DEPARTMENT
Santa Cruz

Ref. No: FSD/Misc/020

Date: 14th Jan 2020

Mr. Atul Garg
Gen. Manager (O) – SMS,
Mobile No: 9892676422
Air India Ltd,
Santa Cruz.

Subject: - Willingness for Guiding Dissertation of Ms. Shilpa Singh (Registration No. 500071778)

Dear Sir,

Ms. Shilpa Singh is registered for **Masters in Business Administration (Aviation Management), with the University of Petroleum & Energy Studies**, Dehradun in April 2018 batch.

I hereby give my acceptance to guide the above student through the Dissertation work titled **"Fatigue Risk Management for Cabin Crew"**, which is a mandatory requirement for the award of EMBA degree.

Thanking You,

Yours Sincerely

Atul Garg.

अतुल गर्ग /Atul Garg
महाप्रबंधक (स्था.)
General Manager-(O)
संरक्षा प्रबंधन प्रणाली
SAFETY MANAGEMENT SYSTEM
एअर इंडिया लिमिटेड
AIR INDIA LIMITED

ओल्ड एअरपोर्ट, कालिना, सांताक्रुज (पूर्व), मुंबई – 400 029. इंडिया. फोन : 2626 5555
Old Airport, Kalina, Santacruz (East), Mumbai - 400 029. India. Phone : 2626 5555
रजिस्टर्ड कार्यालय : एअर इंडिया लि., एअरलाइन्स हाऊस, 113, गुरुद्वारा रकाबगंज रोड, नई दिल्ली – 110 001. इंडिया. फोन : 2342 2000
Regd. Office: Air India Ltd. Airlines House, 113, Gurudwara Rakabganj Rd., New Delhi - 110 001. Tel: 2342 2000
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DECLARATION BY THE GUIDE

This is to certify that Ms. Shilpa Singh, a student of MBA (Aviation Management) , SAP ID 500071778 of UPES has successfully completed this dissertation report on "Fatigue Risk Management for Cabin Crew"under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analysed by her and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfilment for the award of degree of MBA.

Signature

Name & Designation : Atul Garg, General Manager(O), Safety Management System
Address : 2A/11, Indian Airlines 2nd Colony, Kalina, Santacruz East, Mumbai 400029
Mobile : 9892676422
E-mail: gargatul.garg@gmail.com
Date: 25 JAN 2020
Place: Mumbai

ओल्ड एअरपोर्ट, कालिना, सांताक्रुज (पूर्व), मुंबई – 400 029. इंडिया. फोन : 2626 5555
Old Airport, Kalina, Santacruz (East), Mumbai - 400 029. India. Phone : 2626 5555
रजिस्टर्ड कार्यालय : एअर इंडिया लि., एअरलाइन्स हाऊस, 113, गुरुद्वारा रकाबगंज रोड, नई दिल्ली – 110 001. इंडिया. फोन : 2342 2000
Regd. Office: Air India Ltd. Airlines House, 113, Gurudwara Rakabganj Rd., New Delhi - 110 001. Tel: 2342 2000
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EXECUTIVE SUMMARY

While a great deal of research has been conducted on human circadian processes as applied to scheduling and training of Airlines' flight crew, relatively lesser research has been accomplished for cabin crew. Performance of cabin duties is critical to safety and security and the literature suggests that all human performance is vulnerable to sleep loss and daily variations in physiological processes tied to underlying biological body-clock mechanisms. The extent of sleep loss, fatigue, and their impact upon performance of duties among the cabin crew population and within the current duty regulations are unknown however, are under investigation along with several other congressionally directed research projects.

Misconceptions and/or lack of knowledge about the duties of cabin crew have contributed to the perception that their sole purpose is to provide customer service. Unfortunately, only during the time of an inflight emergency it is realized and appreciated of the important role of certified cabin crew and their performance of critical safety functions (e.g., performing emergency assistance by fighting fires, administering first aid, leading evacuations, conducting security checks etc.).

It is therefore imperative, that there needs to be sufficient importance and compliance adhered to the fatigue associated with this workforce in order to have high standards of cabin safety and continuing research methods need to be adopted for ensuring this.

Human performance is defined as the human capabilities and limitations which have an impact on the safety and efficiency of flight operations. Human performance training focuses on relationships between people and equipment, systems, procedures and the environment as well as personal relationships between individuals and groups. It encompasses the overall performance of cabin crew members while they carry out their duties. The goal of this system is to optimize human performance and manage human error. It encompasses Human Factors principles, crew resource management and the development and application of skills, such as decision-making. Human performance training should be oriented towards solving practical problems in the real world.

Fatigue is defined as a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety-related duties. A fatigue risk management system (FRMS) is defined as a data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles and knowledge as well as operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness.

CHAPTER - 01

INTRODUCTION

INTRODUCTION

1.1 OVERVIEW

The purpose of Fatigue Risk Management System (FRMS) is to provide air operators with information for implementing an FRMS that is consistent with ICAO Standards and Recommended Practices (SARPs). As the ICAO provisions for FRMS evolve, every effort will be made to keep this manual up to date. However, it is recommended that operators check the current SARPs to find out if anything important has changed since this version of the manual was developed. Operators also need to ensure that their FRMS meets the requirements of their State's regulatory authority.
A variety of options to address the ICAO Standards for an FRMS are presented throughout this study. These can be adapted to the needs of different sizes and types of operators (international, domestic, passenger, cargo, etc) and to specific operations (Ultra-Long Range (ULR), long haul, short haul domestic, on-call/charter, etc). It is not necessary to implement all of these options to have an effective FRMS that meets regulatory requirements.

Crewmember fatigue can be defined as:
A physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety related duties.
Fatigue is a major human factors hazard because it affects most aspects of a crewmember's ability to do their job. It therefore has implications for safety. ICAO defines a Fatigue Risk Management System (FRMS) as:
A data-driven means of continuously monitoring and managing fatigue-related safety risks,

based upon scientific principles and knowledge as well as operational experience that aims
to ensure relevant personnel are performing at adequate levels of alertness.
An FRMS aims to ensure that flight and cabin crew members are sufficiently alert so they can operate to a satisfactory level of performance. It applies principles and processes from Safety Management Systems (SMS)1 to manage the specific risks associated with crewmember fatigue. Like SMS, FRMS seeks to achieve a realistic balance between safety, productivity, and costs. It seeks to proactively identify opportunities to improve operational processes and reduce risk, as well as identifying deficiencies after adverse events. The structure of an FRMS as described here is modelled on the SMS framework. The core activities are safety risk management (described in the SARPS as FRM processes) and safety assurance (described in the SARPs as FRMS safety assurance processes). These core activities are governed by an FRMS policy and supported by FRMS promotion processes, and the system must be documented.

Both SMS and FRMS rely on the concept of an 'effective safety reporting culture,where personnel have been trained and are constantly encouraged to report hazards whenever observed in the operating environment. To encourage the reporting of fatigue hazards by all personnel involved in an FRMS, an operator must clearly distinguish between:

- Unintentional human errors, which are accepted as a normal part of human behaviour and are recognized and managed within the FRMS; and

- Deliberate violations of rules and established procedures. An operator should have processes independent of the FRMS to deal with intentional non-compliance

The traditional regulatory approach to managing crewmember fatigue has been to prescribe limits on maximum daily, monthly, and yearly flight and duty hours, and require minimum breaks within and between duty periods. This approach comes from a long history of limits on working hours dating back to the industrial revolution. It entered the transportation sector in the early 20th century in a series of regulations that limited working hours in rail, road and aviation operations2. The approach reflects early understanding that long unbroken periods of work could produce fatigue (now known as 'time-on-task' fatigue), and that sufficient time is needed to recover from work demands and to attend to non-work aspects of life.

In the second half of the 20th century, scientific evidence began accumulating that implicated other causes of fatigue in addition to time-on-task, particularly in 24/7 operations. The most significant new understanding concerns:

- The vital importance of adequate sleep (not just rest) for restoring and maintaining all aspects of waking function; and
- Daily rhythms in the ability to perform mental and physical work, and in sleep propensity (the ability to fall asleep and stay asleep), that are driven by the daily cycle of the circadian biological clock in the brain. This new knowledge is particularly relevant in the aviation industry which is unique in combining 24/7 operations with trans-meridian flight.

In parallel, understanding of human error and its role in accident causation has increased. Typically, accidents and incidents result from interactions between organizational processes (i.e. workplace conditions that lead crewmembers to commit active failures), and latent conditions that can penetrate current defenses and have adverse effects on safety1. The FRMS approach is designed to apply this new knowledge from fatigue science and safety science. It is intended to provide an equivalent, or enhanced, level of safety, while also offering greater operational flexibility.
Prescriptive flight and duty time limits represent a somewhat simplistic view of safety – being inside the limits is safe while being outside the limits is unsafe – and they represent a single defensive strategy. While they are adequate for some types of

operations, they are a onesize- fits-all approach that does not take into account operational differences or differences among crewmembers.

In contrast, an FRMS employs multi-layered defensive strategies to manage fatigue-related risks regardless of their source. It includes data-driven, ongoing adaptive processes that can identify fatigue hazards and then develop, implement and evaluate controls and mitigation strategies. These include both organizational and personal mitigation strategies. However, the cost and complexity of an FRMS may not be justified for operations that remain inside the flight and duty time limits and where fatigue-related risk is low. Some operators may therefore choose to place only certain parts of their operations under an FRMS or not implement an FRMS at all. Nonetheless, where an FRMS is not implemented, it remains the operator's responsibility to manage fatigue-related risks through their existing safety management processes. Like SMS, FRMS represents a performance-based regulatory approach (in contrast to the prescriptive regulatory approach of flight and duty time limits). In essence, this means that FRMS regulations define requirements for operators to manage fatigue risk, rather than prescribing limits that cannot consider aspects specific to the organization or operating environment. The Fatigue Management SARPs (Annex 6, Part I and Appendix 8) prescribe components that must be in an FRMS, and the ICAO guidance material provides further information on how an FRMS should function.

Recognizing the prominent role played by flight attendants in protecting the traveling public and the increasing demands on this unique segment of the civilian workforce, in 2005 and 2008, the U.S. Congress directed the FAA's Civil Aerospace Medical Institute (CAMI) to conduct a multi-leveled examination of flight attendant fatigue. The comprehensive project included directives to review current policies and practices, conduct a large-scale survey of active flight attendants, and collect objective data in a field study of "real world" flight attendant operations. As expected, the regulatory reviews confirmed the potential for fatigue-promoting practices (Nesthus, Schroeder, Conners, Rentmeister-Bryant, & DeRoshia, 2007), and the survey provided detailed data on the ubiquitous perception of fatigue within the flight attendant community and the various operational factors thought to produce and exacerbate it (Avers, King, Nesthus, Thomas, & Banks, 2009).

The present report offers an overview of results from the flight attendant field study conducted from May 2009 through June 2010 by the Institutes for Behavior Resources (IBR), an independent non-profit research, services, and educational organization headquartered in Baltimore, MD, USA, in collaboration with researchers at CAMI in Oklahoma City, OK, USA. This initial report focuses primarily on objective quantitative measures of sleep and neurocognitive performance patterns in over 200 U.S.-based flight attendants of all seniority levels working for network, low-cost, and regional carriers embarking on domestic and international flight operations. The detailed assessment of sleep and performance effectiveness patterns across a broad sample of the flight attendant population complements CAMI's prior work by objectively quantifying the presence and extent of fatigue and may critically inform the development of comprehensive fatigue risk management systems or other science-based policy refinements designed to enhance cabin safety.

1.2 BACKGROUND

The traditional regulatory approach to managing crewmember fatigue has been to prescribe limits on maximum daily, monthly, and yearly flight and duty hours, and require minimum breaks within and between duty periods. This approach comes from a long history of limits on working hours dating back to the industrial revolution. It entered the transportation sector in the early 20th century in a series of regulations that limited working hours in rail, road and aviation operations2. The approach reflects early understanding that long unbroken periods of work could produce fatigue (now known as 'time-on-task' fatigue), and that sufficient time is needed to recover from work demands and to attend to non-work aspects of life. In the second half of the 20th century, scientific evidence began accumulating that implicated other causes of fatigue in addition to time-on-task, particularly in 24/7 operations.

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Numerous factors can affect safety, performance, and quality of life in individuals working in 24-hr operational environments such as industrial shiftwork, military, health care, law enforcement, space exploration, and transportation. One issue of increasing importance to commercial aviation is fatigue (Avers, King, Nesthus, Thomas & Banks 2009; Mallis, Banks, & Dinges 2010; Nesthus, Schroeder, Connors, Rentmeister-Bryant, & DeRoshia 2007). Fatigue is generally defined as a state of tiredness due to prolonged wakefulness, extended work periods, and/or circadian misalignment, and is characterized by decreased alertness, impaired decision making, and diminished neurobehavioral performance capacity (Åkerstedt, 1995; Dinges, 1995).

The very nature of 24-hr operational environments superimposed against human circadian physiology all but guarantees the systematic production of fatigue. As such, valid and reliable methods of predicting compromised performance capacity could be valuable as a means of preventing and mitigating fatigue-induced safety risks in applied settings.

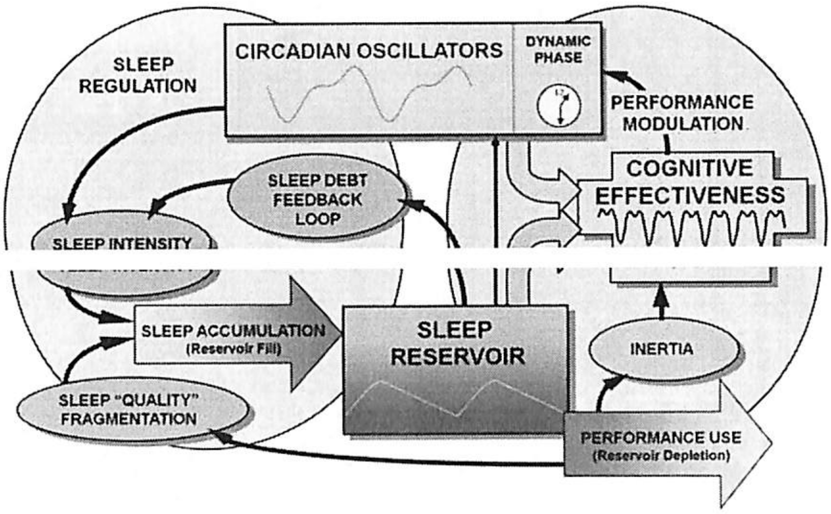


Figure 1: SAFTE Model Schematic

One approach that has attracted attention in recent years is the development and application of biomathematical modeling as a means of predicting, preventing, and mitigating fatigue-induced risks. Among the more mature and well-regarded fatigue models is the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model (Hursh et al., 2004; Hursh & Van Dongen, 2010; Van Dongen, 2004). SAFTE is a predictive rather than descriptive model that incorporates several dynamic components such as a homeostatic sleep reservoir, circadian oscillator, and sleep inertia function (see Figure 1). Final cognitive/task effectiveness predictions integrate with these components but are based on the scientific research literature of wellcontrolled fatigue manipulations in well-controlled laboratory settings, ultimately relying on psychomotor speed (1/Reaction Time, expressed as a percentage of individual well-rested baseline) in the traditional 10-min Psychomotor Vigilance Test (PVT; Basner & Dinges, 2011) as the model's principal outcome metric. Originally developed with support from the U.S. Department of Defense, the SAFTE model has been adopted for use in a variety of operational contexts beyond the military, including rail, industrial shift work, and aviation.

Arguably the most critical aspect of any model is its predictive validity, which in the case of fatigue models and risk management is the extent to which predicted performance decrements correspond to adverse performance outcomes in the operational environment. In their 2008 report for the U.S. Federal Railroad Administration, Hursh and colleagues validated the SAFTE model against a database of 30-day work histories preceding 400 human factors and 1,000 non-human factors freight rail accidents. Although the model had no predictive power for non-human factors accidents, the relative risk of human factors-related accidents increased significantly during periods when SAFTE predicted fatigue-induced impairments in performance effectiveness (beginning at 90% of baseline with a linear increase in risk as predicted effectiveness decreased). Subsequent analyses of 350 human factors accidents later demonstrated that the relative economic risk (accident probability x [material damage + casualty costs]) was increased by 500% when SAFTE- predicted effectiveness scores were at, or below 77%, whereas relative economic risk was reduced by 75% when SAFTE-predicted effectiveness was above 90% (Hursh, Fanzone & Raslear 2011). These validation data powerfully demonstrated the SAFTE model's ability to predict human factors accident risk and financial impact in rail operations; however, given those studies' retrospective design, no measures were taken quantifying changes in the engineers' neurobehavioral performance capacity underlying the accidents. Moreover, the generalizability of the SAFTE model's validity—at least the extent to which variations in predicted effectiveness correspond to variations in performance effectiveness—has never been empirically assessed within the context of commercial aviation.

To address these issues, the present report offers a validation analysis of the SAFTE model drawn from the extensive database collected during the 2009-2010 Civil

Aerospace Medical Institute (CAMI)-sponsored Flight Attendant Field Study (Roma, Mallis, Hursh, Mead & Nesthus 2010). As part of a series of Congressionallymandated projects on fatigue, a major goal of the prospective field study was to evaluate the predictive validity of the SAFTE model, using actual sleep/wake/work patterns and standardized objective neurobehavioral performance metrics taken in the "real world" by a broadly representative sample of professional cabin crew. To the best of our knowledge, the present study is the first validation of any fatigue model to use objective performance measures in the field within the extremely dynamic commercial aviation environment (cf. Civil Aviation Safety Authority [CASA], 2010; also see Spencer and Robertson, 2007).

1.3 PURPOSE OF STUDY

There is increasing recognition that methods which proactively monitor airline safety may be useful in preventing air safety occurrences. Proactive rather than reactive safety programs are particularly important, considering the high social and economic costs of airline accidents to the community. However, in the aviation industry, there are currently few formal proactive safety management systems in use, and none that reliably demonstrate the desirable goal of improving safety performance.
This paper outlines a new proactive safety method for the airline industry, called INDICATE (Identifying Needed Defences In the Civil Aviation Transport Environment). INDICATE is an airline self-management safety tool which encourages regular passenger transport operators to critically evaluate and continually improve the strength of their safety system. INDICATE also provides a formal communication channel for airline operators to regularly identify and report current weaknesses in aviation regulations, policies and standards to the Bureau of Air Safety Investigation (BASI), before they result in an accident. A major Australian regional airline is currently

trialing INDICATE, so that an evaluation of its effectiveness and application to the wider aviation industry can be established. Preliminary results from this trial are presented.

The challenge facing air safety investigators in recent years has been to develop better ways of investigating air safety occurrences. The systemic approach to accident investigation is now firmly established and has received wide acceptance as a result of some highly public aviation accidents.

The crash of an Air Ontario Fokker F28 1000 at Canada's Dryden Airport resulted in a commission of inquiry that went beyond flight crew error as the principal cause and focused instead on systemic problems in the Canadian aviation system (Moshansky, 1992). In Australia, the accident involving a Piper Chieftain aircraft during a night circling approach in poor weather at Young, New South Wales, resulted in the loss of seven lives. The investigation of the accident highlighted significant deficiencies in the operation of the airline, and its interaction with the regulating authority (BASI, 1994).

Systemic investigations such as Dryden and Monarch have revealed that air safety occurrences frequently result from a set of similar safety deficiencies. Because aviation involves people, it is the failure of the human at some point in the system that dominates the accident statistics. The human failure may involve flight crew not following procedures, an incorrectly fitted component by a maintenance engineer, or the failure of management to provide adequate refresher training. What is unfortunate is that many of these human failures are recurrent and provide already well established (but not necessarily well learned) safety lessons.

There is increasing recognition that more effort should be directed at developing a reliable method that proactively monitors airline safety and minimises the potential risk of air safety occurrences. For airline managers, an effective proactive safety program represents very real financial benefits, considering the significant economic costs of an accident. However, in the aviation industry, there are currently few formal safety management programs designed to proactively prevent airline accidents. Much of the methodology behind these proactive safety programs is based on the work of Professor James Reason of the University of Manchester (Reason, 1990).

Reason (1991) contends that modern aircraft accidents are generally the result of latent failures arising from the broad management functions of an organisation. Latent failures are decisions or actions originating within management that have damaging consequences but may lie dormant for a period of time. Reason (1995) has developed the following model (Figure 2).

A model of organisational accident causation
(Adapted from Reason, 1995)

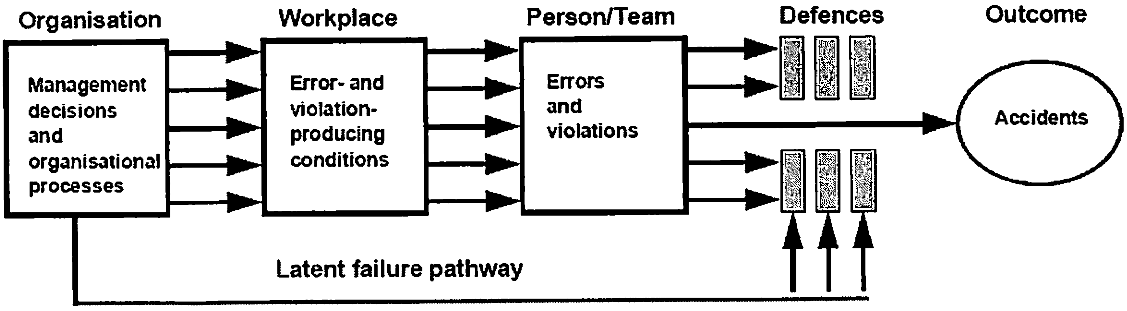


Figure 2

The model suggests that the direction of accident causality is from left to right. That is, accidents originate from latent failures arising from managerial decisions and organisational processes. These latent failures combine with local workplace factors, and errors or violations usually committed by operational personnel. If system defences are breached, the result may be an accident. The International Civil Aviation Organisation (ICAO) has recommended the use of this model to investigate the role of latent failures in aircraft accidents and incidents (ICAO Accident Investigation AIG Divisional Meeting, 1992).

While this model has been used successfully in the retrospective identification of accident contributing factors, there are a number of proactive indicators that also base

their methodology on the Reason model. These indicators periodically monitor those organisational latent failures that have appeared in catastrophic accidents, failures such as inadequate training, poor management communication, inadequate maintenance and poor equipment design. Shell International currently employ Tripod-DELTA (Hudson and others, 1994) in their drilling and exploration operations.
Research at British Rail in the form of REVIEW (Reason, 1993) has focused on predicting or making latent failures more visible so that remedies can be implemented to improve safety. More recently Edkins and Pollock (1996) implemented REVIEW within an Australian public rail authority and found it a useful method for encouraging management and employees to become more involved in safety.

Within the aviation industry, British Airways has developed MESH (Managing Engineering Safety Health), which regularly assesses the current state of safety health along a number of situational and organisational dimensions (Reason, 1994). Organisational dimensions include organisational structure, training and selection, communication and people management. Situational dimensions include morale, fatigue or personnel safety features. The New Zealand Civil Aviation Authority has developed ASMS (Aviation Safety Monitoring System) a computerised management information system that not only stores information from air safety investigations but allows inspectors to carry out safety audits using typical organisational failure items similar to the organisational indicators employed by MESH. BASI has developed an analysis system which proactively identifies ineffective safety defences and recovery measures from aviation incident data.

Current proactive indicators such as MESH and REVIEW provide useful information to management on the safety health of their organisation. However, there are a number of reasons why such systems may not be directly transferable to the Australian airline industry. Some of these systems are limited by an over-reliance on subjective attitude measurement scales. Others require continual input from many employees from diverse areas to be considered valid. Furthermore, in the aviation industry these methods have only been applied in single operational areas rather than in the entire organisation. Current proactive indicators are also limited by their exclusive focus on the identification of potential latent failures. Latent failures can be difficult to identify, may arise for complex reasons, and are often clearer after the event than before.

1.4 RESEARCH HYPOTHESIS

A fatigue risk management system (FRMS) is defined as a data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles and knowledge as well as operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness.

Fatigue management requirements applicable to operators are addressed in Annex 6 — Operation of Aircraft, Part I — International Commercial Air Transport — Aeroplanes. They require States to put in place regulations for managing fatigue based on scientific principles, either through mandatory prescriptive regulations on flight time, flight duty period, duty period and rest period limitations or optional fatigue risk management systems (FRMS) regulations. These provisions are applicable to flight and cabin crew.

The FRMS approach represents an opportunity for operators to use advances in scientific knowledge to improve safety and increase operational flexibility. This chapter reviews the scientific principles needed to develop and implement an effective FRMS.
In Chapter One, the ICAO definition of crewmember fatigue was given as:
A physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety related duties. In flight operations, fatigue can be measured

either subjectively by having crewmembers rate how they feel, or objectively by measuring crewmembers' performance.

Another way of thinking about this is that fatigue is a state that results from an imbalance between:

- The physical and mental exertion of all waking activities (not only duty demands); and
- Recovery from that exertion, which (except for recovery from muscle fatigue) requires sleep.

Following this line of thinking, to reduce crewmember fatigue requires reducing the exertion of waking activities and/or improving sleep. Two areas of science are central to this and are the focus of this Chapter.

1. Sleep science - particularly the effects of not getting enough sleep (on one night or across multiple nights), and how to recover from them; and

2. Circadian rhythms – the study of innate rhythms driven by the daily cycle of the circadian biological clock (a pacemaker in the brain).

These include:

a) Rhythms in subjective feelings of fatigue and sleepiness; and
b) Rhythms in the ability to perform mental and physical work, which affect the effort required to reach an acceptable level of performance (exertion); and
c) Rhythms in sleep propensity (the ability to fall asleep and stay asleep), which affect recovery.

ICAO Annex 6, Part I, Appendix 8 requires that an operator develop, maintain, and document three types of processes for fatigue hazard identification:

1. predictive processes;
2. proactive processes; and
3. reactive processes.

All of these processes gather various kinds of information and data to continuously monitor the levels of fatigue risk in the operation(s) covered by the FRMS. These processes enable the Fatigue Safety Action Group to make data-driven decisions 'based upon scientifically valid principles and measurements' as stated in the ICAO definition of FRMS.

As already mentioned, various types of data are involved including measures of operational performance, which operators are familiar with, and measures of the fatigue levels of crewmembers, which will be less familiar to most operators. The following sections and Appendix B provide guidance about measuring crewmember fatigue. Interpreting crew fatigue data also requires expertise. On some occasions, it may be appropriate for the Fatigue Safety Action Group to seek external scientific advice in this area. However, it is also possible for an operator to develop in-house expertise in fatigue data collection and analysis.

This usually involves a 'fatigue champion' who is interested and motivated to develop skills as required. The complexity of operations and the level of fatigue risk need to be considered evaluating the need for, and level of, expert advice.

The collective experience of managers, schedulers, and crewmembers is an important source of information for identifying aspects of a proposed schedule that may be associated with increased fatigue. For example, crewmembers may recognize a particular destination within a proposed schedule as generating a high level of fatigue because of their past experience of regular delays there caused by heavy traffic. Schedulers may know that a particular city pairing regularly exceeds planned flying time. Management may organize for crew to stay in another hotel where noise is a known problem.

Various information sources should be used. For existing operations, information about schedules may already be available that could be analyzed to check for potential fatigue hazards. Examples include the use of captain's discretion, on-time performance, violations of prescriptive flight and duty time rules, standby usage, Aviation Safety Reports (ASR's), and level of fatigue reports.

When operational demands are changing, reliance on previous experience can have some limitations. Scheduling based only on previous experience may not give the most robust or innovative solutions for new situations. It may also be important to collect data on actual levels of crew fatigue, to check whether the lessons from previous experience are still valid in the new context.

Another way to identify fatigue hazards related to scheduling, for existing or new routes, is to look for information on similar routes. This could include incident reports and crew fatigue reports, or published scientific research and other information available on similar routes flown by other operators. The amount of confidence that can be placed in this approach depends directly on how similar these other operations really are to the operation in which you are trying to identify fatigue hazards.

CHAPTER - 02

LITERATURE REVIEW

2.1 REVIEW AREA BROAD

As a commitment to the continuous improvement of safety, a Company has an FRMS to manage fatigue-related risks.

This FRMS applies to the operations as defined in the Flight Operations and Cabin Operations Manuals. All other operations will operate under the prescriptive flight and duty time regulations. The FRMS Manual describes the processes used for identifying fatigue hazards, assessing the associated risks, and developing, implementing, and monitoring controls and mitigations. The FRMS Manual also describes the safety assurance processes used to ensure that the FRMS meets its safety objectives, and how the FRMS is integrated with our industry-leading SMS programs.

Under this policy following are the requirements:

- Providing adequate resources for the FRMS;
- providing adequate crewing levels to support rosters that minimise fatigue risk;
- providing flight and cabin crew with adequate opportunity for recovery sleep between duties;
- creating an environment that promotes open and honest reporting of fatigue related hazards and incidents;
- providing fatigue risk management training to flight, cabin crew and other FRMS support staff;
- demonstrating active involvement in and understanding of the FRMS;
- ensuring that the fatigue risks within their area(s) of responsibility are managed appropriately;
- regularly consulting with flight and cabin crew regarding the effectiveness of the FRMS; and
- demonstrating continuous improvement and providing annual review of the FRMS.

Flight and cabin crew are required to:

- make appropriate use of their rest periods (between shifts or periods of duty) to obtain sleep;
- participate in fatigue risk management education and training;
- report fatigue-related hazards and incidents as described in the FRMS Manual;
- comply with the Fatigue Risk Management Policy;
- inform their manager or supervisor immediately prior to or during work if:
  - o they know or suspect they or another crew member are suffering from unacceptable levels of fatigue; or
  - o they have any doubt about their or another crew member's capability to accomplish their duties.

Fatigue Risk Management must be considered a core part of our business as it provides a significant opportunity to improve the safety and efficiency of our operation and to maximise the well-being of our staff. The unique challenges that is faced in international medical evacuation operations include 24 hour on-call schedules, a need for immediate response in all weather conditions, and many flights landing at unprepared locations. These challenges require our flight crews to perform at the highest levels of competence and professionalism at all times. They also mean that we are exposed on a regular basis to elevated fatigue risks, which are best managed through FRMS.

We need to manage these risks carefully in order to make consistently sound decisions, particularly to balance the critical needs of patients with the requirement for safe operations. This can only be achieved through the shared responsibility and commitment of management, crew members (cabin crews, doctors and nurses) and our support staff (e.g. crew schedulers) to ensure our fatigue risks remain acceptable.

It will ensure that management, crew and support staff, and all other relevant personnel are aware of:

- the potential consequences of fatigue within our company;
- the unique challenges and fatigue risks confronting our staff due to the nature of our operations;
- the importance of reporting fatigue-related hazards; and

- how to best manage fatigue.

To achieve this we have developed specific policies and procedures within our Safety Management System (SMS) for the management of fatigue risks. These are documented in the FRMS sections of our SMS Manual and apply to all operational staff.

Following must be ensured:

- appropriately resourcing the SMS;
- providing adequate crewing levels to support rosters that minimise fatigue risk;
- providing crew with adequate opportunity for recovery sleep between duties;
- creating an environment that promotes open and honest reporting of fatigue related hazards and incidents;
- providing fatigue risk management training to crew and other support staff;
- demonstrating active involvement in and understanding of our fatigue risks;
- regularly consulting with crew regarding the effectiveness of fatigue management; and
- demonstrating continuous improvement and providing annual review of fatigue management.

Crew and support staff are required to:

- make appropriate use of their rest periods (between shifts or periods of duty) to sleep;
- participate in fatigue risk management education and training;
- report fatigue-related hazards and incidents;
- comply with the Fatigue Risk Management Policy and Practices as contained within our SMS;

inform their manager or supervisor immediately prior to or during work if:

- they know or suspect they or another crew member are suffering from unacceptable levels of fatigue; or
- they have any doubt about their or another crew members capability to accomplish their duties.

- seek external support in accordance with our company policies and procedures to ensure, whenever possible, that third parties (e.g. Chief Cabin crew, Operations Manager) who are not part of your crew are used to support crew decision making.

Whenever crewmembers have doubts about their fatigue risk they are requested to use the company's 24-hour hotline. The effective management of fatigue is critical to ensuring that our company can deliver a quality service to customers.

2.1 REVIEW AREA NARROW

Fatigue management requirements applicable to operators are addressed in Annex 6 — Operation of Aircraft, Part I — International Commercial Air Transport — Aeroplanes. They require States to put in place regulations for managing fatigue based on scientific principles, either through mandatory prescriptive regulations on flight time, flight duty period, duty period and rest period limitations or optional fatigue risk management systems (FRMS) regulations. These provisions are applicable to flight and cabin crew. Refer Figure 3, in general, ICAO Standards and Recommended Practices (SARPs) in various Annexes support two distinct methods for managing fatigue:

- a prescriptive approach that requires the Service Provider to comply with duty time limits defined by the State, while managing fatigue hazards using the SMS processes that are in place for managing safety hazards in general ; and
- a performance-based approach that requires the Service Provider to implement a Fatigue Risk Management System (FRMS) that is approved by the State.

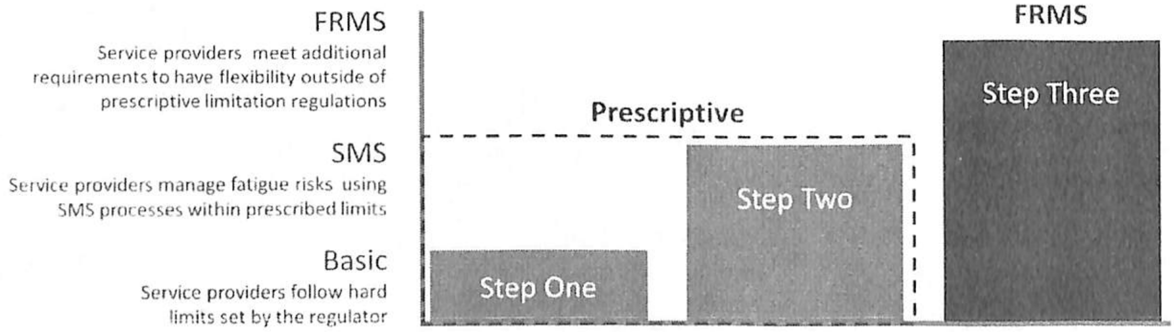


Figure 3

These approaches share two important features

1. They must be based on **scientific principles, knowledge and operational experience:**

- Getting enough sleep (both quantity and quality) on a regular basis is essential for restoring the brain and body. The drive for sleep increases with time awake.
- Reducing the amount or the quality of sleep, even for a single night, decreases the ability to function and increases sleepiness the next day.
- The circadian body clock affects the timing and quality of sleep and produces daily highs and lows in performance on various tasks.
- Workload can contribute to an individual's level of fatigue. Low workload may unmask physiological sleepiness while high workload may exceed the capacity of a fatigued individual.
- Knowledge of the operational and organizational context, as well as understanding of the constraints and motivations of the workforce must be considered alongside the science when determining the safety risk that a fatigue-impaired individual represents in that context.

2. Fatigue management has to be a **shared responsibility** between the State, Service Providers and individuals:

- The **State** is responsible for providing a regulatory framework that enables fatigue management and ensuring that the Service Provider is managing fatigue-related risks to achieve an acceptable level of safety performance.
- **Service Providers** are responsible for providing fatigue management education, implementing work schedules that enable individuals to perform their duties safely, and having processes for monitoring and managing fatigue hazards.
- **Individuals** are responsible for arriving fit for duty, including making appropriate use of non-work periods to obtain sleep, and for reporting fatigue hazards.

2.3 FACTORS CRITICAL TO AREA OF STUDY

An FRMS is a data-driven and scientifically based process that allows for continuous monitoring and management of safety risks associated with fatigue-related error. It is part of a repeating performance improvement process. This process leads to continuous safety enhancements, by identifying and addressing fatigue factors across time and changing physiological and operational circumstances. Structurally, an FRMS is composed of processes and procedures for measuring, modeling, managing, mitigating, and reassessing fatigue risk in a specific operational setting. An FRMS is an effective fatigue mitigation strategy when the organization bases it on valid scientific principles. An FRMS combines schedule assessment, operational data collection, continuous and systematic analysis, and both proactive and reactive fatigue mitigations, guided by information provided by scientific studies of fatigue. Overall, an FRMS offers a way to more safely conduct flights by offering flexibility not available within regulatory limits. An FRMS complements prescriptive flight time, duty time, and rest period requirements.

a. Operational Demands: An FRMS addresses the complexity of operational demands and the inherent fatigue-related challenges associated with aviation operations. The FRMS approach is to apply risk management (RM) techniques to identify and reduce the risk of fatigue relevant to specific operational circumstances. An FRMS aims to ensure high levels of alertness in personnel to maintain acceptable levels of performance and safety.

b Adaptability: An FRMS provides an interactive and collaborative approach to operation performance and safety levels on a case-by-case basis. Therefore, an FRMS permits a certificate holder to adapt policies, procedures, and practices to the specific conditions that create fatigue in a particular aviation operation. Certificate holders may tailor their FRMSs to unique operational demands and focus on mitigations of fatigue that are practical within the specific operational environment.

c Assessment: An FRMS relies on assessments to project and confirm the fatigue effects of an operation on crewmember sleep and alertness. This permits continuous assessment of fatigue levels associated with ever-changing operational conditions. The common tool for this assessment is a biomathematical model of fatigue and alertness levels.

d Risk Management Process (RMP): The FRMS applies the RMP to identify fatigue risks through the use of data-driven systems. An FRMS includes documented processes for collecting and analyzing fatigue-related safety data and implementing corrective actions, always allowing for continuous improvement. A "just" or "safety" culture is integral to a successful FRMS, and it requires a shared responsibility among all levels of the organization, as well as the involvement of regulatory agencies.

e Retrospective (Reactive) Processes for Oversight of Schedules. Certificate holders can use a science-based fatigue model to assess the estimated fatigue levels associated with current or past schedules and determine which schedules are more vulnerable to increased fatigue levels and reductions in performance. First, certificate holders identify those schedules (both trip sequences and monthly cabin crew schedules) that have been associated with the greatest levels of fatigue. Next, certificate holders can derive the fatigue factors present and examine the potential for schedule changes to reduce fatigue. Such changes might include additional layover days, additional recovery days, augmented crews to permit in-flight sleep opportunities, or rescheduled block times to avoid critical tasks at times during or near the WOCL.

f Prospective (Proactive) Processes for Oversight of Schedules. Certificate holders also can assess proposed schedules for potential fatigue impact by using the method described above. Trip sequences that have been identified as leading to acute and chronic fatigue can be removed or modified to prevent the accumulation of fatigue across a bid schedule. For scheduled operations, rules may be embedded into the schedule creation process to avoid those conditions that, according to the fatigue model, could lead to excessive fatigue risk.

g Identification and Management of Aviation Fatigue Drivers. Many operational drivers of fatigue occur in any aviation environment. Some of the common factors that certificate holders must manage to minimize fatigue risk in aviation operations are: • Crew flight and duty periods, and rest breaks to reduce fatigue; • Additional duties assigned to flightcrews that further reduce sleep opportunities; • Schedule changes that extend duties beyond the published schedule; • The duration and timing of layovers between successive flight segments; • Recovery days, following a trip, that permit sufficient sleep to eliminate any accumulated sleep debt prior to scheduling or performing additional flight duties; and • Optimal utilization of available rest opportunities.

h Application of Fatigue Mitigation Procedures. An FRMS is part of a process that requires shared responsibility among management and flight/cabin crewmembers and builds on feedback and nonpunitive reporting within a "just culture." Developing mitigation strategies and schedule adjustments should be part of a collaborative management process that includes all the stakeholders, such as crew schedulers, marketing, safety, and employee representatives. An FRMS should employ multiple layers of defense to prevent fatigue and fatigue-induced errors from progressing to a level that enables incidents or accidents. Based on an analysis of the factors that lead to fatigue and practical mitigation alternatives, one or more of these mitigations may be applied to reduce fatigue associated with specific schedules or situations.

The primary levels of defense and mitigations are:
(1) Viewed together, the flight duty schedule, additional tasks assigned to crewmembers, and schedule change provide recovery sleep opportunities. It may be necessary to adjust scheduling rules to reduce the occurrence of identified fatigue drivers.
(2) Maximizing use of available sleep opportunities reduces cumulative fatigue. This level of defense is largely the responsibility of the crewmember. Comprehensive fatigue training, adequate crew rest facilities at non-domicile locations, and efficient transportation to rest facilities aid crewmembers in fulfilling their responsibility.
(3) Implementing error detection and corrective processes can prevent operational consequences of fatigue. Crew Resource Management (CRM) is a recognized and widely used process to encourage crewmembers to work together to detect and prevent operational errors.
(4) Conducting comprehensive and objective accident, incident, and error analyses can help in determining when fatigue has been a potential contributing factor, so that those conditions can be avoided in the future.

2.4 SUMMARY

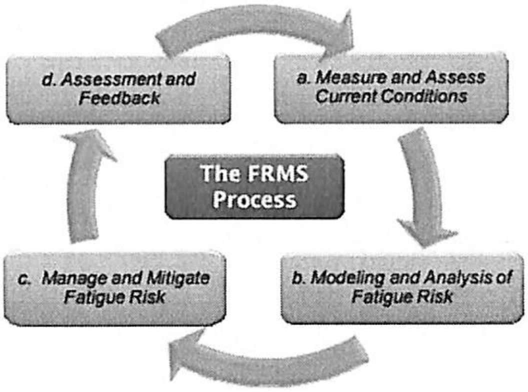


Figure 4

a. Measurement and Assessment of Current Conditions. The first step is to measure and assess the level of fatigue risk associated with current schedules and operations by collecting Page 10 Par 11 5/6/13 AC 120-103A information on crewmember reports of fatigue or fatigue-related errors and incidents, and information on the schedules that led up to these reported fatigue-related errors and incidents. Understanding the current conditions within the organization is critical for the development of a valid mitigation plan.

b. Modeling and Analysis. This second step helps to determine the root cause of fatigue by modeling the work schedules and analyzing fatigue risk associated with them. This step is crucial to the process because it uses scientific principles about fatigue, perhaps aided by computer modeling, to find the specific operational and crewmember factors that could contribute to significant performance changes due to fatigue (Hursh and Van Dongen, 2010). Managing and mitigating fatigue depends on this step because fatigue risk needs to be measured and connected to the conditions (fatigue drivers) that contribute to the risk. Analysis of the fatigue risk can be broken down into two components: likelihood of occurrence of a particular level of fatigue and the severity of the consequence of fatigue, should it occur (Van Dongen and Hursh, 2010). For example, flight time that occurs between midnight and 0600 will inevitably include the period identified as the WOCL. This low point in performance should be evaluated in relation to the duties to be performed at that time; an expected raised level of fatigue is of greater concern if it coincides with critical flight maneuvers.

c. Management and Mitigation of the Fatigue Risk. This third step is based on the measurement and analysis of the fatigue-causing conditions. It requires explicit and regular management activity to consider the information from the first two steps and engage all the stakeholders in a collaborative process to develop solutions to address the fatigue-causing factors.

d. Assessment and Feedback. The fourth step in the process is collection of evidence of success in the form of improved schedules, additional sleep opportunities, enhanced training, and revised policies combined with objective data that demonstrate that these changes have effectively reduced fatigue. Evidence of reduced fatigue includes fewer reports of fatigue and/or errors due to fatigue, evidence of increased sleep, or modeling of schedules that predicts improved performance and reductions in fatigue related risk. This step is important and essential for continuous process improvement. Some measures may not prove to be as effective in reducing fatigue as anticipated, leading to a need for further adjustments. Additionally, changes in schedules, turnover in the workforce, added demands for service, and the addition of new routes can lead to emerging pressures that contribute to increased fatigue risk. This step allows for further adjustments to improve current operations and correct for changes in future operations.

BUILDING BLOCKS OF AN FRMS

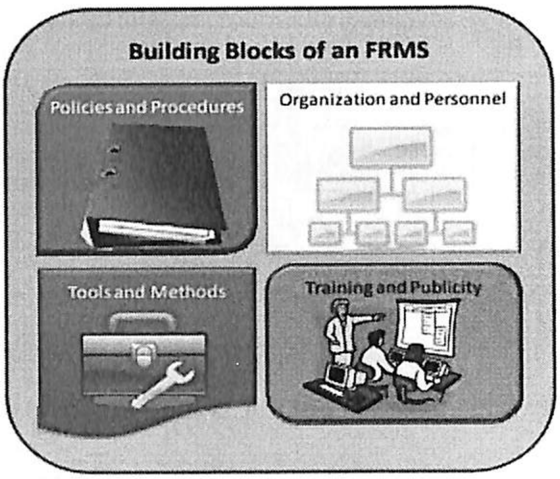


Figure 5

(1) Policies and Procedures. The foundation of the FRMS is documentation that defines the policies and procedures that guide FRM, representing the commitment of the organization to the process and clear statements defining how the system will function. The basic elements of that documentation have been outlined in this AC, but the detail and complexity of the system will depend on the size and diversity of the organization and its operation.

(2) Organization and Personnel. An FRMS is more than documentation; it is an active process that is implemented by members of the organization who regularly meet to review data on fatigue indicators, analyze contributing factors to fatigue, take reactive and proactive actions to mitigate fatigue, audit the effectiveness of the system, and take corrective action to continuously improve the system. Most organizations can form a defined Fatigue Safety Action Group (FSAG) to implement the system. The committee should include representatives of all departments and groups that have a role in reporting, managing, and mitigating

fatigue.

(3) Tools and Methods. A variety of tools and methods are instrumental in aiding the activities of the FRMS organization, such as fatigue modeling, statistical analysis software, performance and sleep measurement systems, and reporting forms and databases. The tools do not constitute the FRMS, but they are essential for the system to function effectively. The organization must be willing to commit resources to procure the necessary supporting tools if the FRMS is to be effective.

(4) Training and Publicity. Training operational personnel and managers about the physiological and behavioral foundations of fatigue, the operational and environmental drivers of fatigue, and effective fatigue mitigations is essential to managing fatigue risk.

Furthermore, all personnel must know the corporate policies that are the foundation of the corporate process, including policies and procedures that govern fatigue reporting, fitness for duty, absence for fatigue, incident reporting, employee privacy, and prevention of coercion to perform duties while fatigued. Finally, an effective FRMS includes feedback and publicity about the system to all affected employees to encourage cooperative participation in the corporate FRM strategy.

a. Extending Processes. The building blocks of the FRMS will be an extension of existing processes to manage overall operational safety. For example, incident report forms may already exist and need only be expanded to collect information relevant to a fatigue analysis.

An organizational structure may already exist to implement safety management, and the addition of an FSAG might be the only change in the organization.

b. Developing an FRMS. The initial development of an FRMS will start with a certificate holder assembling the building blocks described above, starting with developing the policies and procedures and establishing the FRMS organization. The organization will then acquire the necessary tools and methods, and develop supporting training and publicity programs.

There are several pitfalls to avoid in this complex process:

(1) The FRMS organization, such as the FSAG, should include representatives of all the key departments and groups that have a role in identifying, managing and mitigating fatigue in operations. FRM is a collaborative process and will require the commitment of key leaders of the organization and the cooperative participation of relevant groups. An example would be the marketing department, which plays a key role in defining trips and schedules. While their primary responsibility is to advance the business interests of the corporation and provide service to customers, marketing also has a key role in defining the requirements of schedules that may be causing excessive fatigue. Its participation in finding acceptable alternatives that reduce fatigue is essential to a successful FRMS. At the same time, employee groups (e.g., union representatives) should also participate in the process because managing and mitigating fatigue is a shared responsibility between the organization and the employees. Ensuring that employees understand and embrace their responsibilities to report for duty well rested is just as important as arranging schedules that provide sufficient rest opportunities.

(2) There is a danger that the FSAG may adopt a reactive approach to fatigue management, taking constructive action only in response to reports of fatigue or fatigue-related adverse events. The more effective approach is to minimize fatigue by using available tools to forecast potential fatigue well in advance of actual operations, and taking corrective action to proactively eliminate potentially

fatiguing schedules or conditions prior to their occurrence. An indicator of a highly effective FRMS is the frequency of such proactive corrective actions.

(3) The FRMS should include a methodology for evaluating the success of the program and make changes in the program for process improvement. Two equally important parts of the evaluation and validation process are necessary. The first is self-evaluation using established metrics that reflect the degree of fatigue in the organization. The FSAG should monitor those metrics regularly, looking for trends over time that suggest the need for change or validate the effectiveness of actions already taken. The second is an occasional independent audit of the program by an outside agency or consultant.

An outside observer familiar with FRMS principles and cognizance of best practices developed by other organizations can be an invaluable aid to improving the effectiveness and efficiency of the FRMS process. The FRMS approval process consists of five steps that must be satisfactorily completed in succession. Each step is referred to as a phase. Within each phase are specific tasks that must be completed before the certificate holder may move to the next phase.

These tasks are compiled into number gates. Each gate must be completed in succession before that phase is considered completed. The five phases of the approval process are:

- Phase 1: Preapplication, Planning, and Assessment.
- Phase 2: Formal Application.
- Phase 3: Documentation and Data Collection Plan.
- Phase 4: Demonstration and Validation .
- Phase 5: Authorization, Implementation, and Monitoring.

CHAPTER 3

RESEARCH DESIGN, METHODOLOGY AND PLAN

3.1 DATA SOURCES

ICAO Standards stipulate that States should allow an operator to choose whether it will use the FRMS to manage fatigue risk in all its operations, or only in specific types of operations (for example, only a particular fleet, only ULR operations, etc.). It is important that the operator clearly identifies to which operations the FRMS pertains. Different types of flight operations can involve different causes of crewmember fatigue and may require different controls and mitigation strategies to mitigate the associated risks. Within its FRMS, an organization may need to develop multiple sets of different FRMS processes for different operations, and again these should be clearly identifiable. On the other hand, in some cases it will be possible to include multiple types of operations under one set of FRM processes.
the Fatigue Safety Action Group gathers required data and information to be confident that they can identify the likely fatigue hazards in operations that are covered by the FRM processes. To do this, the group needs to have a good understanding of the operational factors that are likely to cause crewmember fatigue.
To illustrate some of the considerations in different operations, Figure 6 compares flight and duty times in daytime short haul, domestic night cargo, and long haul operations studied by the NASA Fatigue Program

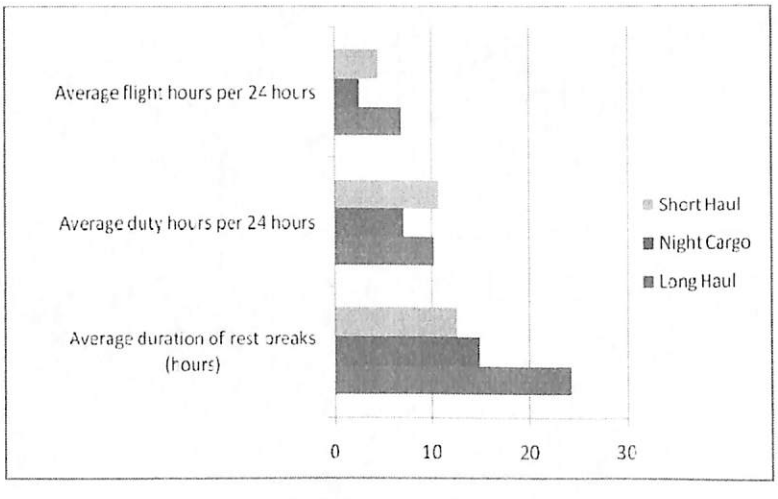


Figure 6- Average flight, duty, and rest periods in a sample of daytime short haul, domestic night cargo, and long haul operations.

The daytime short haul operations (2-person crews) had the longest daily duty hours, averaged 5 flights per day, and had the shortest rest periods. However, they crossed a maximum of 1 time zone per 24 hours and the rest breaks occurred at night, during the optimal part of crewmembers' circadian body clock cycle for sleep. The main causes of fatigue identified in this scientific study were:

- restricted sleep caused by short rest periods and early duty report times; and
- high workload, flying multiple sectors in high density airspace across long duty days.

The domestic night cargo operations (2 cabin crews, 1 flight engineer) had the shortest duty

periods, averaged 3 flights per duty period, and had longer rest periods than the short haul operations. They also crossed a maximum of 1 time zone per 24 hours. However, the night cargo crewmembers' rest periods occurred during the day and their circadian body clocks (tracked by their core body temperature rhythms) did not adapt to this pattern. The main causes of fatigue identified in this scientific study were:

- shorter, less restorative sleep during the day; and
- being required to work at night, at the time in the circadian body clock cycle when selfrated fatigue and mood were worst, and when additional effort would be required to maintain alertness and performance.

The long haul operations (2 cabin crews, 1 flight engineer) had long duty periods, but averaged only 1 flight per duty period and had the longest rest periods. However, every layover was in a different time zone, with a maximum of 8 time zones crossed per 24 hours. The crewmembers' circadian body clocks (tracked by their core body temperature rhythms) did not adapt to the time zone changes or to the non-24-hour duty/rest pattern (averaging 10 hours of duty and 25 hours of rest). The main causes of fatigue identified in this scientific study were:

- long periods of wakefulness (average 20.6 hrs) associated with duty days (there were no onboard crew rest facilities); and

- on some flights, having to operate the aircraft at the time in the circadian body clock cycle when self-rated fatigue and mood were worst, and additional effort was required to maintain alertness and performance; and
- split sleep patterns and short sleep episodes on layovers (usually some sleep at local night and some at body clock night); and
- on some trip patterns, the circadian body clock drifted away from crewmembers' domicile time zone. As a result, additional time for circadian re-adaptation was needed for full recovery after the trip. These examples illustrate a fundamental principle in FRMS - that flight and duty time limitations do not capture all the causes of fatigue, which are different in different types of operations.

3.2 Research Design

ICAO Annex 6, Part I, Appendix 8 requires that an operator develop, maintain, and document three types of processes for fatigue hazard identification:

1. predictive processes;
2. proactive processes; and
3. reactive processes.

All of these processes gather various kinds of information and data to continuously monitor
the levels of fatigue risk in the operation(s) covered by the FRMS. These processes enable
the Fatigue Safety Action Group to make data-driven decisions 'based upon scientifically
valid principles and measurements' as stated in the ICAO definition of FRMS.
As already mentioned, various types of data are involved including measures of operational

performance, which operators are familiar with, and measures of the fatigue levels of crewmembers, which will be less familiar to most operators. The following sections and Appendix B provide guidance about measuring crewmember fatigue. Interpreting crew fatigue data also requires expertise. On some occasions, it may be appropriate for the Fatigue Safety Action Group to seek external scientific advice in this area. However, it is also

possible for an operator to develop in-house expertise in fatigue data collection and analysis.

This usually involves a 'fatigue champion' who is interested and motivated to develop skills

as required. The complexity of operations and the level of fatigue risk need to be considered

evaluating the need for, and level of, expert advice.

In an FRMS, predictive hazard identification focuses on establishing crew schedules and conditions that consider factors known to affect sleep and fatigue in order to minimise their potential future effects. ICAO Annex 6, Part I, Appendix 8 lists three possible ways of doing this:

a) previous experience (of the operator or others in the industry);

b) evidence-based scheduling practices; and

c) bio-mathematical models.

The collective experience of managers, schedulers, and crewmembers is an important source of information for identifying aspects of a proposed schedule that may be associated with increased fatigue. For example, crewmembers may recognize a particular destination within a proposed schedule as generating a high level of fatigue because of their past experience of regular delays there caused by heavy traffic. Schedulers may know that a particular city pairing regularly exceeds planned flying time. Management may organize for crew to stay in another hotel where noise is a known problem.

Various information sources should be used. For existing operations, information about schedules may already be available that could be analyzed to check for potential fatigue hazards. Examples include the use of captain's discretion, on-time performance, violations of prescriptive flight and duty time rules, standby usage, Aviation Safety Reports (ASR's), and level of fatigue reports.

When operational demands are changing, reliance on previous experience can have some limitations. Scheduling based only on previous experience may not give the most robust or innovative solutions for new situations. It may also be important to collect data on actual levels of crew fatigue, to check whether the lessons from previous experience are still valid in the new context.

Another way to identify fatigue hazards related to scheduling, for existing or new routes, is to look for information on similar routes. This could include incident reports and crew fatigue reports, or published scientific research and other information available on similar routes flown by other operators. The amount of confidence that can be placed in this approach depends directly on how similar these other operations really are to the operation in which you are trying to identify fatigue hazards.

The value of operational experience can be enhanced when fatigue science is also applied in the building of schedules. This means considering factors such as the dynamics of sleep loss and recovery, the circadian biological clock, and the impact of workload on fatigue, along with operational requirements. Since the effects of sleep loss and fatigue are cumulative, evidence-based scheduling needs to address both individual trips (multiple, successive duty periods without extended time off), and successive trips across rosters or monthly bid-lines. The following are examples of general scheduling principles based on fatigue science.

- The perfect schedule for the human body is daytime duties with unrestricted sleep at night. Anything else is a compromise.
- The circadian body clock does not adapt fully to altered schedules such as night work. It does adapt progressively to a new time zone, but full adaptation usually takes longer than the 24-48 hours of most layovers.

- Whenever a duty period overlaps a crewmember's usual sleep time, it can be expected to restrict sleep. Examples include early duty start times, late duty end times, and night work.
- The more that a duty period overlaps a crewmember's usual sleep time, the less sleep the crewmember is likely to obtain. Working right through the usual night time sleep period is the worst case scenario.
- requires working through the time in the circadian body clock cycle when selfrated fatigue and mood are worst and additional effort is required to maintain alertness and performance.
- Across consecutive duties with restricted sleep, crewmembers will accumulate a sleep debt and fatigue-related impairment will increase.
- To recover from sleep debt, crewmembers need a minimum of two full nights of sleep in a row, when they are fully adapted to the local time zone. The frequency of rest periods should be related to the rate of accumulation of sleep debt.

These sorts of principles can be used by an expert reviewer, for example by a scheduler trained in fatigue hazard identification, or by the Fatigue Safety Action Group, to develop evidence-based scheduling rules. The scientific basis for the scheduling rules should be recorded in the FRMS documentation. This approach can be validated, by monitoring the reported or estimated levels of fatigue across the schedules, using the tools described below and in Appendix B. Validation data can be used, in turn, to refine and improve evidence-based scheduling rules for an operation.

Bio-mathematical models begin life as computer programs used by scientists to test their current understanding of how factors like sleep loss, circadian rhythms, and workload interact to affect human alertness and performance. The modeling process begins by trying to write a program that can simulate a 'developmental data set' – for example self-rated fatigue and performance measured during a sleep loss experiment in the laboratory. If this works, then the model is used to predict a different situation. Data are then collected in this new situation (a 'validation data set') and model predictions are tested against the new data. Scientific modeling is a continuous improvement process. As scientific tools, biomathematical models are accepted as being incomplete and transient. In scientific best practice, scientists continue designing new experiments to try to find out where their models fail. In this way, they find out where their current understanding is incomplete or possibly wrong. (This is a much more efficient way of increasing scientific knowledge than just doing random experiments.)

A range of bio-mathematical models have been commercialized and are marketed as tools for predicting fatigue hazards relating to scheduling. There are also several models available in the public domain. Used properly, these models can be helpful tools in FRMS, because it is hard to visualize the dynamic interactions of processes like sleep loss and recovery, or the circadian biological clock. To use models properly requires some understanding of what they can and cannot predict. An important question to ask about any model is whether it has been validated against fatigue data from operations similar to those that you are interested in.

Currently available models:

- predict group average fatigue levels, not the fatigue levels of individual crewmembers;
- do not take into account the impact of workload or personal and work-related stressors that may affect fatigue levels;
- into account the effects of personal or operational mitigation strategies that may or may not be used by crewmembers
- do not predict the safety risk that fatigued crewmembers represent in a particular operation, i.e., they are not a substitute for risk assessment (Step 4 in FRM processes- see below). Several available models try to predict safety risk by merging safety data from a range of operations in different industries, but their applicability to flight operations has not yet been validated.

The most reliable use of currently available commercial models is probably for predicting relative fatigue levels - is the fatigue hazard likely to be greater on this schedule versus that schedule? However, model predictions should not be used without reference to operational experience, when making decisions about schedule design. On the other hand, data collected in the course of FRM processes could be a rich resource for improving the performance of biomathematical models, if model designers follow a continuous improvement philosophy.

Note that in ICAO Annex 6, Part I, Appendix 8, it states that methods for predictive fatigue hazard identification may include but are not limited to: operator or industry operational experience and data collected on similar types of operations, evidencebased scheduling practices, and bio-mathematical models. In other words, none of these methods are required, and other methods may be used.

In an FRMS, proactive hazard identification processes focus on monitoring fatigue levels in an operation. Because fatigue-related impairment affects many skills and has multiple causes, there is no single measurement that gives a total picture of a crewmember's current fatigue level.

For this reason, ICAO recommends using multiple sources of data for proactive hazard identification. To decide on which types of data to collect, the most important thing to consider is the expected level of fatigue risk. In other words, it is not a good use of limited resources to undertake intensive data collection with multiple measures on a route where the fatigue-related risk is expected to be minimal. Resources should be targeted towards operations where the risk is expected to be higher.

ICAO Annex 6, Part I, Appendix 8, requires that an operator's FRMS Policy shall 'reflect the shared responsibility of management, flight and cabin crews, and other involved personnel'.

The success of proactive processes (and of the FRMS) depends on the willingness of crewmembers to continue participating in data collection. This makes it important to consider the demands placed on crewmembers by different types of fatigue-related data collection (for example, measures such as filling out a questionnaire once, keeping a sleep/duty diary and wearing a simple device to monitor sleep every day before during and after a trip, doing multiple performance tests and fatigue ratings across flights, etc).

3.3 SURVEY QUESTIONS

The willingness of crewmembers to participate will also reflect their level of understanding of their roles and responsibilities in FRMS, and their confidence that the purpose of the data collection is to improve safety. Gathering fatigue-related data may involve monitoring crewmembers both on duty and off duty, because fatigue levels on duty are affected by prior sleep patterns and by waking activities. There are ethical considerations around issues such as the privacy of crewmembers, confidentiality of data, and whether crewmembers are really free to refuse to participate (voluntary participation is a requirement in scientific studies involving human participants). Many countries have specific legislation around privacy and workplace responsibilities for safety that may need to be considered, in addition to conditions specified in industrial agreements.

Annex 6, Part I, Appendix 8 lists five possible methods of proactive fatigue hazard identification:

a) self-reporting of fatigue risks;

b) crew fatigue surveys;

c) relevant flight crew performance data;

d) available safety databases and scientific studies; and

e) analysis of planned versus actual time worked.

The following sections work through each of these methods in some detail.

Crewmembers' reports about high fatigue levels or fatigue-related performance issues are vital to keep the Fatigue Safety Action Group informed about fatigue hazards in the day-to-day running of an operation. A series of fatigue reports on a particular route can be a trigger for further investigation by the Fatigue Safety Action Group.

An effective fatigue reporting system requires an effective reporting culture. 5 It needs to:

- use forms that are easy to access, complete, and submit;
- have clearly understood rules about confidentiality of reported information;
- have clearly understandable voluntary reporting protection limits;
- include regular analysis of the reports; and
- provide regular feedback to crewmembers about decisions or actions taken based on the reports, and lessons learned.

A fatigue report form (either paper-based or electronic) should include information on recent sleep and duty history (minimum last 3 days), time of day of the event, and measures of different aspects of fatigue-related impairment (for example, validated alertness or sleepiness scales). It should also provide space for written commentary so that the person reporting can explain the context of the event and give their view of why it happened.

Crew fatigue surveys are of two basic types:

1. Retrospective surveys that ask crewmembers about their sleep and fatigue in the past. These can be relatively long and are usually completed only once, or at long time intervals (for example, once a year); and

2. Prospective surveys that ask crewmembers about their sleep and fatigue right now. These are typically short and are often completed multiple times to monitor fatigue across a duty period, trip, or roster. They usually include measures such as sleepiness, fatigue, and mood ratings.

Some standard fatigue and sleepiness measures (rating scales) that can be used for retrospective surveys, and others that can be used for prospective monitoring. These scales have been validated and are widely used in aviation operations. Using standard scales enables the Fatigue Safety Action Group to compare fatigue levels between operations (run by their own operator or others), across time, and with data from scientific studies. This can be helpful in making decisions about where controls and mitigations are most needed.

Crew fatigue surveys can be focused on a particular operation or issue. For example, a series of fatigue reports about a particular trip might trigger the Fatigue Safety Action Group to undertake a survey of all crewmembers flying that trip (retrospective or prospective), to see how widespread the problem is. The Fatigue Safety Action Group might also undertake a survey (retrospective or prospective) to get crewmember feedback about the effects of a schedule change.

Surveys can also be more general, for example providing an overview of fatigue across a particular aircraft fleet or operation type.

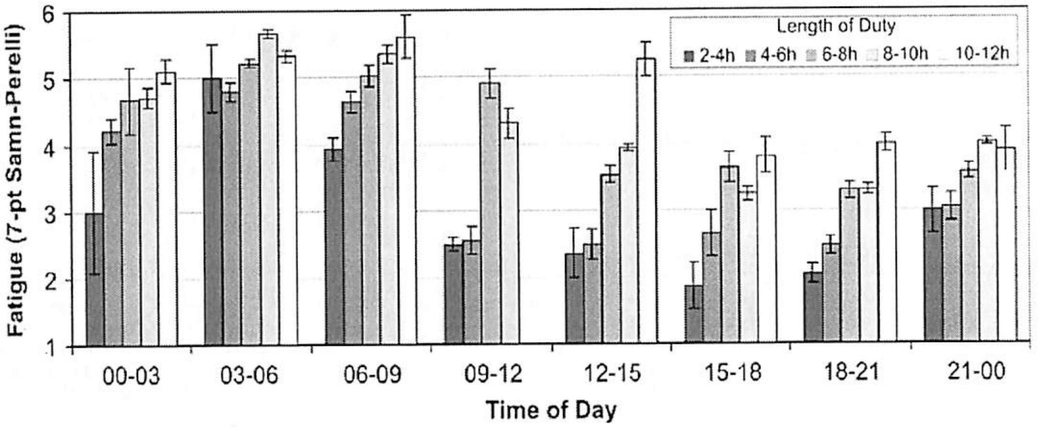


Figure 7- Effects of time of day and duty length on fatigue ratings at top of descent in short haul operations across a 3-month period

Figure 7 shows an analysis of the effects of time of day and duty length on fatigue ratings at top of descent. These data come from the Air New Zealand FRMS and include 3181 ratings made across a 3-month period, at the end of 1-2 sector short haul duty days that stayed in the crewmembers' domicile time zone (two-person crews). 6 For short duty periods (2-4 hours) there is a clear time-of-day variation in how fatigued crewmembers feel at the top of descent, with highest average ratings between 03:00 and 06:00, and lowest average ratings between 15:00 and 18:00. In contrast, at the end of long duty periods (10-12 hours), fatigue ratings remain high from 00:00 to 09:00 and there is a second peak in fatigue between 12:00-15:00. These ratings show an interaction between time-on-task fatigue (duty duration) and the daily cycle of the circadian body clock. In addition, crew members who are at the end of a 10-12 hour duty period between 12:00 and 15:00 will have had their sleep restricted by an early duty report time.

3.4 DATA ANALYSIS PROCEDURES

Compared to some other types of fatigue monitoring, crew fatigue surveys can be conducted relatively quickly and inexpensively to provide a "snapshot" of subjective fatigue levels and their potential causes. If a high proportion of crewmembers participate in a survey (ideally more than 70%), it gives a more representative picture of the range of subjective fatigue levels and opinions across the whole group. The information gathered in surveys is subjective (crewmembers' personal recall and views), so getting a representative picture can be important for guiding the decisions and actions of the Fatigue Safety Action Group

Performance measurements provide objective data that can be used to supplement the subjective data collected in fatigue reports and survey responses. Currently, there are three main approaches to monitoring crewmember performance:

1. simple tests developed in the laboratory, which measure aspects of an individual's performance (for example, reaction time, vigilance, short-term memory, etc.);
2. flight data analysis (FDA), which examines the relationship between identified elements of aircraft performance and
3. cabin crew performance; and having trained flight deck observers rating the performance of crewmembers on the flight deck (for example, Line-Oriented Safety Audit).

For monitoring crewmember fatigue levels during an operation, the first approach is currently the most practical. A range of objective performance tests are used in scientific research.

Things to consider when choosing a performance test for measuring crewmember fatigue include the following.

1. How long does the test last? Can it be completed at multiple time points (for example, in the operations room during pre-flight preparations, near top of climb, near top of

descent, and post-flight before disembarking from the aircraft), without compromising a crewmember's ability to meet duty requirements?

2. Has it been validated? For example, has it been shown to be sensitive to the effects of sleep loss and the circadian body clock cycle under controlled experimental conditions?
3. Is the test predictive of more complex tasks, e.g., crew performance in a flight simulator? (Unfortunately, there is very little research addressing this question at present.
4. Has it been used in other aviation operations, and are the data available to compare fatigue levels between operations?

There is considerable interest in finding ways to link crew member fatigue levels to FDA data particularly during approach and landing. FDA data has the advantages that it is routinely collected and is relevant to flight safety. The difficulty is that a multitude of factors contribute to deviations from planned flight parameters. To use FDA data as an indicator of crewmember fatigue would require demonstrating consistent changes in FDA data that are reliably linked to other indicators of crewmember fatigue (for example sleep loss in the last 24 hours, time in the circadian body clock cycle, etc). Research in this area is ongoing.

Using trained flight deck observers to rate the performance of crewmembers on the flight deck is very labor-intensive and expensive. Having the observer present may also have an alerting effect and place additional demands on crewmembers. These factors currently limit the usefulness of this approach for proactive fatigue hazard identification in an FRMS.

More general guidance about fatigue hazards may be available from external safety databases, such as Aviation Safety Reports (ASRs) and Mandatory Occurrence Reports (MORs) maintained by safety authorities, or databases maintained by airline organizations or research institutions. Because safety events are relatively rare, databases that collect and analyze them are an important additional source of information that complements direct assessment of fatigue levels in the operation(s) covered by the FRMS.

This type of research tends to be costly and labour-intensive and not all types of aviation operations have been studied in depth. The particular value of these studies is in their use of more rigorous scientific approaches, which increases the reliability of their findings. The level of detail in some studies may be more than is needed for proactive identification of fatigue hazards. However, most reports and published.

The aim of Step 2 is to validate the effectiveness of the fatigue controls and mitigations (ICAO Annex 6, Part I, Appendix 8). It involves analyzing the information gathered to check whether:

- all specified FRMS safety performance targets are being met; and
- all specified FRMS safety performance indicators remain in the tolerable region defined in the risk assessment process and
- the FRMS is meeting the safety objectives defined in the FRMS policy; and
- the FRMS is meeting all regulatory requirements.

The following are examples of safety performance targets and indicators that could be used in FRMS safety assurance processes and that correspond with the safety performance indicators identified above . The length of the maximum duty days in operations covered by the FRMS does not exceed the limits defined in the FRMS policy. This is reviewed monthly by a computer algorithm and trends across time are evaluated every 3 months.

- By the fourth month after the introduction of a new operation, there must be a stable low number of voluntary fatigue reports per month, or a clear downward trend in the number per month (allowing time for crewmembers and other affected personnel to adjust to the new operation). The Fatigue Safety Action Group is to provide a written report on the validation phase of the new operation, including analysis of all fatigue-related events and voluntary fatigue reports, and documentation of the corresponding adjustments made in fatigue controls and mitigations.
- No specific pairing (trip) exceeds the average fatigue call rate by flight crews by more

than 25%.

- ULR operations covered by the FRMS do not attract any more fatigue reports than the long haul operations covered by the prescriptive flight and duty time regulations.
- In the last quarter, designated management has provided adequate resourcing for the FRMS, as specified in the FRMS policy.
- In the last quarter, the Fatigue Safety Action Group has met as often as is required in the FRMS policy and has maintained all the documentation of its activities that is required for internal and regulatory auditing.
- All personnel responsible for schedule design and rostering have met annual FRMS training requirements as specified in the FRMS promotion processes.
- Measures of the effectiveness of FRM training and education programs (see Chapter 6 for examples).
- Quarterly levels of absenteeism are below the target specified for each operation covered by the FRMS.

When FRMS safety performance targets are not met or when safety performance indicators are not at an acceptable level, the controls and mitigations in use may need to be modified by re-entering the FRM processes. It may also be appropriate to seek additional information from outside the organization (for example, by looking at fatigue studies). It may be necessary to undertake a review of compliance of crewmembers and other departments with the recommendations of the Fatigue Safety Action Group. It may also sometimes be necessary to review the functioning of the Fatigue Safety Action Group itself, to find out why the FRMS is not working as intended.

Figure 8 tracks a measure of the effectiveness of the Air New Zealand FRMS across time12. It shows that the percentage of cabin crews reporting duty-related fatigue occurring at least once a week has declined across a series of surveys conducted between 1993 and 2006.

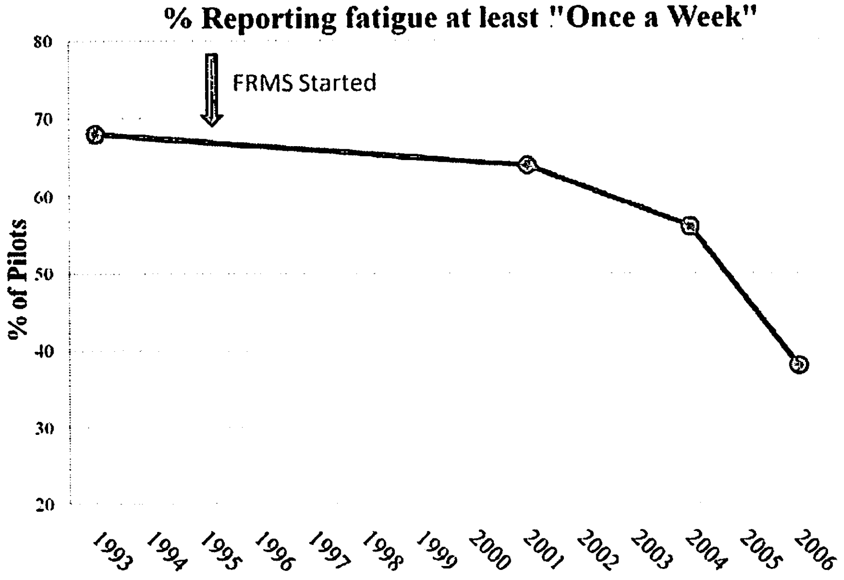


Figure 8 - Declining reports of crewmember fatigue across successive Air New Zealand surveys

Analysis of trends in safety performance indicators may indicate the emergence of fatigue hazards that have not previously been recognized through the FRM processes. For example, changes in one part of the organization may increase workload and fatigue risk in another part of the organization. Identifying emerging fatigue-related risks is an important function of FRMS safety performance processes, which take a broader system perspective than FRM processes. Any newly identified fatigue risk, or combination of existing risks for which current controls are ineffective, should be referred back to the Fatigue Safety Action Group for evaluation and management using FRM processes (risk assessment, design and implementation of effective controls and mitigations).

Annex 6, Part I, Appendix 8 requires that an operator has FRMS safety assurance processes that provide a formal methodology for the management of change. These must

include (but are not limited to):

1. identification of changes in the operational environment that may affect FRMS;

2. identification of changes within the organization that may affect FRMS; and
3. consideration of available tools which could be used to maintain or improve FRMS performance prior to implementing changes. A change management process is a documented strategy to proactively identify and manage the safety risks that can accompany significant change in an airline.

When a change is planned, the following steps can be followed.

- Use the FRM processes to identify fatigue hazards, assess the associated risk, and propose controls and mitigations;
- Obtain appropriate management and/or regulatory sign-off that the level of residual risk is acceptable.

During the period of implementation of the change, use the FRMS safety assurance processes to provide periodic feedback to line managers that the FRMS is functioning as intended in the new conditions. An example would be having a validation period for a new ULR route, during which additional monitoring of crewmember fatigue is undertaken, together with more frequent assessment of FRMS safety performance targets and indicators.

Documentation of the change management strategy in relation to fatigue management is also the responsibility of the Fatigue Safety Action Group. Changes in the operational environment may also necessitate changes in the FRMS itself. Examples include bringing new operations under the scope of the FRMS, collecting different types of data, adjustments to training programs, etc. The Fatigue Safety Action Group should propose such changes and obtain approval for them from appropriate management.

CHAPTER 4

FINDINGS AND ANALYSIS

4.1 DESCRIPTIVE STATISTICS AND CORRELATION REGRESSION ANALYSIS

Modeling input and predictions. For each individual participant, actigraphy-derived sleep/wake patterns and log data (including activity, time, and location) were merged into a single file suitable for entry into the SAFTE-based Fatigue Avoidance Scheduling Tool (FAST) software package.

Actigraphy-based sleep episodes took precedence over manually logged sleep episodes; however, logged sleep was used during periods for which valid actigraphy data were unavailable. To ensure that all participants were modelled with an equally full sleep reservoir at the beginning of the study, a 3-day period of 8-hr sleep at home between 2300-0700 hr was inserted into each individual's schedule prior to the empirical actigraphy and schedule data. Each participant's FAST file was manually checked against his/her processed actigraphy file (to confirm correct sleep/wake patterns) and PDA activity log (to confirm correct times, locations, and sleep periods). Once completed, validated, and entered, the SAFTE-FAST program processed each individual's final composite file to produce a continuous record of model-predicted effectiveness in 30-min increments throughout the study period.

Neurobehavioral performance. Each PVT test yields a number of output variables per session, including mean Reaction Time (RT, msec), mean Speed (1/RT), total Lapses (RTs > 500 msec), and total False Starts (FS, premature responses), all of which were included as objective neurobehavioral performance metrics. However, since the SAFTE model's output metric of Performance Effectiveness is based on PVT speed, we used that metric as the foundation for initial data processing. Specifically, the project database began with a total of 11,567 individual PVT test sessions. Analysis of mean speeds from all sessions revealed a bi-modal distribution, with values ranging from 0.93 to 92.21 per session (mean + SD = 4.87 + 4.68; median + IQR = 3.82 + 1.02), high kurtosis (46.68) from the low end of the distribution where most sessions fell, and a very heavy positive skew (5.45). To avoid undue influence of extreme outliers on the eventual calculation of PVT speeds as a percentage of individual baselines, sessions with mean speeds greater than two standard deviations above the grand distribution mean were excluded from further processing. This 6.85% reduction in the database then left 10,775 individual PVT sessions with which to work. We then removed practice sessions recorded during training, sessions with timestamps dated outside the respective individual's activity log, and all sessions from individuals for whom valid FAST reports could not be produced due to corrupted files, processing errors, or unreliable activity logging.

Following these corrective procedures, the final dataset was comprised of 10,659 individual PVT sessions from 178 flight attendants (mean + SD sessions/participant = 60 + 15, range = 15-92). Once the final PVT database was established, optimum baseline performances were calculated. Defining "baseline" in the types of controlled laboratory studies upon which the SAFTE model was based is relatively straightforward, typically relying on test sessions conducted following several days of optimal sleep conditions but immediately prior to the experimental sleep restriction protocol. Since these orderly sequential conditions do not apply to observational field studies, we developed an analogous performance-based, rather than time-based, method for defining baseline. Specifically, for each individual, we rank-ordered all PVT sessions by mean speed per session, then used the median of the top 10% highest speeds as that individual's baseline. This metric cannot assume that the individual is "well-rested," as in a laboratory study baseline, but like a laboratory study.

This baseline still represents "typical best" performance with ample room for fatigue-induced decrements and countermeasure-induced improvements. Once established, mean speeds for all individual PVT test sessions were then expressed as a percentage of that median of the top 10% fastest speeds. The final outcome metric is comparable to the predicted effectiveness score used by the SAFTE model and is referred to henceforth as "PVT Actual Effectiveness," separate from RT, non-transformed Speed, Lapses, and FS.

Data analysis. Each PVT test session was paired with its corresponding performance effectiveness prediction to the nearest 30-min interval from the respective participant's

SAFTE-FAST file. All test session results were then organized into 5% SAFTE Predicted Effectiveness bins (<65%, 65-70%, 70-75%, 75-80%, 80-85%, 85-90%, 90-95%, 95-100%, >100%), and the relationship between mean SAFTE prediction and mean PVT performance across bins was quantitatively assessed via linear regression analysis. Identical regression analyses were performed on all performance metrics, including PVT Actual Effectiveness, RT, Speed, Lapses, and FS. This suite of analyses was also conducted in a nested fashion with increasing operational focus, first with all 10,659 sessions collected throughout the entire study, then only with the 7,533 sessions taken during multi-day work trips (limiting the data to more controlled settings governed by work schedules), then finally separate analyses of only the Pre-Work (*n* = 1,712) and Post-Work (*n* = 1,934) sessions to focus on the model's ability to predict variations in performance capacity specifically before and after a work day. Unless otherwise noted, all data are presented as mean + SEM. All analyses were two-tailed as applicable, and statistical significance was set at alpha = 0.05.

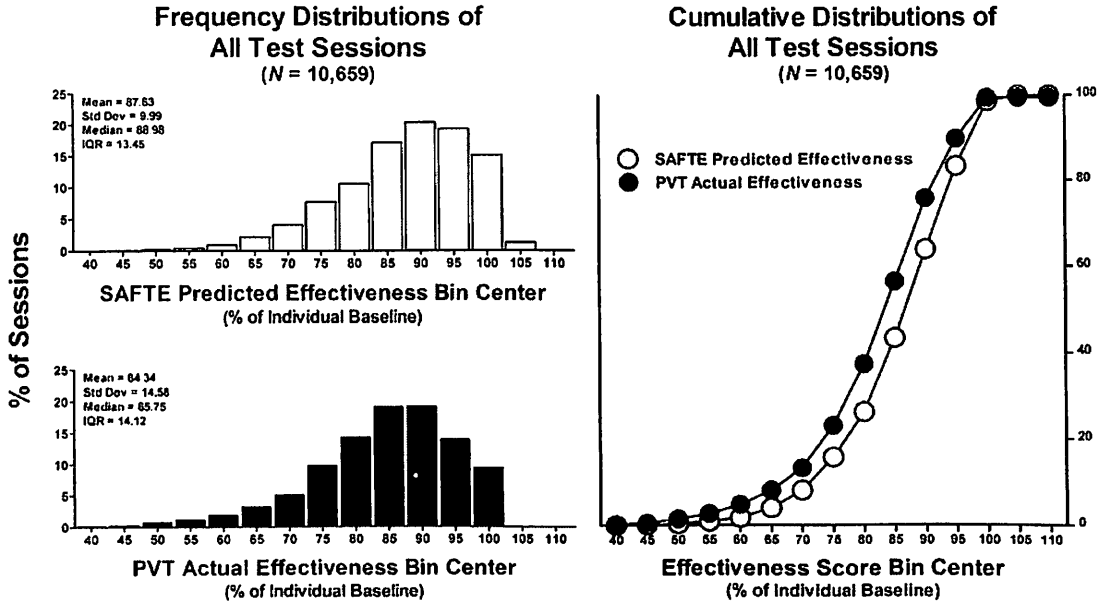


FIGURE 9- Frequency and Cumulative Distributions of Predicted and Actual Effectiveness Scores for All Test Sessions

Figure 9 (previous page) shows that the frequency distributions of SAFTE Predicted Effectiveness and the primary outcome measure of Actual Effectiveness were similar in shape, both with a negative skew, as may be expected from measures expressed as a percentage (scaled from zero to ~100). It also reveals a modest gap in cumulative distributions, indicating more Actual Effectiveness data falling within the 75-90% range compared to the model predictions, although both distributions assumed similar, parallel sigmoidal shapes.

As illustrated in the above figure, linear regression analyses of mean performances across the 5% SAFTE prediction bins revealed significant correlations between SAFTEP predicted Effectiveness and Actual Effectiveness. It also shows that focusing only on sessions completed while participants were away on a work trip had no obvious effect on the frequency distributions or cumulative distributions of SAFTE-Predicted Effectiveness and the primary outcome measure of Actual Effectiveness.
Whether examining all test sessions, sessions completed throughout a multi-day work trip, or just those sessions completed before and after a work day, predicted performance effectiveness scores rendered by the SAFTE model correlated significantly with average performances on multiple PVT metrics. Specifically, as predicted effectiveness decreased, RTs increased, Speed decreased, and Lapses increased—all patterns consistent with impaired neurobehavioral performance capacity. Importantly, SAFTE-Predicted Effectiveness most strongly and consistently correlated (positively) with the analogous PVT .
Actual Effectiveness metric, and the SAFTE model's predictive ability generally increased with increasing focus on test sessions whose timing was governed by operational schedules. Given the broadly representative sample of participants, extensive longitudinal and standardized data collection, and the use of actual sleep/wake/work patterns, the results strongly support the validity of the SAFTE model for predicting population-level variations in objective performance effectiveness.

Of course, for as encouraging as these results are, there are several features of the dataset worth considering when interpreting the findings. First, despite the strong correlations between SAFTE-Predicted Effectiveness and PVT Actual Effectiveness, the concordance between the two variables was limited by the differences in the range of the two metrics. Mean predicted effectiveness values ranged from well below 65% to above 100%, whereas the paired actual mean effectiveness scores ranged from 75-90%.

It is in this context that the differences between the laboratory data used to develop the SAFTE model and the field methods used in the present study may be most relevant. For example, the use of a PDA-based touchscreen PVT vs. the traditional push-button PVT "box," the use of a 5-min PVT session vs. the traditional 10-min session, and the technical limitations of off-the-shelf consumer-grade electronics may all have ontributed to limit the sensitivity, or at least the functional range, of mean performance effectiveness. In addition, the differences between laboratory- and field-based definitions of "baseline" may also have affected the final calculations, although the influence of this factor is virtually impossible to determine.

Nonetheless, these concerns only apply to the PVT Actual Effectiveness variable since it is analogous to the SAFTE-Predicted Effectiveness metric. We contend that differences in scale between predicted and actual effectiveness are less important than the essential finding that periods of relatively high- and low-predicted performance capacity were strongly associated with respective periods of relatively high and low actual performance capacity, as measured by several PVT variables. Since the 5-min PVT itself is not a task inherent to aviation operations but rather measures core neurobehavioral processes necessary for more complex operational tasks (Lim & Dinges, 2008), the key to the SAFTE model's validation is that when the model predicts peak performance, one is most likely to be at his or her best, and when the model predicts severely impaired performance, one is most likely to be at their worst, regardless of how "best" and "worst" are quantified or otherwise translated to the operational context.

Another noteworthy feature of the data was the high variability in mean PVT performances observed at the low range of predicted effectiveness, particularly at and below the 75% bin. The reasons for this are unclear, although we do not necessarily view this pattern observed in nearly all outcome variables as a limitation. One possibility is that fewer test sessions were available in the low-range bins, and hence higher SEMs after averaging; however, re-analysis of the data in bins of 100 sessions each still yielded a similar pattern (results not shown).

More likely explanations draw from specific features of the fatigue construct itself. One possibility comes from an emerging area in fatigue research on inherent individual differences in sleep need and vulnerability to fatigue (Goel & Dinges, 2011; Van Dongen, Baynard, Maislin & Dinges 2004a). Simply put, not every individual will exhibit performance impairments or the same level of impairment under sleep/wake/work patterns expected to produce fatigue in the general population, and conversely, particularly vulnerable individuals may consistently implement prophylactics and countermeasures (e.g., caffeine, nicotine, light exposure, exercise) to mitigate fatigue effects, regardless of their schedules.

In both cases, individuals who perform with high intra individual consistency, despite model predictions, will add variability to the average performances provided by their more susceptible colleagues.

Another potential contributor is the disparity between subjective fatigue and objective decrements in performance capacity (Van Dongen, Maislin & Dinges 2004b). Indeed, one particularly insidious feature of fatigue is a reduced ability to recognize the transition from baseline to moderate impairment, so individuals whose performance capacity is altered by fatigue may not realize it at predicted effectiveness levels above 75%, thereby yielding objective performance outcomes in line with model predictions. Yet, sleep/wake/work patterns that modeled as extremely impaired may have produced sufficient subjective fatigue to provoke countermeasure implementation (which we did not monitor or control), thus mitigating the objective performance decrements one would observe in a controlled laboratory setting, ultimately producing PVT performances more similar to sessions associated with higher predicted effectiveness bins.

Finally, another likely contributor is the notion of fatigue as "state instability" (or state lability; Dinges & Kribbs, 1991; Dorrian, Rogers & Dinges 2005), which defines fatigue more as inconsistent performance while the brain struggles to maintain vigilance, rather than consistently suppressed performance, reflecting the steady state of sleep pressure. From this perspective, higher variability at the very low end of predicted effectiveness would be expected, especially when coupled with individual differences in sensitivity to fatigue or other extraneous factors, and our ability to detect this variability actually speaks well of the 5-min touchscreen PVT's sensitivity as a field research tool (cf. Lamond et al., 2006; Fergusonet al., 2008). Since this study was intentionally designed to capture naturally occurring sleep/wake/work patterns and behavior without any field-validated means of quantifying individual vulnerability to fatigue, we must accept all of the possibilities described above as potential complications.

Nonetheless, it is at least provocative, if not encouraging from a model validation perspective, to observe that this apparent 75% predicted effectiveness "cutoff " point in performance stability is nearly identical to the point at which accident severity risk increases 5-fold in freight rail operations (77%; Hursh et al., 2011). Despite the various issues described above, the emergence of significant orderly relationships between model predictions and multiple objective neurobehavioral performance metrics further supports the SAFTE model's general validity for use in 24-hr operational settings while providing direct support for the model's applicability to commercial aviation.

CHAPTER 5

INTERPRETATION OF RESULTS

5.1 INTEPRETATION OF RESULTS

There is no simple formula for evaluating the contribution of crewmember fatigue to a safety event. For the purposes of the FRMS, the aim is to identify how the effects of fatigue could have been mitigated, in order to reduce the likelihood of similar occurrences in the future.

Basic information can be collected for all fatigue reports and safety events, with more indepth analyses reserved for events where it is more likely that fatigue was an important factor and/or where the outcomes were more severe.

To establish that fatigue was a contributing factor in an event, it has to be shown that;

- the person or crew was in a fatigued state; and
- the person or crew took particular actions or decisions that were causal in what went wrong; and
- those actions or decisions are consistent with the type of behaviour expected of a fatigued person or crew.

In 1997, the Canadian Transportation Safety Board produced guidelines for fatigue analysis.

They suggest four initial questions to decide whether or not fatigue was a contributing factor to an event.

1. At what time of day did the occurrence take place?
2. Was the crewmember's normal circadian rhythm disrupted?
3. How many hours had the crewmember been awake at the time of the occurrence?
4. Does the 72-hour sleep history suggest a sleep debt?

If the answer to any one of these questions indicates a problem, then fatigue should be investigated in greater depth. This requires working through two checklists (adapted from the Canadian Transportation Safety Board guide).

Airline operators within the aviation industry undergo constant change. Expansion may take the form of new additions to existing aircraft fleet, recruitment of new staff, or the opening of new passenger routes. It is important for operators to proactively monitor how these changes may affect the current status of system safety. Current attempts to proactively monitor potential latent failures may be misplaced, due to their unforeseeable nature and the crucial role that defences play in preventing accidents. INDICATE is offered as a new method which provides a formal means for the airline industry to identify current safety deficiencies and bring them to the attention of Bureau of Air Safety Investigation,1994 (BASI).

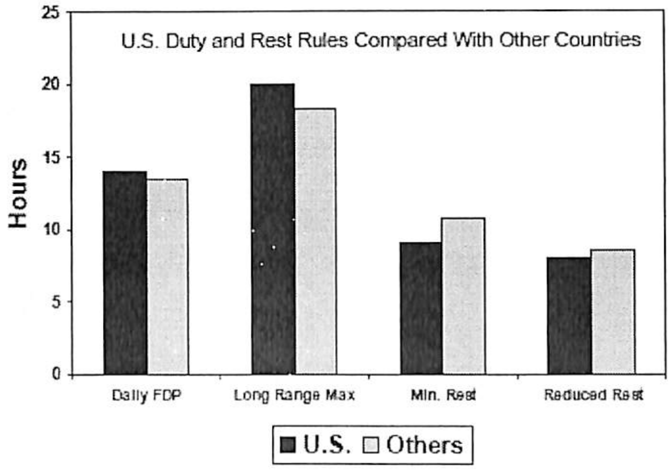
It is expected that INDICATE may provide a number of benefits for an airline:

- encourage better communication between management and employees about safety;
- reveal critical areas for development of procedures or training, and for priority inspections;
- provide a framework for feedback as to the efficacy of assumptions made about hardware or operational procedures
- provide a baseline for management decisions regarding safety issues; and
- provide a cost-effective safety management tool

INDICATE also encourages airlines to report safety problems more consistently. In Australia it is a legal requirement to report air safety incidents via an Aviation Safety Incident Report (ASIR).

However, despite this mandatory requirement, there is a recognised problem of under-reporting, which in part stems from a lack of awareness about what should be reported. While the implementation of INDICATE is only in its infancy, the results from the intervention phase of this study are encouraging. The response from regional airline staff participating in this trial has been positive and software is currently being developed by BASI to better manage the information produced from this program. A formal evaluation of INDICATE is yet to be completed, and further results from this trial will be published in BASI's Asia-Pacific AIR SAFETY magazine in early 1997.

Based on the results to date, it is expected that INDICATE will contribute to improving the quality of system safety within the Australian airline industry. Proactively identifying safety deficiencies before
they have a damaging effect will ultimately improve airline safety performance and encourage 'best practice'.



The results indicate that internationally, common practices are based on prescriptive rules that specify duty time and rest limitations within a period of time. Globally, each operator schedules flight attendants based on prescriptive rules, while bracing for likely disruptions that increase the costs of airline operations. "Domestic flight delays last year cost the U.S. economy as much as $41 billion and raised airlines' operating costs by $19 billion" (Fleming, 2008, p.1).

Due to recent cost increases, operators appear to be scheduling to the prescriptive limits more frequently. An FAA cabin safety ASI explained, "Now as a result of the economics, airlines are now scheduling down to the rule.

When [airline] changed from the agreed labor contract down to the requirements of 121.467, in 2002, this office received over 108 national hotline complaints in a 90-day period" (T. Blower, personal communication, October 30, 2008). Some U.S. flight attendants have complained that airlines are now so focused on their "on-time performance" that they don't leave enough time in the schedule for meal breaks, particularly when they are working domestic trips with multiple legs and quick turns (Avers, et al., 2009, under review). Ultimately, going without nourishment gradually decreases energy levels during a 12-14 hr duty day with multiple legs, which undoubtedly increases the risk of fatigue and reduces safety margins.

These reports indicate that the existing prescriptive rules are insufficient for effectively managing fatigue in round-the-clock operations. Dawson and McCulloch (2005) reported that using prescriptive rules alone is limiting and inflexible because they permit legal scheduling to extreme fatigue levels and do not take into account a schedule with night flying, early starts, late finishes, and time zone changes. Prescriptive rules also do little to address individual fatigue issues that many flight attendants endure (e.g., interrupted sleep, difficulty falling asleep, and lack of proper nutrition). Essentially, prescriptive rules manage the duty time of flight attendants but, they do not effectively account for the amount of sleep a flight attendant will receive between duty periods. Hence, they fail to optimally manage the risk of fatigue. When comparing U.S. prescriptive rules with the other nations in this study, U.S. flight attendants are required to work a longer FDP and long-range maximum hr per day and have less recovery time due to a shorter minimum rest and reduced rest period (See Fig. 1). Hence, U.S. prescriptive rules are among the least restrictive, representing a greater than typical fatigue risk. Best practices are adaptive and manage fatigue by incorporating science-based knowledge. An FRMS is a popular solution to counterbalance the inflexibility of the prescriptive rules and shows some effectiveness within airlines currently applying this approach to fatigue mitigation. The ICAO is requiring international regulatory authorities to integrate a FRMS as part of their overall SMS, while the EU-OPS requires the implementation of a FRMS if a country has a reduced rest, extended duty, or split-time rule provision. However, it should be noted that simply modifying the prescriptive rules to allow for increased flexibility in FDP limits does not necessarily lead to improved or more comprehensive management of fatigue (Signal, Ratieta & Gander, 2006).

Only a mature FRMS program with the following should be considered:

- Data-driven.
- Adaptive.
- Recognizes fatigue risks.
- Develop and evaluate mitigation strategies.
- Manage any emerging operational risk.
- Iterative feedback and solutions.
- Identifies operational aspects that contribute to fatigue.

5.2 COMPARISON OF RESULTS WITH ASSUMPTIONS (HYPOTHESIS)

Controlled rest on the flight deck is an effective fatigue mitigation for flight crews. It should not be used as a scheduling tool. It is not a substitute for proper preflight sleep or for normal crew augmentation, but intended as a response to unexpected fatigue experienced during operations.

Some basic principles:

It should be considered a safety net.

The Fatigue Safety Action Group should be able to monitor the use of controlled rest on the flight deck to evaluate whether existing mitigation strategies are adequate. Crew reports are encouraged.

It should only be used on flights of sufficient length that it does not interfere with required operational duties.

It should only be used during low workload phases of flight (e.g., during cruise flight).

It should not be used as a method for extending crew duty periods.

Procedures for controlled rest on the flight deck should be published and included in the Cabin Crew Operations Manual.

Controlled rest should only be utilized during the cruise period from the top of climb to minutes before the planned top of descent. This is to minimize the risk of sleep inertia.

- A short period of time should be allowed for rest preparation. This should include an operational briefing, completion of tasks in progress, and attention to any physiological needs of either crew member.
- During controlled rest, the non-resting cabin crew must perform the duties of the cabin crew flying and the Cabin crew monitoring, be able to exercise control of the aircraft at all times and maintain situational awareness. The non-resting cabin crew cannot leave his/her seat for any reason, including physiological breaks.
- Aids such as eye shades, neck supports, ear plugs, etc., should be permitted for the resting Cabin crew.

Flight and Duty Period (FDP). ICAO Regulation, Annex 6, Part I requires its members to establish aircrew flight and duty time limitation and rest requirement scheduling practices that minimize fatigue. As flight attendants carry out their duties both on and off the aircraft, their workload varies; and it has been reported that underload and overload conditions are potential causes of fatigue (Hancock & Verwey, 1997). The combination of workload and flight and duty period (FDP) has the potential to magnify the effects of fatigue significantly; therefore, prescribing a proper balance between workload and the number of working hours.

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The probability of fatigue also increases as more sectors are flown, as reported by Powell, Spencer, Holland, et al., (2007). Although these studies were pilot specific, they

are consistent with and relevant to flight attendant duties, since many airlines have opted to apply pilot flight time limitation (FTL) rules to their flight attendants.
Flight Time. Many airlines have opted to apply FTL rules to flight attendant schedules. The majority of the regulations (53%) and Canadian Bar Association; CBA (31%) with a FTL rule restricted the hr of work within a month (28 or 30 consecutive days). However, there was significant variability (85 - 210 hr) per month that a flight attendant could work, depending on the Civil Aviation Authority; CAA or operator. This variability suggests: (1) Lack of international standardization: (2)
Outdated regulations that have not incorporated current scientific principles and knowledge on human fatigue; (3) Different flight operations require more or less hours per month (i.e., night time, long-haul, short-haul, and international operations). Research results are clear in describing the differences in fatigue associated with these diverse operations (Co, Gregory, Johnson, Rosekind, 1999; Nagda & Koontz, 2003; Rosekind, Neri, Miller, et al., 1997; Rosekind, Miller, Gregory, & Dinges, 2000).
Most of the CBAs (75%) and 45% of the regulations with an FTL rule used a 100-hr limitation within a 28 or 30 consecutive day period.

This is effective if the 100 hr are spread out evenly within the month, instead of all occurring during a portion of the month (e.g., a flight attendant completing 100 hr in the last two weeks of the month). Some regulators specified that scheduled flight hours had to occur evenly during any 28/30 consecutive day time period which guards against accumulating and working many hours within a short time frame. Long Range and Crew Complement. Most regulations were ambiguous regarding whether or not they addressed short- and long-range operations. For example, in a section of one country's regulation, the rule stated the operator shall not assign a cabin crewmember an FDP to exceed 14 consecutive hr within 24 consecutive hr. However, in another section of the same regulation, the FDP was 16 hr or more, provided they added cabin crew members to the original crew complement.

We made an assumption that, if the regulation had a provision for crew complement, then it had "long-range" or "long-haul" operations. Also, the organization of some regulations were ambiguous in differentiating between the duty time and rest rules applied at home base vs. during a layover.

The long-range rule used in 63% of the regulations and 54% of the CBAs had an average 18-hr FDP per 24 consecutive hr. The United Arab Emirates had a provision Standby Rules. Standby duty may be counted as full or half working time, depending on whether the flight attendant is in the airport, at home, or in a hotel. However, fatigue normally increases over a period of time during wakefulness, whether an individual is performing tasks with higher than normal workload or idle (Åkerstedt, Folkard, & Portin, 2004; Hancock & Verwey, 1997). Some regulators provide limitations on the maximum hours for standby and also require that the accommodations provided by the operator during standby will be suitable to allow rest. The maximum period a flight attendant was allowed to spend on standby for the regulations (34%) and CBAs (31%) was approximately 12 hr, but 66% of the regulations and 69% of the CBAs had no maximum allowable standby period provision. Only 29% of the regulations and 7% of the CBAs provided guidance on the rest period associated with standby duty.

Depending upon whether positioning precedes or follows an FDP and rest period, at least half, or in some cases all, of the time required for positioning is counted toward the cumulative total duty hours. Although a flight attendant might have a sleep opportunity during positioning, the duration and quality of that sleep is expected to be significantly reduced. The average maximum time for positioning for the CBAs (18-hr) was greater than the regulations (13-hr) and 7% of the regulations and 61% of the CBAs had a provision for extending the maximum time allowed for positioning.

Assessment Stage 1: Selecting a model suited to the intended application(s)

The first consideration when selecting a biomathematical fatigue model is to ask whether the model delivers the specific application or applications required by the user organisation. Although all models considered here have the capacity to assist with fatigue management, they have been designed to fulfil different purposes, using different inputs, computations and outputs. Users will need to select a model that is best suited to delivering the intended outcomes. Table 1 shows the seven biomathematical models and lists for each the applications they provide, as described in Section 5 of this document.

Model Applications	**BAM**	**CAS**	**FAID**	**FRI**	**SAFE**	**SAFTE-FAST**	**SWP**
Forward Scheduling	✓	✓	✓	✓[8]	✓	✓	✓
Non-scheduled / Irregular operations	✓	✓	✓	✓	✓	✓[9]	✓
Work / Rest cycles in augmented crew	✓	✓	✓[10]		✓	✓	
Evaluation of light exposure countermeasures	✓	✓					
Evaluation of napping countermeasures	✓	✓			✓	✓[11]	✓
Individual fatigue prediction	✓	✓			✓		✓
Training	✓	✓	✓	✓	✓	✓	✓
Safety Investigation	✓	✓	✓		✓	✓	

Key: ✓ **Indicates application is supported by the model**

Table 1 - Comparison of Model Applications

All of the models can be used to assist operators with forward scheduling by helping build schedules that better manage fatigue risk. Compared to other models however, the FRI is somewhat cumbersome when used for large-scale roster production as it was primarily designed for comparing work schedules, and for identifying the fatigue or risk associated with particular shifts. Similarly, the Sleep / Wake Predictor; SWP is more suitable for evaluating particular work schedules than for large-scale roster development.

The other models have forward scheduling as a primary application and are well suited to the purpose. For instance, Boeing Alertness Model; BAM, Circadian Alertness Simulator; CAS, Fatigue Assessment Tool by Inter-Dynamics; FAID, System for Aircrew Fatigue Evaluation SAFE and Sleep, Activity, Fatigue and Task Effectiveness-Fatigue Avoidance Scheduling Tool; SAFTE-FAST can be connected to crew planning tools used by larger airlines to support large-scale roster building and modification. BAM and FAID have the capacity to interact with industry strength crew optimisers and affect crew schedules during construction. The FAID Roster Tool is a standalone application that provides immediate feedback as a roster is being developed.

SAFE can also be configured with the capacity to interact with optimisers and produce fatigue scores in response to new data entered. The other models evaluate rosters after they have been built. All models can be used for short-term scheduling to assess the suitability of duties associated with non-scheduled or irregular operations and several can be used to assist in evaluating work/rest cycles in augmented crews. Several models have been designed to assist in developing and evaluating fatigue countermeasures. BAM and CAS have the capacity to assist in evaluating countermeasures relating to light exposure, and several models can assist with napping countermeasures.

SAFTE-FAST for example incorporates napping as a configurable automatic countermeasure for long wake times prior to duty events, in the form of configurable in-flight naps, and as an explicitly scheduled countermeasure during split duties. Using the graphical tool associated with the model, users can manually insert naps anywhere in a schedule and compare the effects on performance.

The SAFE model can also be used in a similar way. FAID does not have the capacity to evaluate countermeasures directly, but does provide intra-shift displays of FAID scores to allow targeted risk mitigation strategies (including napping and light exposure) at appropriate times.

That is, while FAID cannot calculate the fatigue reduction associated with the implementation of countermeasures such as light exposure, it does enable the times of highest risk within a shift (at which countermeasures may be of most benefit) to be identified. BAM has the capacity to automatically produce fatigue mitigation strategies for a certain point in time, incorporating sleep / wake patterns and timings for light exposure. BAM, CAS and SWP all allow some individualised data to be input to refine fatigue prediction, while others only incorporate population averages. There are benefits to each approach, with the former permitting outputs to be more customised to individuals, and the latter having fewer and more easily accessible input requirements (i.e. work hours).

Most models can be used to support training of schedulers by helping them to understand the dynamics of the sleep/wake cycle and demonstrating the effects that changes to schedules or nap times, for instance, can have on projected fatigue levels. The models vary with respect to their applicability for safety investigation (i.e., accident and incident analysis).

Some models, such as SAFE and BAM, can be used for this application by allowing the actual sleep of a pilot to be input into the model and enabling the predicted fatigue level at the time of the event to be estimated. Other models, including FRI and FAID, use average population data and while not appropriate for estimating a particular individual's fatigue level at specific times, have been used for safety investigation purposes by assessing the impact of the individual's hours of work.

Assessment Stage 2: Comparison of Model Features

The second stage in selecting an appropriate biomathematical model is to evaluate specific features of all suitable models, to determine the best fit for the requirements of the organisation. As discussed in Section 6, biomathematical fatigue models vary in terms of the components that are taken into account, inputs required, and the outputs produced. The components that are incorporated into the various models are shown in Table 2.

Model Components	**BAM**	**CAS**	**FAID**	**FRI**	**SAFE**	**SAFTE-FAST**	**SWP**
Homeostatic Sleep Drive	✓	✓	✓	✓	✓	✓	✓
Circadian Processes	✓	✓	✓	✓	✓	✓	✓
Sleep Inertia	✓	✓		✓	✓	✓	✓
Circadian Phase Adaptation	✓	✓	✓[13]		✓	✓	✓
Work Type	✓	✓		✓	✓	✓	
Time on Task	✓	✓	✓	✓	✓	✓	✓

Key: ✓ **Indicates the component is incorporated into the model**

Table 2 - Comparison of Model Components

Table 2 shows a high degree of commonality in the underlying components of the models. All models account for homeostatic sleep drive and circadian processes. All except FAID take into account the effects of sleep inertia and all but FRI account for circadian phase adaptation.

Many of the models take work type into account, although the way in which they do this varies. SAFE calculations assume different levels of workload for office duties, training, simulator activities, flying duties and cabin crew duties, and the FRI similarly takes the type of activity being undertaken during the shift into account within fatigue risk calculations.

CAS does not focus on specific job types but does incorporate several workload categories which distinguish between flight crew and cabin crew, between flight crew performing training, flying or on-duty but not flying, and between take-off and landing phases versus other phases of flight, for example.

BAM and SAFTE-FAST similarly distinguish between different duty types, so that pilots flying multiple short-range flight sectors over a short time period will have a higher calculated workload than those flying a longer single sector, for example. While FAID does not incorporate work type into model calculations, it does take work-related fatigue exposure into account during interpretation of the results.

For instance, a lower FAID score benchmark figure (Fatigue Tolerance Level) may be set for tasks or roles designated as higher-risk, and a higher level for tasks or roles designated as lower-risk (up to three task risk benchmark figures may be set within the same data set).
Similarly, SAFTE-FAST users can set different effectiveness criteria for specific work groups to account for differences in risk associated with their activities. SAFTE-FAST calculates a separate workload factor based on the density of flight segments and reports it as a separate component of fatigue. All models take time on task into account.

The required and optional inputs for the various models considered in this review are shown in Table 3.

Model Inputs	**BAM**	**CAS**[15]	**FAID**[16]	**FRI**	**SAFE**	**SAFTE-FAST**	**SWP**
Actual sleep timing	Op	Op	Op[17]		Op	Op	Op
Work schedule	✓	✓	✓	✓	✓	✓	✓
Time zone changes	✓	Op	✓			✓	✓
Crew composition	✓	✓	Op		✓	✓	
In-flight rest facilities (bunk or seats)	Op	Op	Op		✓	Op	
Take off and landing waypoints	✓	✓	✓		✓	✓	
Multiple sectors	✓	✓	Op		✓	✓	
Workload		Op	Op	✓			
Habitual sleep duration	Op	Op			Op		Op
Chronotype	Op	Op					Op
Commuting	✓	Op	Op	✓	Op	Op	

Key: ✓ Required input
Op Optional input

Table 3 - Comparison of Model Inputs

Table 3 shows that many models can incorporate actual sleep / wake timing as an optional input, overriding model predictions of sleep and wake. This feature is often used in models such as SAFE when being used to investigate fatigue reports or incidents and accidents that could have a fatigue-related element. All models have work schedule as a required input.

The models vary considerably in terms of inputs relating to time zone changes, crew composition, sleep location, take off and landing waypoints and number of sectors. Many models require time zone changes as an input. Others, including SAFE and CAS, do not require time zone changes as a specific input but calculate these automatically from airport codes.

BAM, CAS, SAFE and SAFTE-FAST require inputs relating to crew composition (e.g., single pilot / multi-crew / augmented or non-augmented crew) to produce estimates. This is an optional input in FAID TZ. SAFE permits cabin crew as an additional crew composition option.

Several models also take into account location of sleep (bunk or seats) as an indicator of sleep quality. Different models use different categories for these inputs. For instance, SAFE allows use of bunk, business passenger seat, flight deck seat, economy seat and jump seat as input options, SAFTE-FAST considers four levels of sleep quality, CAS can consider home, hotel and inflight (economy/business/bunk) sleeping locations and FAID TZ considers different quality of in-flight rest by a recovery factor based on research on in-flight sleeping conditions.

Many models require inputs regarding takeoff and landing waypoints. In some models, such as CAS, this input is used to derive other information such as time zone changes. BAM, CAS, SAFE and SAFTE-FAST all require direct inputs on the number of sectors. SAFE and SAFTEFAST use this input to calculate workload. The FRI requires both workload and the attention demand of the shift as an input so that these can be taken into account in determining the fatigue risk.

FAID allows for a designation of Task Risk level as an input which, while not changing the calculation, can be used as a proxy for category of workload, with measures highlighted accordingly in the outputs. CAS can incorporate workload as an optional input and can take this into account in calculation of fatigue risk scores. In regard to the individualisation of models, BAM, CAS and SWP can be configured to incorporate individual sleep need (habitual sleep duration) and individual chronotype. In CAS, individualisation also incorporates short or long sleeper, napper or consolidated sleeper and flexible or rigid sleeper categories.

BAM and CAS can also incorporate commute times to further refine estimates. SAFE can incorporate habitual sleep duration (all sleep periods are configurable by the user), but not the other individual inputs. SAFE, SAFTE-FAST and FAID generally use population averages for inputs such as chronotype and commute times rather than individualised data, so that fewer inputs are required. SAFTE-FAST can incorporate specific commute times for individual fatigue reports and have the outputs recalculated accordingly, but works on set commute times (based on standard commute times or commute times based on the location) in batch processing. Other models can accommodate changes in commute times indirectly.

In FAID TZ and SAFE, for instance, extended commute times can be modelled indirectly by editing inputs such as the start and finish times. Similarly, FAID TZ can only incorporate multiple sectors indirectly, by entering the duty time as a series of component activities with different start and end periods so that multiple sectors are identified as separate work activities. The FRI and SWP require very few inputs in order to produce fatigue predictions. The third criterion for comparison is the output produced by the models, shown in Table 4.

Model Outputs	**BAM**	**CAS**	**FAID**	**FRI**	**SAFE**	**SAFTE-FAST**	**SWP**
Subjective alertness	✓	✓	✓	✓	✓		✓
Estimated sleep / wake times	✓	✓	✓		✓	✓	✓
Performance		✓	✓			✓	✓
Fatigue-related task errors		✓				✓	✓
Fatigue-related risk of operational accidents		✓	✓	✓		✓	✓
Confidence intervals	✓					✓	✓

Key: ✓ Indicates factor is an output of the model

Table 4 - Comparison of Model Outputs

As shown in Table 4, all models except SAFTE-FAST produce a fatigue or alertness prediction value over a given work period, referred to as a 'subjective alertness metric'. SAFTE-FAST does, however, report subjective workload based on density of flight segments. All models except the FRI produce estimated sleep and wake times as outputs. CAS, FAID, SAFTEFAST and SWP aim to provide performance-based metrics. For instance SAFTE-FAST is designed to predict effectiveness (cognitive throughput), reaction time, lapse likelihood, and average cognitive performance.

SAFE does not currently incorporate a performance metric but previous version did indicate predicted reaction times and predicted vigilance performance, and it is intended that these will be reinstated in a future version. Several models predict the probability of fatigue-related risk of task error or of operational accidents.

In regard to the former, SAFTE-FAST predicts changes in reaction time and increases in fatigue-related lapses of attention. The current version of SAFE does not predict the fatigue-related risk of task error, but this will be incorporated in the upcoming version of the model. In regard to the fatigue-related risk of operational accidents, the CAS, for example, incorporates a Fatigue Risk Index, which claims to be a sensitive measure of the risk of incidents, accidents and injury in multiple transportation modes. Based on validation studies, these relate directly to changes in railroad accident likelihood and severity. FAID provides increasing colour bands of risk, representing the increasing risk of fatigue-related operational accidents.

BAM and SWP produce outputs incorporating confidence intervals. SAFTE-FAST does not produce standard confidence intervals around the mean, but instead reports and graphs the percentile variations from the mean, based on estimates of the standard deviation of performance for a population of subjects. For example, the model can display the lowest 20th percentile subject along with the average subject performance.

CHAPTER 6

CONCLUSIONS AND SCOPE FOR FUTURE WORK

Managing fatigue is critical to the future of aviation. Aircraft are increasingly able to operate longer sectors, and while our understanding of the relationship between human fatigue and performance continues to evolve, managing the balance between what is technically possible with what is humanly possible, is complex.

In response to the need to manage fatigue-related risks, ICAO recently approved amendments to Annex 6 Part I, to include Fatigue Risk Management Systems (FRMS) Standards and Recommended Practices (SARPs). In addition EASA is finalizing EU wide FTL rules to be effective by April 2013. An FTL NPA was issued and revisions to the proposal are scheduled to be released in December 2011 (CRD), with opinion by June 2012.

This document reviews a selected group of biomathematical fatigue models with respect to their suitability for use as a component of an effective FRMS within the civil aviation industry. The included models were selected on the basis of factors including their availability and suitability for use within the aviation environment, their scientific basis and rigour, and their capacity to contribute to the identification and management of fatigue risk within the operational environment.

Information on the models was compiled from various sources, including a blend of available peer-reviewed publications, promotional material, and self-reported responses from current vendors or suppliers of the respective models. The scope of this review, however, did not extend to independent field trials of any of the models. Prospective users are thus advised to use this document for initial guidance, but to then carry out their own evaluations as to whether a specific model is suitable for deployment for the operating environment and activities most relevant to them.

It should be noted that while this document reflects the current status of biomathematical fatigue modelling, this is an area of continuing research and rapid development and it is expected that there will be significant enhancements to fatigue modelling science in the near future, including the capacity to predict specific risks associated with fatigue. Biomathematical fatigue models have the unique benefit of enabling scientific knowledge on fatigue, gained from empirical observations and research studies, to be incorporated into work scheduling decisions. Prospective users are also reminded, however, to carefully consider the generic cautions and limitations of biomathematical models discussed within this document before putting any such models to use. While these models can be very useful tools to assist with the identification and management of fatigue risk, they should only ever be considered as one element of a comprehensive FRMS.

The last 70 years - changes in the wind:

The report included aviation industry-specific recommendations, including that fatigue management should be a basic requirement for air operators, including aircraft maintenance activities, and that the management of fatigue should be a component of safety audits.

The report also recommended that "The Civil Aviation Safety Authority should implement Fatigue Risk Management Systems to regulate flight and duty times for aircrew as soon as it is feasible to do so. The new rules were timed to follow ICAO amendment to Annex 6. They followed a comprehensive review of existing rules and standard exemptions. Available science as well as national and international experience will be considered in future enabling continuing evolvement of safety culture and its compliance in a 360 degree environment.

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