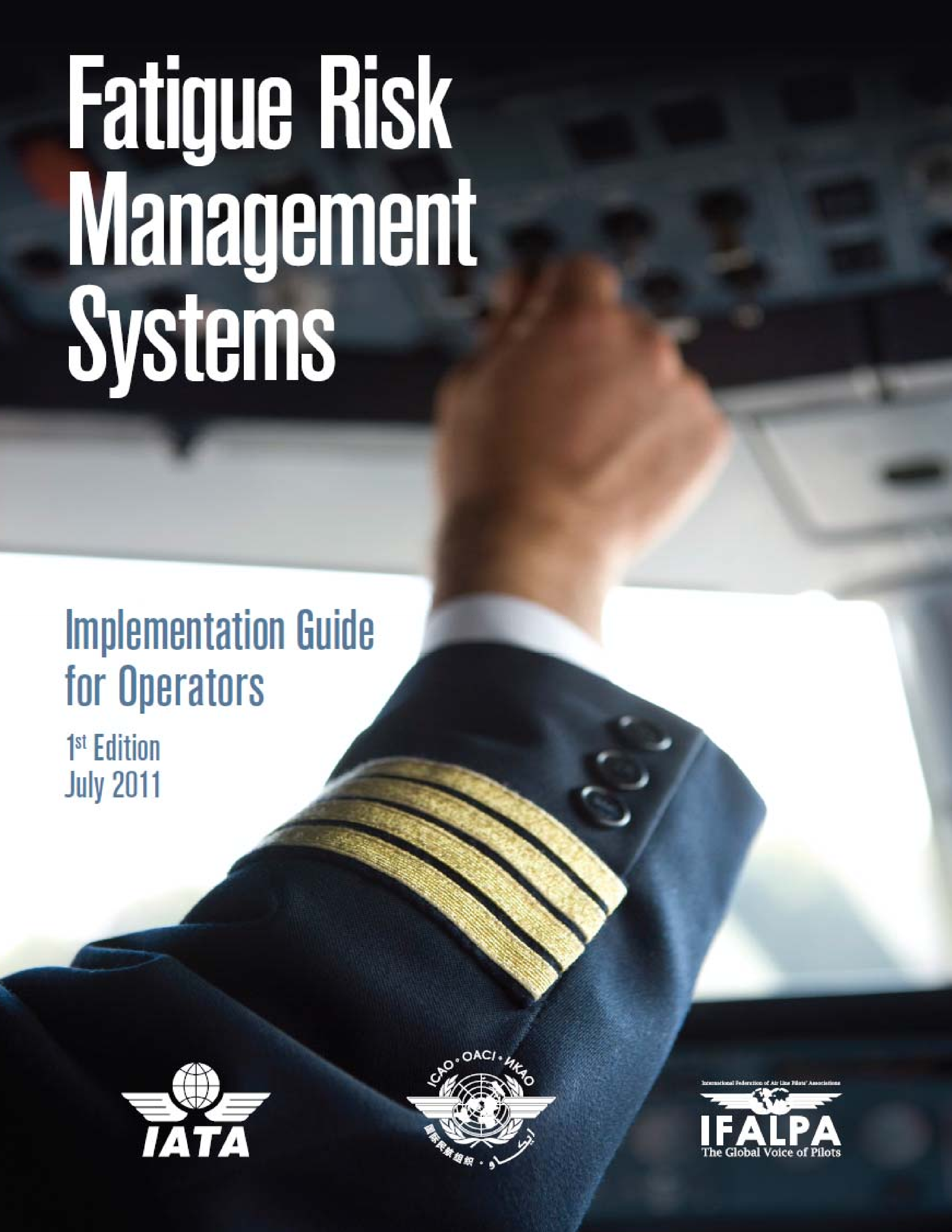
Fatigue Risk Management Systems



Implementation Guide for Operators

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IATA

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International Federation of Air Line Pilots' Associations
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EXECUTIVE LETTER

Dear Colleagues,

Air travel continues to be the safest means of transportation, but that does not allow for us to become complacent. We continually strive for improvements in our industry safety record, which is a testament to our ongoing commitment to safety.

Fatigue Risk Management Systems (FRMS) continues the move from prescriptive to performance based regulatory oversight. As in Safety Management Systems (SMS), FRMS strives to find the realistic balance between safety, productivity and costs in an organization, through collection of data and a formal assessment of risk.

Traditionally, crewmember fatigue has been managed through prescribed limits on maximum flight and duty hours, based on a historical understanding of fatigue through simple work and rest period relationships. New knowledge related to the effects of sleep and circadian rhythms provides an additional dimension to the management of fatigue risks. An FRMS provides a means of adding this safety dimension, allowing operators to work both safer and more efficiently.

This FRMS Implementation Guide for Operators is a significant milestone. It marks the successful collaboration between IATA, IFALPA and ICAO to jointly lead and serve industry in the ongoing development of fatigue management, using the most current science. The input of these three organizations has ensured that this document presents a scientifically-based approach that is widely acceptable to the operators and the crew members who will be using it. It also offers this information in an accessible and practical way to assist implementation.

We are extremely proud to mutually introduce this FRMS Implementation Guide for Operators, which will contribute to the improved management of fatigue risk, and to ultimately achieve our common goal of improving aviation safety worldwide.

Guenther Matschnigg Senior Vice President Safety, Operations & Infrastructure, IATA	Nancy Graham Director Air Navigation Bureau ICAO	Don Wykoff President International Federation of Air Line Pilots' Associations

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1.0 INTRODUCTION TO FRMS

The purpose of this FRMS Implementation Guide 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 guide. 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.

1.1 WHAT IS A FATIGUE RISK MANAGEMENT SYSTEM?

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'[1] ,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

[1] See ICAO Safety Management Manual (Doc 9859) and IATA Introduction to Safety Management Systems (SMS), 2nd Edition.

1.2 WHY THE AVIATION INDUSTRY IS INTRODUCING FRMS

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 operations[2]. 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 safety[1]. 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 one-size-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.

[2] Gander PH, Hartley L, Powell D, Cabon P, Hitchcock E, Mills A. Popkin S (2010). Fatigue risk management I: organizational factors. *Accident Analysis and Prevention 43:573-590*

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.

1.3 ICAO Requirements for Fatigue Risk Management Systems

This section describes the Standards and Recommended Practices (SARPs) relating to the management of fatigue experienced by flight and cabin crew. These SARPs provide the high-level regulatory framework for both prescriptive flight and duty limitations and FRMS as methods for managing fatigue risk. Both methods share two important basic features:

1. They are required to take into consideration the dynamics of transient and cumulative sleep loss and recovery, the circadian biological clock, and the impact of workload on fatigue, along with operational requirements.
2. Because fatigue is affected by all waking activities not only work demands, regulations for both are necessarily predicated on the need for shared responsibility between the operator and individual crewmembers for its management. So, whether complying with prescriptive flight and duty limitations or using and FRMS, operators are responsible for providing schedules that allow crewmembers to perform at adequate levels of alertness and crewmembers are responsible for using that time to start work well-rested. The requirement for shared responsibility in relation to FRMS is discussed further in Chapter Three.

FRMS also shares the building blocks of SMS. This means that an FRMS is predicated on: effective safety reporting; senior management commitment; a process of continuous monitoring; a process for investigation of safety occurrences that aims to identify safety deficiencies rather than apportioning blame; the sharing of information and best practices; integrated training for operational personnel; effective implementation of standard operating procedures (SOPs); and a commitment to continuous improvement. So, together, the foundations of prescriptive flight and duty time limitations and SMS form the building blocks of FRMS (see Table 1).

Table 1 – FRMS Building Blocks

	FRMS Building Blocks
Prescriptive flight and duty time limitations	• Addresses transient and cumulative fatigue • Shared operator-individual responsibility
SMS	• Effective safety reporting • Senior management commitment • Continuous monitoring process • Investigation of safety occurrences • Sharing of information • Integrated training • Effective implementation of SOPs • Continuous improvement

However, an FRMS, as a management system focused on fatigue, also has added requirements beyond that which would be expected of an operator complying with prescriptive flight and duty time limitations and managing their fatigue risks through their SMS. In meeting these additional FRMS-specific requirements, an operator with an approved FRMS may move outside the prescribed limits. Therefore, the fatigue management SARPs in Section 4.10, Annex 6, Part I, and include particular Standards that enable the effective regulation of FRMS.

The following text box contains the SARPs in Annex 6 Part I that relate to Fatigue Management. States are required to have regulations for prescriptive flight and duty time limitations, but they also have the option to establish FRMS regulations. In addition, there is a requirement that when FRMS is used, operations manuals reflect the FRMS option (Annex 6, Part I, Appendix 2).

Appendix 8 has been added to Annex 6, Part I to give detailed requirements for an FRMS which must include, at a minimum, the following components.

1. FRMS policy and documentation;
2. Fatigue risk management processes;
3. FRMS safety assurance processes; and
4. FRMS promotion processes.

Table 1.1 shows how these components map to the requirements of SMS.

See Example 1 to view Annex 6, Part 1, which recommends "*where an operator has an FRMS, it is integrated with the operator's SMS*."

Example 1 – Annex 6 Part I – 4.10 Fatigue Management

4.10.1 The State of the Operator shall establish regulations for the purpose of managing fatigue. These regulations shall be based upon scientific principles and knowledge, with the aim of ensuring that flight and cabin crew members are performing at an adequate level of alertness. Accordingly, the State of the Operator shall establish:

a) regulations for flight time, flight duty period, duty period and rest period limitations; and
b) where authorizing an operator to use a Fatigue Risk Management System (FRMS) to manage fatigue, FRMS regulations.

4.10.2 The State of the Operator shall require that the operator, in compliance with 4.10.1 and for the purposes of managing its fatigue-related safety risks, establish either:

a) flight time, flight duty period, duty period and rest period limitation that are within the prescriptive fatigue management regulations established by the State of the Operator; or
b) a Fatigue Risk Management System (FRMS) in compliance with 4.10.6 for all operations; or
c) an FRMS in compliance with 4.10.6 for part of its operations and the requirements of 4.10.2 a) for the remainder of its operations.

4.10.3 Where the operator adopts prescriptive fatigue management regulations for part or all of its operations, the State of the Operator may approve, in exceptional circumstances, variations to these regulations on the basis of a risk assessment provided by the operator. Approved variations shall provide a level of safety equivalent to, or better than, that achieved through the prescriptive fatigue management regulations.

4.10.4 The State of the Operator shall approve an operator's FRMS before it may take the place of any or all of the prescriptive fatigue management regulations. An approved FRMS shall provide a level of safety equivalent to, or better than, the prescriptive fatigue management regulations.

4.10.5 States that approve an operator's FRMS shall establish a process to ensure that an FRMS provides a level of safety equivalent to, or better than, the prescriptive fatigue management regulations. As part of this process, the State of the Operator shall:

a) require that the operator establish maximum values for flight times and/or flight duty periods(s) and duty period(s), and minimum values for rest periods. These values shall be based upon scientific principles and knowledge, subject to safety assurance processes, and acceptable to the State of the Operator;
b) mandate a decrease in maximum values and an increase in minimum values in the event that the operator's data indicates these values are too high or too low, respectively; and
c) approve any increase in maximum values or decrease in minimum values only after evaluating the operator's justification for such changes, based on accumulated FRMS experience and fatigue-related data.

4.10.6 Where an operator implements an FRMS to manage fatigue-related safety risks, the operator shall, as a minimum:

a) incorporate scientific principles and knowledge within the FRMS;
b) identify fatigue-related safety hazards and the resulting risks on an ongoing basis;
c) ensure that remedial actions, necessary to effectively mitigate the risks associated with the hazards, are implemented promptly;
d) provide for continuous monitoring and regular assessment of the mitigation of fatigue risks achieved by such actions; and
e) provide for continuous improvement to the overall performance of the FRMS.

4.10.7 **Recommendation.—** *States should require that, where an operator has an FRMS, it is integrated with the operator's SMS.*

4.10.8 An operator shall maintain records for all its flight and cabin crew members of flight time, flight duty periods, duty periods, and rest periods for a period of time specified by the State of the Operator.

Table 1.1 Comparing SMS and FRMS Components

SMS Framework	FRMS
1. Safety policy and objectives	1. FRMS policy and documentation
2. Safety risk management	2. FRM processes • Identification of hazards • Risk assessment • Risk mitigation
3. Safety assurance	3. FRMS safety assurance processes • FRMS performance monitoring • Management of operational and organisational change • Continuous FRMS improvement
4. Safety promotion	4. FRMS promotion processes • Training programs • FRMS communication plan

The core operational activities of the FRMS are the FRM processes and the FRMS safety assurance processes. They are supported by organizational arrangements defined in the FRMS policy and documentation, and by the FRMS promotion processes.

1.4 Structure of this Manual

Figure 1.1 shows a basic framework linking the required components of an FRMS. For ease of explanation, Figure 1.1 presents a single, central, functional group, designated as the "Fatigue Safety Action Group", responsible for all of these FRMS components. The Fatigue Safety Action Group includes representatives of all stakeholder groups (management, scheduling, and crewmembers) and other individuals as needed to ensure that it has appropriate access to scientific and medical expertise. However, depending on the organizational structure, some of the Fatigue Safety Action Group functions as described in this manual may be undertaken by other groups within the organization (discussed further in Chapter 3). The important thing is that, irrespective of who does them, all of the component functions required under an FRMS be performed.

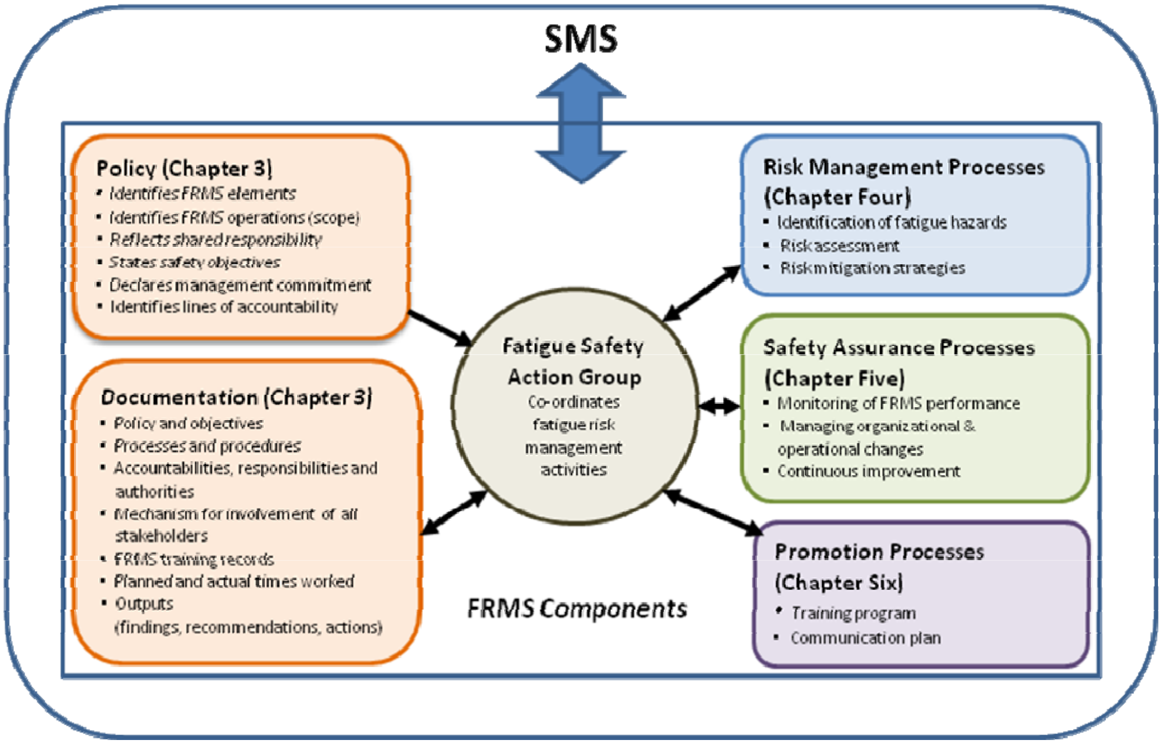

Figure 1.1: Linking the required components of an FRMS

Communication between the FRMS processes and the SMS (in both directions) is necessary to integrate the management of the fatigue risks into the broader risk management activities of the SMS.

The detailed structure of an FRMS, and the specific ways in which it links to an operator's SMS, will vary according to:

- the size of the organization;
- the type and complexity of the operations being managed;
- the relative maturity of the FRMS and the SMS; and
- the relative importance of the fatigue hazards.

The FRMS approach is based on applying scientific principles and knowledge to manage crewmember fatigue. Chapter Two introduces the essential scientific concepts that are needed to develop and implement an FRMS. Chapters Three, Four, Five, and Six each deal with one of the required FRMS components. Chapter Seven steps though a staged approach for implementing an FRMS.

Appendices A, B and C provide extra information to support that provided in the preceding chapters. For ease of reference, Appendix A provides a glossary of terms used in this manual. Appendix B provides more detailed information on methods of measuring fatigue as part of the FRM processes presented in Chapter Three. Appendix C also supports Chapter Three by providing further information on the use of controlled rest on the flight deck as a mitigator of fatigue risk.

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2.0 SCIENCE FOR FRMS

2.1 INTRODUCTION

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 (Chapter Four and Appendix B).

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.

2.2 ESSENTIAL SLEEP SCIENCE

There is a widespread belief that sleep time can be traded off to increase the amount of time available for waking activities in a busy lifestyle. Sleep science makes it very clear that sleep is not a tradable commodity.

2.2.1 What is Happening in the Brain During Sleep

There are a variety of ways of looking at what is happening in the sleeping brain, from reflecting on dreams to using advanced medical imaging techniques. Currently, the most common research method is known as polysomnography (see Appendix B for details). This involves sticking removable electrodes to the scalp and face and connecting them to a recording device, to measure three different types of electrical activity: 1) brainwaves (electroencephalogram or EEG); 2) eye movements (electroculogram or EOG); and 3) muscle tone (electromyogram or EMG). Using polysomnography, it is possible to identify two very different kinds of sleep.

Non-Rapid Eye Movement Sleep

Compared to waking brain activity, non-Rapid Eye Movement sleep (non-REM sleep) involves gradual slowing of the brainwaves. The amplitude (height) of the brainwaves also becomes larger as the electrical activity of large numbers of brain cells (neurons) becomes synchronized so that they fire in unison. Heart rate and breathing tend to be slow and regular.

People woken from non-REM sleep do not usually recall much mental activity. However, it is still possible for the body to move in response to instructions from the brain. Because of these features, non-REM sleep is sometimes described as 'a relatively inactive brain in a movable body'.

Non-REM sleep is usually divided into 4 stages, based on the characteristics of the brainwaves.

- Stages 1 and 2 represent lighter sleep (it is not very difficult to wake someone up). It is usual to enter sleep through Stage 1 and then Stage 2 non-REM.
- Stages 3 and 4 represent deeper sleep (it can be very hard to wake someone up). Stages 3 and 4 are characterized by high amplitude slow brainwaves, and are together often described as **slow-wave sleep** (or deep sleep).

Slow-wave sleep has a number of important properties. Pressure for slow-wave sleep builds up across waking and discharges across sleep. In other words:

- The longer you are awake, the more slow-wave sleep you will have in your next sleep period; and
- Across a sleep period, the proportion of time spent in slow-wave sleep decreases.

This rising and falling of pressure for slow wave sleep is sometimes called the **sleep homeostatic process,** and it is a component in most of the bio-mathematical models that are used to predict crewmember fatigue levels (see Chapter Four).

Even in slow-wave sleep, the brain is still about 80% activated and capable of active cognitive processing. There is growing evidence that slow-wave sleep is essential for the consolidation of some types of memory, and is therefore necessary for learning.

Operational Note:

Mitigation Strategies for Sleep Inertia

Operationally, slow-wave sleep may be important because the brain can have difficulty transitioning out of it when someone is woken up suddenly. This is known as **sleep inertia** – feelings of grogginess and disorientation, with impaired short-term memory and decision-making. Sleep inertia can occur coming out of lighter sleep, but it tends to be longer and more disorienting when someone is woken abruptly out of slow-wave sleep. This is sometimes used as an argument against the use of flight deck napping or in-flight sleep. It would not be desirable to have a crewmember who is woken up because of an emergency, but who is impaired by sleep inertia. This argument is based on the effects of sleep inertia seen in laboratory studies. However, studies of napping on the flight deck and of sleep in onboard crew rest facilities show that sleep in flight contains very little slow-wave sleep. (It is lighter and more fragmented than sleep on the ground). This means that sleep inertia is much less likely to occur waking up from sleep in flight than would be predicted from laboratory sleep studies.

The risk of sleep inertia can also be reduced by having a protocol for returning to active duty that allows time for sleep inertia to wear off. Overall, the demonstrated benefits of controlled napping and in-flight sleep greatly out-weigh the potential risks associated with sleep inertia. To reduce the risk of sleep inertia after flight deck napping, the recommendation is to limit the time available for the nap to 40 minutes. Given the time taken to fall asleep, a 40-minute opportunity is too short for most people to enter slow-wave sleep. Refer to Appendix C for suggested Flight Operations Manual procedures for controlled napping.

Rapid Eye Movement Sleep

During Rapid Eye Movement sleep (REM sleep), brain activity measured by polysomnography looks similar to brain activity during waking. However in REM sleep, from time to time the eyes move around under the closed eyelids – the so-called 'rapid eye movements' –and this is often accompanied by muscle twitches and irregular heart rate and breathing.

People woken from REM sleep can typically recall vivid dreaming. At the same time, the body cannot move in response to signals from the brain so dreams cannot be 'acted out'. (The signals effectively get blocked in the brain stem and cannot get through to the spinal cord.) People sometimes experience brief paralysis when they wake up out of a dream, when reversal of this 'REM block' is slightly delayed. Because of these features, REM sleep is sometimes described as 'a highly activated brain in a paralyzed body'.

Dreams have always been a source of fascination, but are difficult to study using quantitative scientific methods. They have been interpreted as everything from spiritual visitations to fulfillment of instinctual drives, to being a meaningless by-product of activity in various parts of the brain during REM sleep. The current neuro-cognitive view of dreaming argues that it results from brief moments of consciousness when we become aware of all the processing that our brains normally do 'off-line', i.e. when they are not busy dealing with information coming in from the environment through the senses, and are not being directed by our conscious control. This 'off-line' processing includes reactivating memories and emotions from previous experiences, and integrating them with experiences from the latest period of waking. Dreams in this view are a glimpse into your brain reshaping itself so that you can wake up in the morning still yourself, but a slightly revised version as a result of your experiences yesterday, and ready to start interacting with the world again.

People vary greatly in their ability to recall dreams, and we generally only recall them when we wake spontaneously out of REM sleep (and then only fleetingly unless we write them down or talk about them). Nevertheless, most adults normally spend about a quarter of their sleep time in REM sleep.

Non-REM/REM Cycles

Across a normal night of sleep, non-REM sleep and REM sleep alternate in a cycle that lasts roughly 90 minutes (but is very variable in length, depending on a number of factors). Figure 2.1 is a diagram describing the non-REM/REM cycle across the night in a healthy young adult. Real sleep is not as tidy as this - it includes more arousals (transitions to lighter sleep) and brief awakenings. Sleep stages are indicated on the vertical axis and time is represented across horizontal axis[3].

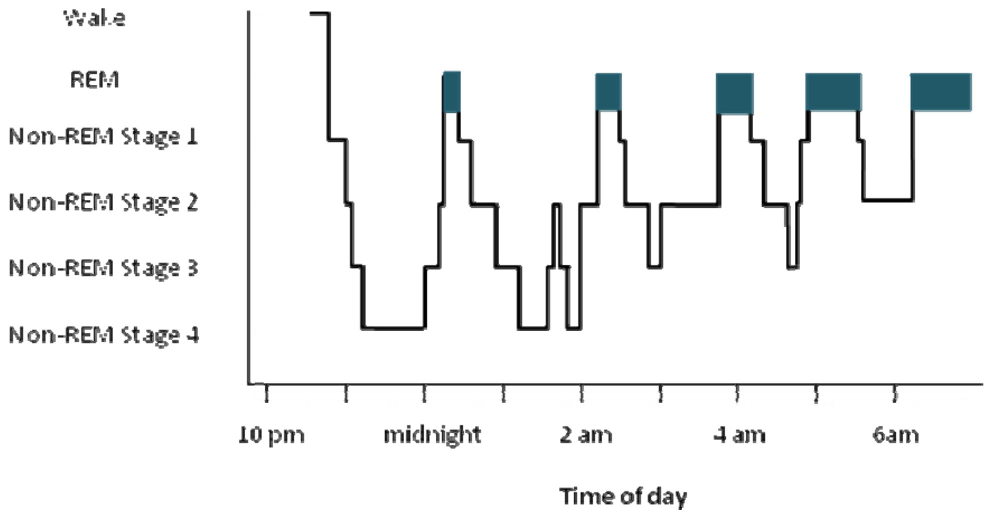

Figure 2.1: Diagram of the non-REM/REM cycle across the night in a young adult

Sleep is entered through Stage 1 non-REM and then progresses deeper and deeper into non-REM. About 80-90 minutes into sleep, there is a shift out of slow-wave sleep (non-REM stages 3 and 4). This is often marked by body movements, as the sleeper transitions briefly through Stage 2 non-REM and into the first REM period of the night. (REM periods are indicated as shaded boxes in Figure 2.1). After a fairly short period of REM, the sleeper progresses back down again through lighter non-REM sleep and into slow-wave sleep, and so the cycle repeats.

The amount of slow-wave sleep in each non-REM/REM cycle decreases across the night, and there may be none at all in the later cycles. In contrast, the amount of REM sleep in each non-REM/REM cycle increases across the night. The sleeper depicted in Figure 2.1 wakes up directly out of the final REM period of the night, and so would probably recall dreaming.

3 Gander PH (2003) Sleep in the 24-Hour Society. Wellington, New Zealand: Open Mind Publishing. ISBN 0-909009-59-7

Interestingly, slow-wave sleep always predominates at the beginning of a sleep period, regardless of when sleep occurs in the day/night cycle or in the circadian body clock cycle. There seems to be a priority to discharge the **homeostatic sleep pressure** first. In contrast, the time from sleep onset to the first bout of REM (the REM latency) and the duration of each REM bout varies markedly across the **circadian body clock cycle**. The circadian drive for REM sleep is strongest a few hours before normal wakeup time. These two processes – the **homeostatic sleep process** and the **circadian body clock** are the main components in most of the bio-mathematical models that are used to predict crewmember fatigue levels (see Chapter Four).

Operational Note:

Mitigation Strategies for Sleep Loss

Restoration of a normal non-REM/REM cycle is one measure of recovery from the effects of sleep loss. Lost sleep is not recovered hour-for-hour, although recovery sleep may be slightly longer than usual.

- On the first recovery night, there is more slow-wave sleep than usual. Indeed, there can be so much slow-wave sleep that there is not enough time to make up REM sleep.
- On the second recovery night, there is often more REM sleep than usual.
- By the third recovery night, the non-REM/REM cycle is usually back to normal.

Operationally, this means that schedules need to periodically include an opportunity for at least two consecutive nights of unrestricted sleep, to enable crewmembers to recover from the effects of sleep loss.

This does not equate to 48 hours off. For example, 48 hours off duty starting at 02:00 would only give most people the opportunity for one full night of unrestricted sleep. On the other hand, 40 hours off starting at 21:00 would give most people the opportunity for two full nights of unrestricted sleep.

Additional nights may be needed for recovery if a crewmembers' circadian body clock is not already adapted to the local time zone (see Section 2.3).

2.2.2 The Issue of Sleep Quality

Sleep quality (its restorative value) depends on going through unbroken non-REM/REM cycles (which suggests that both types of sleep are necessary and one is not more important than the other). The more the non-REM/REM cycle is fragmented by waking up, or by arousals that move the brain to a lighter stage of sleep without actually waking up, the less restorative value sleep has in terms of how you feel and function the next day.

Operational Note:

Mitigation Strategies to Minimize Sleep Interruptions

Because uninterrupted non-REM/REM cycles are the key to good quality sleep, operators should develop procedures that minimize interruptions to crewmembers' sleep.

Rest periods should include defined blocks of time (sleep opportunities) during which crewmembers are not contacted except in emergencies. These protected sleep opportunities need to be known to flight crews and all other relevant personnel. For example, calls from crew scheduling should not occur during a rest period as they can be extremely disruptive.

Operators should also develop procedures to protect crewmember sleep at layover and napping facilities. For example, if a rest period occurs during the day at a layover hotel, the operator could make arrangements with the hotel to restrict access to the section of the hotel where crewmembers are trying to sleep (such as no children, crewmembers only) and instruct their staff to honor the necessary quiet periods (for example, no maintenance work or routine cleaning

Quality of In-Flight Sleep

As mentioned above, polysomnography studies show that crewmembers' sleep in onboard crew rest facilities is lighter and more fragmented than sleep on the ground[4]. Sleep during flight deck naps is also lighter and more fragmented than would be predicted from laboratory studies[5]. Nevertheless, there is good evidence that in-flight sleep improves subsequent alertness and reaction speed and is a valuable mitigation strategy in an FRMS.

Interestingly, studies of sleep in hypobaric chambers at pressures equivalent to cabin pressure at cruising altitude indicate that the fragmented quality of in-flight sleep is not due to altitude[6]. Several studies have asked crewmembers what disturbs their sleep on board. The factors most commonly identified are random noise, thoughts, not feeling tired, turbulence, ambient aircraft noise, inadequate bedding, low humidity, and going to the toilet..

Sleep Quality and Aging

Across adulthood, the proportion of sleep time spent in slow-wave sleep declines, particularly among men. In addition, sleep becomes more fragmented. For example, one study with 2,685 participants aged 37–92 yrs found that the average number of arousals (transitions to lighter sleep and awakenings) rose from 16 per hour of sleep for 30-54 year-olds to 20 per hour of sleep for 61-70 year-olds[7].

These age-related trends are seen in the sleep of flight crewmembers, both on the ground and in the air[2,8]. A study of in-flight sleep on delivery flights of B-777 aircraft (from Seattle to Singapore or Kuala Lumpur) found that age was the factor that most consistently predicted the quality and duration of bunk sleep. Older pilots took longer to fall asleep, obtained less sleep overall, and had more fragmented sleep.

It is not yet clear whether these age-related changes in sleep reduce its effectiveness for restoring waking function. Laboratory studies that experimentally fragment sleep are typically conducted with young adults. On the flight deck, experience (both in terms of flying skills and knowing how to manage sleep on trips) could help reduce potential fatigue risk associated with age-related changes in sleep.

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4 Signal, T.L., Gale, J., and Gander, P.H. (2005) Sleep Measurement in Flight Crew: Comparing Actigraphic and Subjective Estimates of Sleep with Polysomnography. *Aviation Space and Environmental Medicine* 76(11):1058-1063

5 Rosekind, M.R., Graeber, R.C., Dinges, D.F., et al., (1994) Crew Factors in Flight Operations IX: Effects of planned cockpit rest on crew performance and alertness in long haul operations. NASA Technical Memorandum 108839, Moffett Field: NASA Ames Research Center.

6 Mumm, J.M., Signal, T.L., Rock, P.B., Jones, S.P., O'Keeffe, K.M., Weaver, M. R., Zhu, S., Gander, P.H., Belenky, G. (2009) Sleep at simulated 2438 m: effects on oxygenation, sleep quality, and post-sleep performance. *Aviation, Space, and Environmental Medicine* 80 (8):691-697.

7 Redline, S., Kirchner, H.L., Quan, S.F., Gottlieb, D.J., Kapur, V., Newman, A. (2004). The effects of age, sex, ethnicity, and sleep-disordered breathing on sleep architecture. *Archives of Internal Medicine* 164:406–418.

8 Signal, T.L., Gander, P.H., van den Berg, M. (2004) Sleep in flight during long rest opportunities. *Internal Medicine Journal* 34(3): A38.

Sleep Disorders

The quality of sleep can also be disrupted by a wide variety of sleep disorders, which make it impossible to obtain restorative sleep, even when people spend enough time trying to sleep. Sleep disorders pose a particular risk for flight crewmembers because, in addition, they often have restricted time available for sleep. It is recommended that FRMS training (Chapter Six) should include basic information on sleep disorders and their treatment, where to seek help if needed, and any requirements relating to fitness to fly.

2.2.3 Consequences of Not Getting Enough Sleep

Even for people who have good quality sleep, the amount of sleep they obtain is very important for restoring their waking function. An increasing number of laboratory studies are looking at the effects of 'trimming' sleep at night by an hour or two (known as **sleep restriction**). There are several key findings from these studies that are important for FRMS.

1. The effects of restricting sleep night after night accumulate, so that people become progressively less alert and less functional day after day. This is sometimes described as **accumulating a sleep debt**. This is a common occurrence for crewmembers (see below), for example when minimum rest periods are scheduled for several days in a row.
2. The shorter the time allowed for sleep each night, the faster alertness and performance decline. For example, one laboratory study found that spending 7 hours in bed for 7 consecutive nights was not enough to prevent a progressive slowing down in reaction time[9]. The decline was more rapid for a group of participants who spent only 5 hours in bed each night, and even more rapid for a group who spent only 3 hours in bed each night. This is described as a **dose-dependent** effect of sleep restriction.
3. The pressure for sleep increases progressively across successive days of sleep restriction. Eventually, it becomes overwhelming and people begin falling asleep uncontrollably for brief periods, known as **micro-sleeps**. During a micro-sleep, the brain disengages from the environment (it stops processing visual information and sounds). In the laboratory, this can result in missing a stimulus in a performance test. Driving a motor vehicle, it can result in failing to take a corner. Similar events have been recorded on the flight deck during descent into major airports[5].
4. Full recovery of waking function after sleep restriction can take **longer than two nights** of recovery sleep (i.e., longer than it takes the non-REM/REM cycle to recover). Indeed, chronic sleep restriction may have effects on the brain that can affect alertness and performance days to weeks later[10].
5. For the first few days of severe sleep restriction (for example, 3 hours in bed), people are aware that they are getting progressively sleepier. However, after several days they no longer notice any difference in themselves, even although their alertness and performance continues to decline. In other words, as sleep restriction continues, people become increasingly unreliable at assessing their own functional status. This finding raises a question about the reliability of subjective ratings of fatigue and sleepiness as measures of a crewmember's level of fatigue-related impairment (see Appendix B).

[9] Belenky, G., Wesensten, N.J., Thorne, D.R., et al. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *Journal of Sleep Research* 12:1-12.

[10] Rupp, T.L., Wesensten, N.J, Bliese, P.D. et al. (2009). Banking sleep: realization of benefits during subsequent sleep restriction and recovery. *Sleep* 32 (3): 311-321

6. At least in the laboratory, some people are more resilient to the effects of sleep restriction than others. Currently, there is a lot of research effort aimed at trying to understand why this is, but it is still too early for this to be applied in an FRMS (for example, by recommending different personal mitigation strategies for people who are more or less affected by sleep restriction).

In general, more complex mental tasks such as decision making and communication seem to be more severely affected by sleep loss than simpler tasks. Brain imaging studies also suggest that the brain regions involved in more complex mental tasks are the most affected by sleep deprivation and have the greatest need for sleep to recover their normal function.

Laboratory sleep restriction studies are currently the main source of information on the effects of sleep restriction. However, they have some obvious limitations. The consequences of reduced alertness and poor task performance are quite different in the laboratory than for crewmembers on duty. Laboratory studies usually look at the effects of restricting sleep at night and participants sleep in a dark, quiet bedroom. This may mean that current understanding is based on a 'best case scenario'. More research is needed on the effects of restricting sleep during the day, and on the combination of restricted sleep and poor quality sleep. Laboratory studies also focus on the performance of individuals, not people working together as a crew.

One simulation study with 67 experienced B747-400 crews has demonstrated that sleep loss increased the total number of errors made by the crew[11]. The study design was set up so that the pilot in command was always the pilot flying. Paradoxically, greater sleep loss among first officers improved the rate of error detection. On the other hand, greater sleep loss among pilots in command led to a higher likelihood of failure to resolve errors that had been detected. Greater sleep loss was also associated with changes in decision making, including a tendency to choose lower risk options, which would help mitigate the potential fatigue risk. Simulator studies like this are expensive and logistically complex to conduct properly, but they provide vital insights on the links between crewmember sleep and operational fatigue risk.

Sleep Restriction in Flight Operations

The idea of **sleep restriction** implies that there is an optimum amount of sleep that people need to obtain each night. The concept of **individual sleep need** is an area of active debate in sleep research. One way to measure sleep restriction that avoids this problem is to look at how much sleep crewmembers obtain when they are at home between trips, compared to how much sleep they obtain during trips.

Table 2.1 summarizes data on sleep restriction across different flight operations that were monitored by the NASA Fatigue Program in the 1980s[12]. In these studies, crewmembers completed sleep and duty diaries before, during, and after a scheduled commercial trip. For each crewmember, his average sleep duration per 24 hours at home before the trip was compared with his average sleep duration per 24 hours on the study trip. During night cargo and long haul trips, crewmembers often had split sleep (slept more than once in 24 hours).

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[11] Thomas, M.J.W., Petrilli, R.M., Lamond, N.A., et al. (2006). Australian Long Haul Fatigue Study. In: *Enhancing Safety Worldwide: Proceedings of the 59th Annual International Air Safety Seminar*. Alexandria, USA, Flight Safety Foundation.

[12] Gander, P.H., Rosekind, M.R., and Gregory, K.B. (1998) Flight crew fatigue VI: an integrated overview. *Aviation, Space, and Environmental Medicine* 69: B49-B60

Scheduling has undoubtedly changed since these studies, so the data in Table 2.1 are likely to be unrepresentative of the current situation in many cases. However, they indicate that sleep restriction is very common across different types of flight operations.

Table 2.1: Sleep restriction during commercial flight operations

	Short Haul	Night Cargo	Long Haul
Crewmembers averaging at least 1 hour of sleep restriction per trip day	67%	54%	43%
Crewmembers averaging at least 2 hours of sleep restriction per trip day	30%	29%	21%
Length of trip	3-4 days	8 days	4-9 days
Time zones crossed per day	0-1	0-1	0-8
Number of crewmembers studied	44	34	28

Note: The night cargo trips included a 1-2 night break in the sequence of night shifts.

Splitting long haul trips into 24 hours days is rather arbitrary, because the average duty day lasted 10.2 hours and the average layover lasted 24.3 hours.

A growing amount of evidence, from both laboratory studies and from epidemiological studies that track the sleep and health of large numbers of people across time, indicates that chronic short sleep may have negative effects on health in the long term. This research suggests that short sleepers are at greater risk of becoming obese and developing type-2 diabetes and cardiovascular disease. There is still debate about whether habitual short sleep actually contributes to these health problems, or is just associated with them. In addition, flight crewmembers as a group are exceptionally healthy compared to the general population. What is clear is that good health depends not only on good diet and regular exercise, but also on getting enough sleep on a regular basis. Sleep is definitely not a tradable commodity.

Operational Note:

Mitigation Strategies for Managing Sleep Debt

Sleep restriction is common across different types of flight operations. Because the effects of sleep restriction are cumulative, schedules must be designed to allow periodic opportunities for recovery. Recovery opportunities need to occur more frequently when daily sleep restriction is greater, because of the more rapid accumulation of fatigue.

The usual recommendation for a recovery opportunity is for a minimum of two consecutive nights of unrestricted sleep. Some recent laboratory studies of sleep restriction suggest that this may not be enough to bring crewmembers back up to their optimal level of functioning. There is evidence that the sleep-restricted brain can stabilize at a lower level of functioning for long periods of time (days to weeks).

Especially in irregular operations, procedures that allow a crewmember to continue sleeping until needed can reduce the rate of accumulation of sleep debt. For example, if an aircraft with an anticipated repair time of 0730 will not actually be ready until 11:30, then a reliable procedure that allows the crew member to continue sleeping would be beneficial. One airline has a system where the operator contacts the layover hotel to update the report time by slipping a message under the crewmember's door. The hotel provides a wakeup call one hour before pick up time.

2.3 INTRODUCTION TO CIRCADIAN RHYTHMS

Sleeping at night is not just a social convention. It is programmed into the brain by the circadian body clock, which is an ancient adaptation to life on our 24-hour rotating planet. Even very ancient types of living organisms have something equivalent, which means that circadian biological clocks have been around for several billion years.

A feature of circadian clocks is that they are light sensitive. The human circadian clock monitors light intensity through a special network of cells in the retina of the eye (this special light input pathway to the circadian clock is not involved in vision). The clock itself resides in a fairly small cluster of cells (neurons) deeper in the brain (in the suprachiasmatic nuclei (SCN) of the hypothalamus). The cells that make up the clock are intrinsically rhythmic, generating electrical signals faster during the day than during the night. However, they have a tendency to produce an overall cycle that is a bit slow – for most people the 'biological day' generated by the circadian body clock is slightly longer than 24 hours. The sensitivity of the circadian body clock to light enables it to stay in step with the day/night cycle. However, that same sensitivity to light also creates problems for crewmembers who have to sleep out of step with the day/night cycle (for example on domestic night cargo operations), or who have to fly across time zones and experience sudden shifts in the day/night cycle.

2.3.1 Examples of Circadian Rhythm

It is not possible to directly measure the electrical activity of the circadian body clock in human beings. However, almost every aspect of human functioning (physical or mental) undergoes daily cycles that are influenced by the circadian body clock. Measuring overt rhythms in physiology and behaviour is like watching the hands of an (analogue) wrist watch. The hands move around the watch face because they are driven by the time-keeping mechanism inside the watch, but they are not part of the time-keeping mechanism itself. Similarly, most circadian rhythms that can be measured, such as rhythms in core body temperature or self-rated fatigue, are driven by the circadian body clock, but they are not part of the biological time-keeping mechanism.

Figure 2.2 shows an example of circadian rhythms in core body temperature and self-rated fatigue of a 46-year old short haul crewmember monitored before, during, and after a 3-day pattern of flying on the east coast of the USA (staying in the same time zone)[13]. The crewmember had his core temperature monitored continuously and kept a sleep and duty diary, in which he noted his sleep times and rated the quality of his sleep, as well as rating his fatigue every 2 hours while he was awake (on a scale from 0 = most alert to 100 = most drowsy).

[13] Gander, P.H., Graeber , R.C., Foushee, H.C., Lauber, J.K., Connell, L.J. (1994). *Crew Factors in Flight Operations II: Psychophysiological Responses to Short-Haul Air Transport Operations.* NASA Technical Memorandum #108856. Moffett Field: NASA Ames Research Center.

Core body temperature typically fluctuates by about 1˚C across the 24-hour day. Note that the crewmember's core temperature starts to rise each morning before he wakes up. In effect, his body is beginning to prepare ahead of time for the greater energy demands of being more physically active. (If body temperature only began to rise after he started to be more physically active, it would be a lot harder to get up in the morning).

Looking at his self-rated fatigue, this crewmember did not feel at his best first thing in the morning. He tended to feel least fatigued about 2-4 hours after he woke up, after which his fatigue climbed steadily across the day. The dashed line across the sleep period indicates that he was not asked to wake up every 2 hours to rate his fatigue across this time.

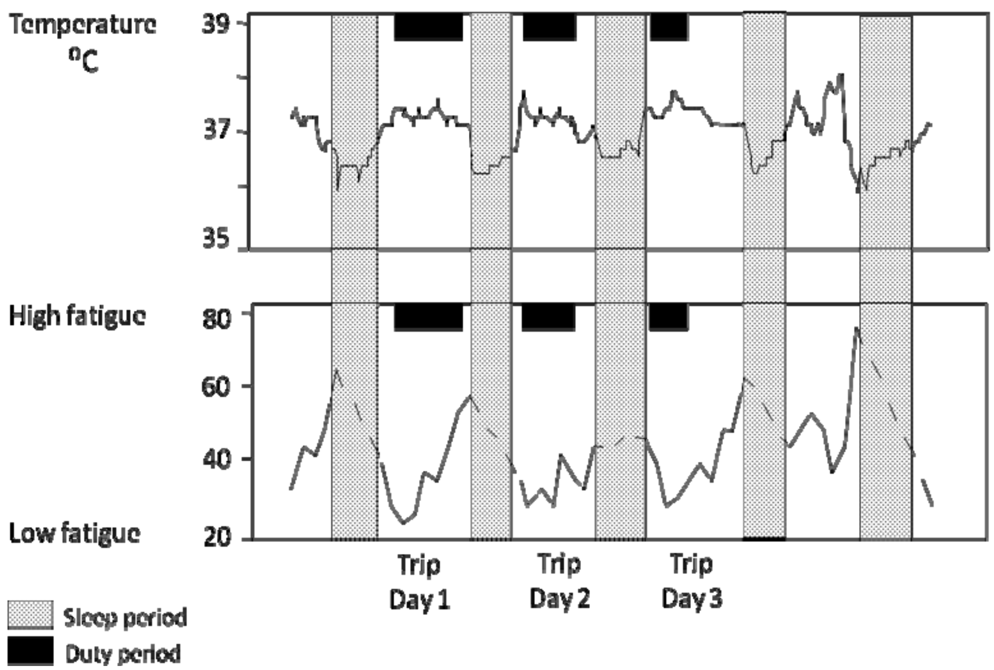

Figure 2.2: Circadian rhythms of a short haul pilot

Core body temperature is often use as a marker rhythm to track the cycle of the circadian body clock because it is relatively stable and easy to monitor. However, no measurable rhythm is a perfect marker of the circadian body clock cycle. For example, changes in the level of physical activity also cause changes in core temperature, which explains the small peaks and dips in temperature in Figure 2.2.

The daily minimum in core body temperature corresponds to the time in the circadian body clock cycle when people generally feel most sleepy and are least able to perform mental and physical tasks. This is sometimes described as the **Window of Circadian Low (WOCL)**.

2.3.2 The Circadian Body Clock and Sleep

As mentioned in Section 2.2, the circadian body clock influences sleep in a number of ways. (It has connections to centers in the brain that promote wakefulness and to opposing centers that promote sleep, as well as to the system that controls REM sleep.) Figure 2.3 is a diagram that summarizes the effects of the circadian clock on sleep. It is based on data collected from 18 night cargo pilots on their days off, i.e., when they were sleeping at night[14]. Like the crewmember in Figure 2.2, they also had their core temperature monitored continuously, and kept sleep and duty diaries.

The core temperature rhythm is summarized as a simple (continuous) curve. The daily time of the minimum in temperature (shown by the black dot) is the average for all crewmembers and is used as a reference point for describing the other rhythms. Note that changes in temperature are not the cause of the other rhythms. The core body temperature rhythm is being 'read' like the hands of an analogue wrist watch, as a way of following the underlying cycle of the circadian body clock.

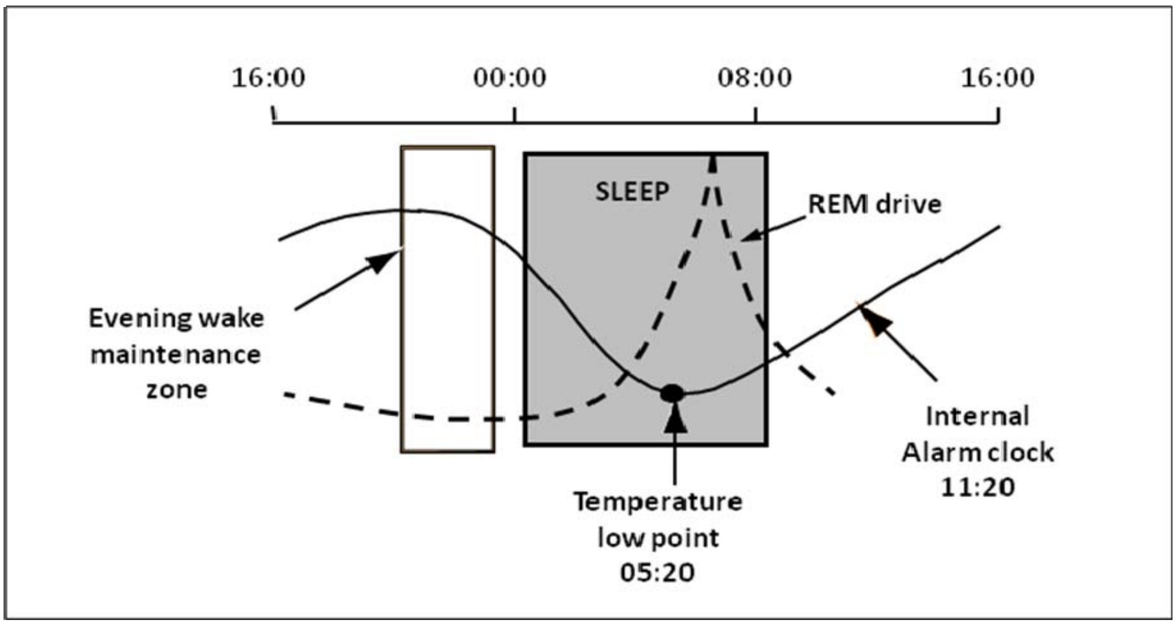

Figure 2.3: Summary of the influences of the circadian body clock on sleep at night

[14] Gander, P.H., Rosekind, M.R., and Gregory, K.B. (1998) Flight crew fatigue VI: an integrated overview. *Aviation, Space, and Environmental Medicine* 69: B49-B60

Figure 2.3 summarizes the following features of sleep at night (when crewmembers are fully adapted to the local time zone).

- Sleep normally begins about 5 hours before the minimum in core body temperature.
- Wakeup normally occurs about 3 hours after the minimum in core body temperature.
- REM sleep is entered fastest, and REM periods are longest and most intense, just after the minimum in core body temperature. This is sometimes described as the peak of the circadian rhythm in REM propensity (the dashed curve in Figure 2.3).
- A variety of laboratory protocols have demonstrated people are extremely unlikely to fall asleep 6-8 hours before the minimum in core body temperature. This has become known as the evening wake maintenance zone.
- Laboratory studies also show that as body temperature begins to rise, there is an increasing pressure to wake up. This peaks about 6 hours after the circadian temperature minimum. This is sometimes referred to as an internal alarm clock, because it is very hard to fall asleep or stay asleep during this part of the circadian body clock cycle.

The interaction between the homeostatic pressure for sleep and the circadian variation in sleepiness driven by the body clock results in **two times of peak sleepiness in 24 hours**;

- A peak in the early hours of the morning – the so-called Window of Circadian Low (WOCL), which occurs around 3-5 am for most people; and
- A peak in the early afternoon - sometimes called the afternoon nap window (around 3-5 pm for most people). Restricted sleep at night, or disturbed sleep makes it harder to stay awake during the next afternoon nap window.

The precise timing of the two peaks in sleepiness is different in people who are **morning types** (whose circadian rhythms and preferred sleep times are earlier than average) and **evening types** (whose circadian rhythms and preferred sleep times are later than average). Across the teenage years, most people become more evening-type. Across adulthood, most people become more morning-type. This progressive change towards becoming more morning-type has been documented in flight crewmembers across the age range 20-60 years.

The combined effects of the homoeostatic pressure for sleep and the circadian biological clock can be thought of as defining 'windows' when sleep is promoted (the early morning and afternoon times of peak sleepiness) and 'windows' when sleep is opposed (the time of the internal alarm clock in the late morning, and the evening wake maintenance zone).

Operational Note:

The Circadian Body Clock, Sleep, and FRMS

- The daily minimum in core body temperature corresponds to the time in the circadian body clock cycle when people feel most sleepy and are least able to perform mental and physical tasks. This is sometimes called the **Window of Circadian Low (WOCL)** and it is a time of high risk for fatigue-related error. In FRMS incident investigations, it is important to estimate the time that errors occur relative to the expected time of the WOCL. The **WOCL** can occur in flight during domestic night operations and during long haul and ULR operations when the duty/rest cycle is out of step with crewmembers' circadian body clock cycles.

- The evening wake maintenance zone occurs in the few hours before usual bedtime. This makes it very difficult to fall asleep early the night before an early duty report time. This has been identified a cause of restricted sleep and increased fatigue risk in short haul operations that require early starts.
- The increasing drive for wake that accompanies the increase in core body temperature in the morning makes it difficult to fall asleep or stay asleep later in the morning and in the early afternoon. This has been identified as a cause of restricted sleep and increased fatigue risk in night cargo operations, which require crewmembers to delay their main sleep period until the morning.
- The internal alarm clock and the evening wake maintenance zone can also interfere with the in-flight sleep and layover sleep of long haul and ULR crewmembers when the duty/rest cycle is out of step with crewmembers' circadian body clock cycles.

2.3.3 Sensitivity of the Circadian Body Clock to Light

At the beginning of this Chapter, there was a brief description of how the circadian body clock is able to track light intensity in the environment. This enables it to stay in step with the day/night cycle, even although it has a tendency to generate a 'biological day' that is slightly longer than 24 hours.

The effect of light on the circadian body clock changes according to when in the clock cycle the light exposure occurs. For a crewmember adapted to local time and sleeping at night:

- light exposure in the morning (after the temperature minimum) causes the circadian clock to speed up temporarily, resulting in a phase advance (equivalent to crossing time zones in an eastward direction);
- light exposure in the middle of the day has very little effect; and
- light exposure in the evening (before the temperature minimum) causes the circadian clock to slow down temporarily, resulting in a phase delay (equivalent to crossing time zones in a westward direction).

Bright light causes bigger shifts in the circadian body clock cycle than dim light, and the clock is particularly sensitive to blue light.

In theory, this means that just the right amount of light exposure at the same time every morning would speed up a 24.5-hour circadian clock cycle just enough to synchronize it to exactly 24 hours. In practise, staying in step with the day/night cycle is more complex than this. In modern industrialised societies, people have very haphazard exposures to light, particularly bright outdoor light. In addition, the circadian body clock is sensitive to other time cues from the environment, notably social cues, and can also be moved backwards or forwards in its cycle by bouts of physical activity.

The ability of the circadian clock to 'lock on' to the 24-hour day/night cycle is a key feature of its usefulness for most species, enabling them to be diurnal or nocturnal as needed to enhance their survival. However, it has become a disadvantage in the 24/7 society because it causes the human circadian body clock to resist adaptation to any pattern other than sleep at night.

2.3.4 Shift Work

From the perspective of human physiology, shift work can be defined as any duty pattern that requires a crewmember to be awake during the time in the circadian body clock cycle that they would normally be asleep.

The further sleep is displaced from the optimum part of the circadian body clock cycle, the more difficult it becomes for crewmembers to get adequate sleep (i.e., the more likely they are to experience sleep restriction). For example, crewmembers flying domestic night cargo operations are typically on duty through most of the optimum time for sleep in the circadian body clock cycle. This happens because the circadian body clock is 'locked on' to the day/night cycle, and does not flip its orientation to promote sleep during the day when crewmembers are flying at night.

Figure 2.4 summarises what happened to the circadian biological clock and sleep when the night cargo crewmembers in Figure 2.3 were flying at night and trying to sleep in the morning. (Recall that they had their core temperature monitored continuously across 8 day-trip patterns, and kept sleep and duty dairies.)

The core temperature rhythm is summarized as a simple (continuous) curve. Looking back at Figure 2.3, when these crewmembers were off duty and sleeping at night, the average time of the temperature minimum was 05:20. In Figure 2.4, when they were working through the night, the average time of the temperature minimum shifted to 08:08 (a delay of 2 hours 48 minutes). This confirms that the circadian body clock did not adapt fully to night duty (which would have required a shift of about 12 hours).

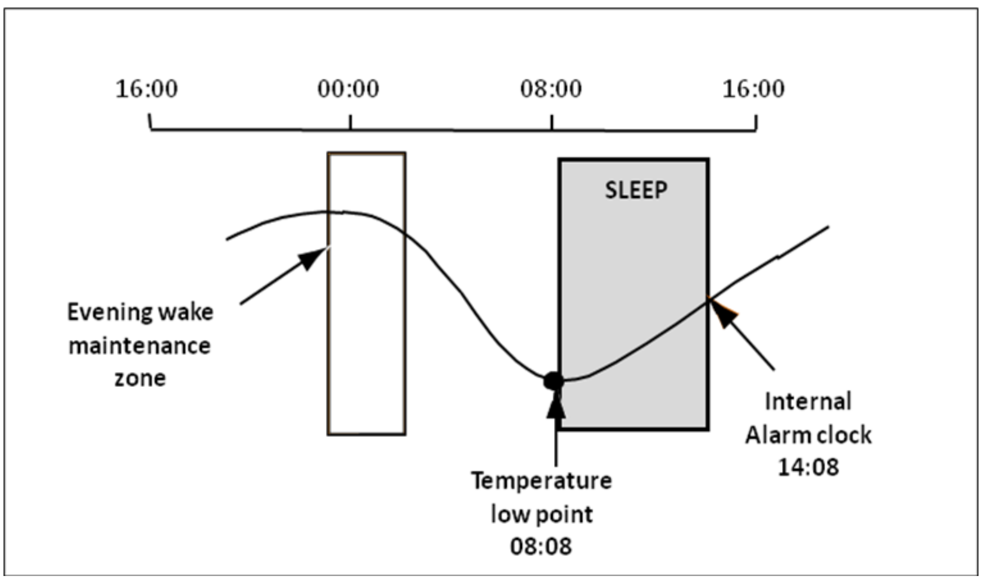

Figure 2.4: The circadian body clock and sleep after night duty

The incomplete adaptation of the circadian clock forced crewmembers to sleep in a different part of the circadian body clock cycle after night duty.

- At home before the trip (Figure 2.3), they went to sleep about 5 hours before the temperature minimum and woke up about 3 hours after the temperature minimum.
- After night duty (Figure 2.4), they went to sleep close to the circadian temperature minimum and woke up about 6 hours later. The average time of waking up after morning sleep periods was 14:13. The predicted time of the **internal alarm clock** (6 hours after the temperature minimum) was 14:08. Crewmembers were not asked what woke them up, but they rated themselves as not feeling well-rested after these restricted morning sleep episodes.

Another consequence of the incomplete adaptation of the circadian body clock to night duty was that crewmembers were often operating the last flight of the night in the Window of Circadian Low (WOCL) when they would be expected to be sleepy and having to make additional effort to maintain their performance. No fatigue-related incidents were observed on these flights (all crews were accompanied by a flight deck observer). However, all flights were routine, i.e., there were no operational events that tested the capacity of these crewmembers to respond to non-routine situations.

Operational Note:

Mitigation Strategies for Night Duty

- Night duty forces crewmembers to sleep later than normal in their circadian body clock cycle. This means that they have a limited amount of time to sleep before the circadian body clock wakes them up. Consequently, they need to get to sleep as soon as possible after coming off duty.
- Getting off duty earlier increases the time available for sleep in the morning, before the circadian body clock makes it difficult for crewmembers to stay asleep.
- Napping before going on duty is beneficial to help maintain alertness and performance through to the end of the night
- Napping during the duty period (for example, on the ground while aircraft are being loaded and unloaded) is beneficial to help maintain alertness and performance through to the end of the night. The napping opportunity should be limited to 40-45 minutes, with an additional 10-15 minutes allowed to ensure that sleep inertia (if any) has dissipated.
- In some operations, it may be possible to schedule a longer sleep opportunity during the night, for example during loading and unloading of freight, or during continuous duty overnight periods. Providing a sleeping room away from the aircraft and protected time to sleep would increase the amount of sleep that crewmembers are able to obtain. Once again 10-15 minutes allowed, to ensure that sleep inertia (if any) has dissipated.

2.3.5 Jet Lag

Flying across time zones exposes the circadian body clock to sudden shifts in the day/night cycle. Because of its sensitivity to light and (to a lesser extent) social time cues, the circadian body clock will eventually adapt to a new time zone. Studies with participants flown as passengers have identified a number of factors that affect the rate of adaptation to a new time zone. These factors include the following.

1. The number of time zones crossed - adaptation generally takes longer when more time zones are crossed.
2. The direction of travel - adaptation is usually faster after westward travel than after eastward travel across the same number of time zones.
   a) This probably reflects the fact that most people have a circadian body clock that has an innate cycle slightly longer than 24 hours, which makes it easier to lengthen the cycle to adapt to a westward shift (a phase delay).
   b) After eastward flights across 6 or more time zones, the circadian body clock may adapt by shifting in the opposite direction, for example shifting 18 time zones west rather than 6 time zones east. When this happens some rhythms shift eastward and others westward (known as resynchronization by partition) and adaptation can be particularly slow.
3. Rhythms in different functions can adapt at different rates, depending on how strongly they are influenced by the circadian body clock.
   a) This means that during adaptation to the new time zone, rhythms in different body functions can be disturbed from their usual relationships to one another.
4. Adaptation is faster when the circadian body clock is more exposed to the time cues that it needs to lock onto in the new time zone. This relates to the extent to which people adopt the pattern of sleep, eating etc, in the new time zone and the amount of time they spend outdoors in the first few days.
5. Beginning a trip with a sleep debt seems to increase the duration and severity of jet lag symptoms.

During the period of adaptation to the new time zone, common symptoms include wanting to eat and sleep at times that are out of step with the local routine, problems with digestion, degraded performance on mental and physical tasks, and mood changes.

The situation for long haul and ultra-long range flight crew is different to that for the passenger who plans to spend long enough at the destination to adapt fully to local time. Typically, layovers in each destination last only 1-2 days, after which crewmembers are asked to operate a return flight or additional flights in the destination region, followed by the return flight(s) to their city of origin. This means that the circadian body clock does not have enough time to adapt to any of the destination time zones. In addition, the combination of a long duty day followed by 1-2 day layovers gives a duty/rest cycle that does not follow a regular 24-hour pattern, so the circadian body clock cannot lock on to the duty/rest cycle.

Relatively few studies have tracked the circadian body clock across commercial long-haul trip patterns and none have tracked it across ULR operations. Figure 2.5 depicts data from one NASA study conducted in the mid-1980s on B747 200/300 operations (3-person crews consisting of a pilot in command, first officer, and flight engineer) [15]. Similar trip patterns are still being flown by some operators but with an additional pilot, not a flight engineer. Participants had their core body temperature monitored continuously and kept sleep and duty diaries before, during, and after this trip, which included 4 trans-Pacific flights plus one round trip within Asia (NRT-SIN-NRT). The dots on the graph indicate the time of the temperature minimum (averaged for 6 crewmembers per day).

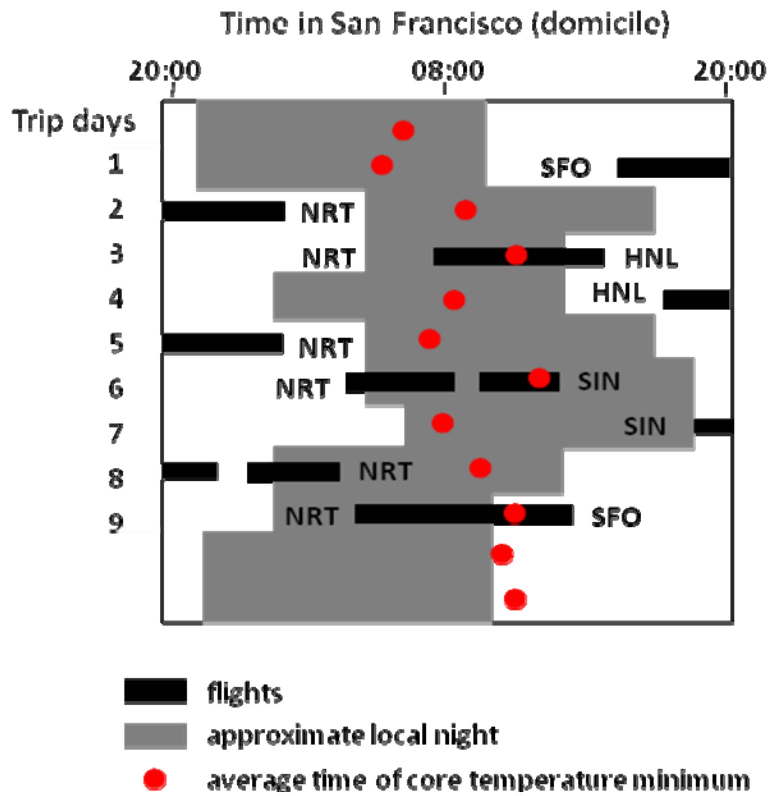

Figure 2.5: Study tracking the circadian body clock across multiple trans-Pacific flights

By the end of this trip pattern, the temperature minimum had delayed by about 4.5 hours, giving an average drift rate of about 30 minutes per 24 hours (or an average cycle length of the circadian body clock of about 24.5 hours). The drift presumably was the result of the fact that the circadian body clock did not have any 24-hour time cues to lock on to, with the non-24 hr duty/rest cycle and every layover in a different time zone.

One consequence was that the temperature minimum (corresponding to the **Window of Circadian Low** or **WOCL**) sometimes occurred in flight, for example on the last flight from NRT to SFO. At these times, crewmembers would be expected to be sleepy and having to make additional effort to maintain their performance. This would be an ideal time to take an in-flight nap (crewmembers did not have in-flight sleep opportunities on this trip).

Another consequence was that when crewmembers returned home, their circadian body clocks were on average 4.5 hours delayed with respect to local time and took several days to readapt.

Layover Sleep Patterns on Long-Haul and ULR Trips

The fact that long haul and ULR crewmembers seldom stay long enough in any destination time zone to become adapted to local time has effects on their layover sleep. Often, crewmembers split their sleep, having one sleep period on local night and another corresponding to local night in their home time zone, which overlaps the preferred part of the circadian body clock cycle for sleep (at least for the first 24-48 hours in a new time zone).

Another factor affecting layover sleep, particularly for un-augmented crews who do not have the opportunity for in-flight sleep, is that long haul duty days are often associated with extended periods of waking. For example, in a series of long haul trips studied by the NASA Fatigue Program the average period of waking associated with a duty day was 20.6 hours (the average length of a duty period was 9.8 hours)[13]. Across these long periods of waking, **the homeostatic pressure for sleep** builds so that crewmembers tend to sleep, at least for a short time, soon after arrival at the destination layover hotel. For example, this is a common pattern after eastward night flights across multiple time zones. A short sleep is taken soon after arrival, during the local afternoon, and then the main sleep period is then taken during local night.

FRMS training for long haul and ULR crewmembers needs to include discussion of the effects of trans-meridian flights on the circadian body clock and sleep. One way to reduce the complexity of this material is to develop specific guidance for sleep and the use of personal fatigue mitigation strategies on different routes.

Operational Note:

Effects of Different Types of Long Haul Trip Patterns on the Circadian Body Clock

Relatively few studies have tracked the circadian body clock across long haul trip patterns, and many are over 20 years old. The available studies suggest that different types of trip patterns affect the circadian body clock in different ways.

- Sequences of back-to-back trans-meridian flights (separated by 24 hour layovers) that do not return to the domicile time zone for long periods of time (such as the pattern illustrated in Figure 2.5) tend to cause the circadian body clock to drift on its innate cycle, which is typically slightly longer than 24 hours. This is probably because these trips contain no regular 24-hour pattern to which the circadian body clock can synchronize. When they arrive back in their home time zone, crewmembers need additional days to readapt to local time.

- Sequences of out-and-back transmeridan flights (separated by 24 hour layovers) that return to the home time zone on alternate layovers seem to enable the circadian body clock to remain synchronized to the home time zone. For example, a trip pattern studied by the NASA Fatigue Program involved three back-to-back return flights between the US West Coast and London (6 flights in total) with 24-hour layovers between each flight. Returning to their home time zone on every second layover appeared to keep crewmembers' circadian body clocks (monitored by the core temperature rhythm) synchronized to West Coast time. As a result, crewmembers obtained relatively good sleep on the West Coast layovers and did not need additional days to readapt to West Coast time at the end of the trip.
- There is some evidence that when crewmembers stay longer in the destination region, for example doing several days of local flying with minimal time zone changes before flying the long haul trip home, their circadian body clocks begin to adapt to the destination time zone. This may improve layover sleep. On the other hand, when they arrive back in their home time zone, they need additional days to readapt to local time.

The scarcity of data on what happens to the circadian body clock across different long haul trip patterns is one reason most current bio-mathematical models do not have a validated approach for simulating what happens to the circadian clock across sequences of trans-meridian flights (see Chapter Four).

2.4 SUMMARY OF ESSENTIAL SCIENCE FOR FRMS

Discoveries in sleep science and circadian rhythms provide a strong scientific basis for FRMS. The science does not address every detailed operational question and it never will. In other words, there will always be a need to combine operational experience and scientific knowledge to come up with workable controls and mitigations to manage fatigue risk in an FRMS.

The scientific basis for FRMS can be continuously improved if data that are routinely collected as part of FRM processes (Chapter Four) and FRMS Assurance processes (Chapter Five) can be shared in appropriate ways in the public domain.

Operational Note:

Key Facts about Sleep

Sleep is vital for recovery from fatigue. Two aspects of sleep are important – the amount of sleep and the quality of sleep.

Amount of Sleep

- Sleep restriction is common in flight operations.
- Not getting enough sleep leads to: feeling sleepier, difficulty staying alert, getting irritable, slower reactions, poorer coordination, slower thinking, getting fixated on part of a problem and losing the big picture (loss of situation awareness), less creative problem solving, and reduced memory consolidation (impaired learning).
- The effects of restricted sleep accumulate:
  - the rate of accumulation of fatigue is related to the rate of sleep loss (less sleep per day = more rapid accumulation of fatigue);
  - sleep pressure eventually becomes uncontrollable, which results in unintentional sleep (micro sleeps or unintended naps).

- Lost hours of sleep do not need to be recovered hour-for-hour.
- At least two consecutive nights of unrestricted sleep are required to recover from the cumulative effects of multiple nights of restricted sleep. Unrestricted sleep means being free to fall asleep when tired and wake up spontaneously, with sleep occurring at the appropriate time in the cycle of the circadian body clock. In some cases, this recovery period can be built into schedules (for example with short day time duty periods).
- Controlled napping can temporarily relieve the symptoms of sleep loss. It is a valuable personal mitigation strategy, for example prior to a night duty period or on long haul flights.
  - A NASA study of flight deck napping showed improved alertness at the end of unaugmented long haul flights (8-9 hrs) when flight crew members were given a 40-min nap opportunity in their flight deck seat

Quality of Sleep

- Good quality sleep involves regular cycles through two different types of sleep – Rapid Eye Movement sleep (REM sleep) and non-REM sleep. A full non-REM/REM sleep cycle takes roughly 90 minutes.
- Sleep that is fragmented by multiple awakenings, or arousals into lighter stages of sleep, breaks up the non-REM/REM cycle and is less restorative than continuous sleep.
  - Sleep in onboard crew rest facilities is lighter and more fragmented than sleep in hotels or at home. This does not appear to be an effect of altitude.
- Both flight deck naps and in-flight sleep in crew rest facilities contain very little deep non-REM sleep (known as slow-wave sleep), so sleep inertia is less likely after in-flight sleep than is predicted by laboratory studies.

Two main physiological processes interact to regulate sleep

1. The homeostatic sleep process is evident in the pressure for slow-wave sleep that builds up across waking and discharges across sleep.
2. The circadian body clock regulates the timing of REM sleep and dictates the preference for sleep at night.

The interaction between the homeostatic pressure for sleep and the circadian body clock results in two times of peak sleepiness in 24 hours:

- A peak in the early afternoon (the afternoon nap window) that occurs around 3-5 pm for most people; and
- A peak in the early hours of the morning (the window of circadian low or WOCL) that occurs around 3-5 am for most people.

Note: These two processes are the main components in most of the bio-mathematical models that are used to predict crewmember fatigue levels (see Chapter Four)

Operational Note:

Key Facts about the Circadian Body Clock

- The circadian body clock is a pacemaker in the brain that is sensitive to light through a specialized input pathway from the eyes (separate from vision).
- The circadian biological clock generates an innate ‘biological day’ that is slightly longer than 24 hours for most people. Its sensitivity to light enables it to stay in step with the 24-hour day/night cycle.
- Almost every aspect of human functioning (physical or mental) undergoes daily cycles that are influenced by the circadian body clock.

- The daily minimum in core body temperature corresponds to the time in the circadian body clock cycle when people feel most sleepy and are least able to perform mental and physical tasks. This is sometimes called the Window of Circadian Low (WOCL) and it is a time of high risk for fatigue-related error.

Shift Work

- Shift work can be defined as any duty pattern that requires a crewmember to be awake during the time in the circadian body clock cycle that they would normally be asleep.
- The ability of the circadian clock to 'lock on' to the 24-hour day/night cycle makes it resist adaptation to any pattern other than sleep at night.
- The fact that the circadian body clock does not adapt fully to altered sleep/wake patterns has two main consequences;
  - duty days that overlap crewmembers' usual sleep times (particularly all-night operations) tend to cause sleep restriction; and
  - crewmembers who are working through the window of circadian low (WOCL) can be expected to be sleepy and have to make additional effort to maintain their performance.
- The further sleep is displaced from the optimum part of the circadian body clock cycle, the more difficult it becomes for crewmembers to get adequate sleep.
- In scheduling, the frequency of recovery breaks (at least 2 consecutive nights of unrestricted sleep) needs to reflect the rate of accumulation of sleep debt

Jet Lag

- Flying across time zones exposes the circadian body clock to sudden shifts in the day/night cycle. Because of its sensitivity to light and (to a lesser extent) social time cues, the circadian body clock will eventually adapt to a new time zone.
- The rate of adaptation depends on the number of time zones crossed, the direction of travel (faster after westward flights) and the extent to which the circadian body clock is exposed to the 24-hour cues in the new time zone (outdoor light, sleeping and eating on local time, etc).
- Layovers of 24-48 hours are not long enough to allow the circadian body clock to adapt to local time.
- Different types of long haul trip patterns affect the circadian body clock in different ways.
  - Sequences of back-to-back trans-meridian flights that do not return to the domicile time zone for long periods of time tend to cause the circadian body clock to drift on its innate cycle. On return to the home time zone, additional days are needed to readapt to local time.
  - Sequences of out-and-back transmeridan flights that return to the home time zone on alternate layovers seem to enable the circadian body clock to remain synchronized to the home time zone.
  - On trips that include longer periods in the destination region, for example several days of local flying before the return flight home, the circadian body clock begins to adapt to the destination time zone. This may improve layover sleep. On the other hand, on return to the home time zone, additional days are needed to readapt to local time.
- On long haul layovers, sleep is affected by competition between physiological processes (the homeostatic sleep drive and the circadian biological clock) and a preference for sleeping during the local night.
- Route-specific recommendations for personal fatigue mitigation strategies may be useful in FRMS training for long haul and ULR crewmembers.

Operational Note:

How Much Sleep in 24 hours is Enough?

This common question is usually aimed at trying to get a 'magic number' for the minimum amount of sleep that a crewmember needs, or the minimum rest period that needs to be scheduled. From a sleep science perspective, the answer is 'it depends on many factors, including individual differences'. Some of the things it depends on are:

- Recent sleep history - one restricted sleep period is a smaller fatigue risk for a crewmember who is starting out well-rested than for a crewmember who has already accumulated a sleep debt;
- The amount of sleep a crewmember needs to be fully-rested (which varies among crewmembers);
- Whether the crewmember is likely to obtain good quality sleep during the restricted sleep period. (For example, is sleep at home, in an onboard crew rest facility, in a layover hotel? Does the sleep opportunity occur at an appropriate time in the circadian body clock cycle?);
- Whether sleep is shortened because a crewmember has to stay awake for an extended time beforehand (increasing the homeostatic pressure for sleep and the risk of micro-sleeps prior to the sleep period);
- Whether sleep is shortened because a crewmember has to stay awake for an extended time afterwards (increasing the homeostatic pressure for sleep and the risk of micro-sleeps prior to the next sleep period);
- Whether the crewmember will be trying to work through times of increased circadian sleep drive (the early hours of the morning and mid-afternoon when the circadian body clock is adapted to local time);
- The criticality of the tasks that a crewmember will be undertaking after the restricted sleep period;
- Other defensive strategies that are in place to manage the safety risk if that crewmember is fatigue-impaired as a result of the restricted sleep period; and
- When the opportunity will occur for recovery from the effects of the restricted sleep period (for example, is it the first in a series of restricted sleep periods, or is it followed by two unrestricted nights of recovery sleep?).

From a safety perspective, the answer is that no single defensive strategy is 100% sure. (The same desire for simplicity is a risk with bio-mathematical models that define a 'safety threshold' for crewmember fatigue. For example, there is a tendency to believe that an operation is safe if it is predicted to be below the threshold, but unsafe if it is predicted to be above it.) In an FRMS, safety comes from having a data-driven multi-layered system of defenses to manage fatigue risk, not from a reliance on simple thresholds. The FRMS answer is – measure crewmember fatigue levels, do a risk assessment and implement controls and mitigations as needed. These processes are the subject of Chapters Five and Six.

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3.0 FRMS POLICY AND DOCUMENTATION

This Chapter works through what needs to be included in an FRMS policy, and through the documentation that has to be kept to describe the FRMS and record its activities. The policy and documentation define organizational arrangements that support the core operational activities of the FRMS (the FRM processes and the FRMS safety assurance processes). The linkages between policy and documentation and other FRMS components are outlined in Figure 3.1.

The FRMS policy specifies the operator's commitment and approach to the management of fatigue risk. In some cases, it may be appropriate to include the FRMS policy in an operator's SMS policy, if this is acceptable to the regulator. However, it should be noted that ICAO Annex 6, Part I, Appendix 8 requires an operator to clearly define all elements of the FRMS in its FRMS policy. The operator's FRMS policy must be able to be distinguishable from the general SMS policy to allow separate review.

The FRMS documentation describes the components and activities of the entire FRMS. It makes it possible for the effectiveness of the FRMS to be audited (internally and externally) to check whether it is meeting the safety objectives defined in the FRMS policy. Maintaining the required documentation is one of the recommended functions of the Fatigue Safety Action Group

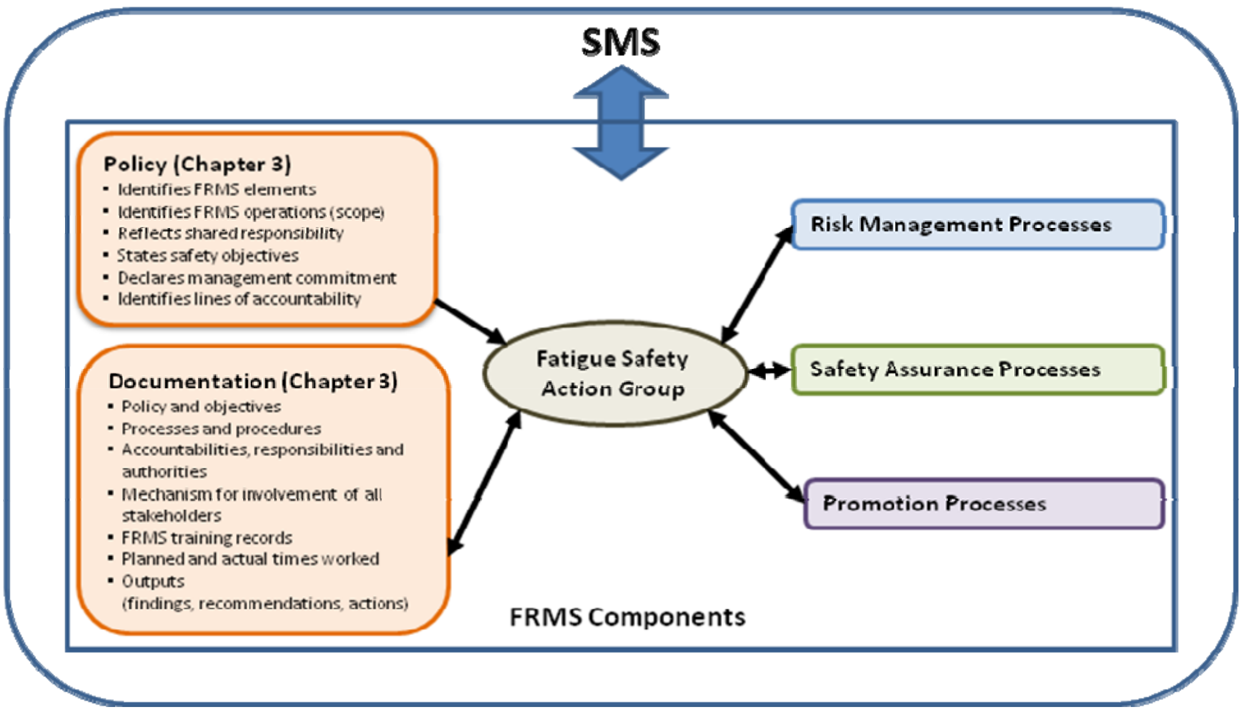


Figure 3.1: Linkages between FRMS policy and documentation and other FRMS components

Annex 6, Part I, Appendix 8

FRMS policy and documentation

1.1 FRMS policy

1.1.1 The operator shall define its FRMS policy, with all elements of the FRMS clearly identified.

1.1.2 The policy shall require that the scope of the FRMS operations be clearly defined in the Operations Manual.

1.1.3 The policy shall:

a) reflect the shared responsibility of management, flight and cabin crews, and other involved personnel;
b) clearly state the safety objectives of the FRMS;
c) be signed by the accountable executive of the organization;
d) be communicated, with visible endorsement, to all the relevant areas and levels of the organization;
e) declare management commitment to effective safety reporting;
f) declare management commitment to the provision of adequate resources for the FRMS;
g) declare management commitment to continuous improvement of the FRMS;
h) require that clear lines of accountability for management, flight and cabin crews, and all other involved personnel are identified; and
i) require periodic reviews to ensure it remains relevant and appropriate.

Note: Effective safety reporting is described in Doc 9859, Safety Management Manual (SMM).

1.2 FRMS documentation

An operator shall develop and keep current FRMS documentation that describes and records:

a) FRMS policy and objectives;

b) FRMS processes and procedures;

c) accountabilities, responsibilities and authorities for these processes and procedures;

d) mechanisms for ongoing involvement of management, flight and cabin crew members, and all other involved personnel;

e) FRMS training programs, training requirements and attendance records;

f) scheduled and actual flight times, duty periods and rest periods with significant deviations and reasons for deviations noted; and

g) FRMS outputs including findings from collected data, recommendations, and actions taken.

3.2 FRMS POLICY

The FRMS policy provides the umbrella under which the FRMS operates. Annex 6, Part I, Appendix 8 states that the FRMS policy must define the elements and scope of the FRMS and lists all aspects that it must cover.

3.2.1 Scope of the FRMS

ICAO Standards recommend that States allow an operator to choose whether it will use the FRMS to manage fatigue risk in all its operations, or only in designated specific types of operations (for example, only a particular fleet, only ULR operations, etc.). All operations not covered by the FRMS must operate under the applicable prescriptive flight and duty time limits (ICAO Annex 6, Part I, 4.10)

As an operator's familiarity and experience with FRMS builds, they may wish to expand the scope of the FRMS. This could be viewed as a natural evolution of the FRMS, and both the operator and the regulator need to give consideration to the procedures that would govern expanding the scope of an FRMS. The following text boxes show examples of statements of the scope of an FRMS.

Example 1:

Airline A - large international carrier with 11 different fleet types.

> 'The FRMS for Airline A will apply to all operations as specifically identified in the Flight Operations Manual (FOM). All other operations will be conducted under the prescriptive flight and duty time regulations.'

In Example 1, the Flight Operations Manual initially lists the entire B-777 fleet and Ultra-Long Range (ULR) flights on the B-787, and only includes pilots. Subsequently, Airline A decides that it wants to add its A-330 fleet to the FRMS.

With approval from the regulator, the A-330 fleet can be added to the list in the Flight Operations Manual that identifies operations covered by the FRMS, without requiring a change to the FRMS policy statement. This change makes the Fatigue Safety Action Group responsible for establishing FRMS processes to identify fatigue hazards in the A-330 operations, assess the risks, and develop and implement controls and mitigations. FRMS safety assurance processes also need to be established to monitor the effectiveness of the FRMS in managing fatigue risk in the A-330 operations.

The addition of cabin crewmembers to the FRMS would require an amended policy statement, as follows.

> 'The FRMS for Airline A will apply to all operations as specifically identified in the Flight Operations Manual (FOM) <u>and Cabin Operations Manual (COM).</u> All other operations will be conducted under the prescriptive flight and duty time regulations.'

Example 2:

Airline B - domestic carrier operating both scheduled and charter operations with 3 fleet types. Airline B chooses to operate its charter operations under FRMS and to operate its scheduled operations under the prescriptive flight and duty time regulations.

'The FRMS for Airline B will apply to all flight crew members in all charter aircraft operations.'

Example 3:

Airline C - two airplane on-demand carrier that chooses to cover all its operations under FRMS.

'The FRMS for Airline C will apply to all flight crew members in all operations.'

3.2.2 Things that the FRMS Policy Must Cover

ICAO Annex 6, Part I, Appendix 8, Section 1.1.3 states that the FRMS policy must:

a) reflect the shared responsibility of management, flight and cabin crews, and other involved personnel;
b) clearly state the safety objectives of the FRMS;
c) be signed by the accountable executive of the organization;
d) be communicated, with visible endorsement, to all the relevant areas and levels of the organization;
e) declare management commitment to effective safety reporting;
f) declare management commitment to the provision of adequate resources for the FRMS;
g) declare management commitment to continuous improvement of the FRMS;
h) require that clear lines of accountability for management, flight and cabin crews, and all other involved personnel are identified; and
i) require periodic reviews to ensure it remains relevant and appropriate.

Management is primarily responsible for the management of fatigue risk because it controls the activities of personnel and the distribution of resources in the organization[16]. The FRMS is an organizational system that enables management to meet that responsibility. However, an FRMS can only be effective if all stakeholders are aware of their responsibilities and have the commitment, skills and resources to meet those responsibilities.

[16] ICAO Safety Management Manual (Doc 9859)

The particular nature of crewmember fatigue as a safety hazard also makes shared responsibility essential. Fatigue is affected by all waking activities, not only work demands - sometimes described as a 'whole-of-life issue' (Chapter Two). For example, crewmembers have personal responsibility because they can choose the amount of time they spend trying to sleep during available rest breaks, and choose when to use personal fatigue mitigation strategies (Chapter Four). In addition, their cooperation is vital for voluntary reporting of fatigue hazards, and when fatigue levels need to be measured for FRM processes (Chapter Four) and FRMS safety assurance processes (Chapter Five). Crewmembers' willingness to cooperate will depend on their confidence that the operator is committed to the principles of an effective safety reporting culture (Chapter One).

Like SMS, the Accountable Executive when signing the FRMS policy accepts accountability for the FRMS, either directly or through supervision and management of others, including those to whom the Accountable Executive has delegated responsibility.

The safety objectives in the FRMS policy specify what the operator wants the FRMS to achieve. To track whether the FRMS is meeting these objectives, its performance needs to be monitored. Examples of safety performance indicators and targets that can be used to measure how well the FRMS is meeting the safety objectives can be found in Chapter Four and Chapter Five.

The FRMS policy needs to be reviewed periodically by the operator, to ensure that it is adequate to meet changing operational demands. In addition, it should be subject to periodic review by the regulator.

3.3 EXAMPLES OF FRMS POLICY STATEMENTS

The following examples are intended to be used as guidance, not templates. Each operator needs to develop an FRMS appropriate their specific organizational context and operational needs.

3.3.1 FRMS Policy Statement for a Major Air Carrier

[Insert Company Name] Fatigue Risk Management Policy

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

This Fatigue Risk Management System (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:

Management is responsible for:

- 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:
    - 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 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.

Policy authorised by:

(Signed) ___________________________________
Insert Title (Accountable Executive**)**
Date: __________________________

3.3.2 FRMS Policy Statement for a Small Operator Providing Medical Evacuation Services

[Insert Company Name] Fatigue Risk Management Policy

The unique challenges that we face in our international medical evacuation operations here at **[Insert Company Name]** 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 a Fatigue Risk Management System (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 (pilots, doctors and nurses) and our support staff (e.g. crew schedulers) to ensure our fatigue risks remain acceptable.

[Insert Company Name] 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.

Management are responsible for:

- 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 Pilot, 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 our customers.

Policy authorised by:

(Signed) ____________________________________
Insert Title Accountable Executive)
Date: ___________________________

3.4 FRMS DOCUMENTATION

The documentation describes all the elements of the FRMS and provides a record of FRMS activities and any changes to the FRMS. The documentation can be centralized in an FRMS Manual, or the required information may be integrated into an operator's SMS Manual. However, it needs to be accessible to all personnel who may need to consult it, and to the regulator for audit.

ICAO Annex 6, Part I, Appendix 8 requires that an operator must develop and keep current FRMS documentation that describes and records:

a) FRMS policy and objectives;
b) FRMS processes and procedures;
c) accountabilities, responsibilities and authorities for these processes and procedures;
d) mechanisms for ongoing involvement of management, flight and cabin crew members, and all other involved personnel;
e) FRMS training program, training requirements and attendance records;
f) scheduled and actual flight times, duty periods and rest periods with significant deviations and reasons for deviations noted; and
g) FRMS outputs including findings from collected data, recommendations, and actions taken.

As a way of meeting these requirements, it is recommended that an operator create a functional group that is responsible for coordinating the fatigue management activities within the organisation. Such a group is referred to here as the Fatigue Safety Action Group. The principle functions of the Fatigue Safety Action Group are to:

- develop and maintain the FRMS documentation;
- manage the FRM processes (Chapter Four);
- contribute to the FRMS safety assurance processes (Chapter Five); and
- be responsible for the FRMS promotion processes (Chapter Six).

However, in order to ensure that the focused management of fatigue risks does not result in unintended consequences in overall risk management for a particular organisation, some of the functions of the Fatigue Safety Action Group as described here may in fact be undertaken by the SMS team or other functional groups within the organisation. Regardless of who undertakes these functions, the regulator will need to observe and monitor all of the functions required under an FRMS.

The composition of the Fatigue Safety Action Group should reflect the shared responsibility of individuals and management by including representatives of all stakeholder groups (management, scheduling staff, and crewmember representatives) and other individuals as needed to ensure that it has appropriate access to scientific and medical expertise. It should operate under Terms of Reference that are included in the FRMS documentation and which specify the lines of accountability between the Fatigue Safety Action Group and the operator's SMS.

The size and composition of the Fatigue Safety Action Group will vary for different operators, but should be related to the size and complexity of the operations covered by the FRMS, and to the level of fatigue risk in those operations. In small operators, a single individual may represent more than one stakeholder group, for example the chief pilot may also be the primary scheduler. In very small operators, there may not even be a designated Fatigue Safety Action Group, simply extra items on the Safety Meetings agenda, as long as long as all fatigue risk management activities are documented. Larger airlines will have specialized departments that interact with the Fatigue Safety Action Group.

Appendix 8, paragraph 1.2 f) also requires that significant deviations in scheduled and actual flight times, duty periods and rest periods, and reasons for those significant deviations be recorded by operators. As an initial step, the Fatigue Safety Action Group, or other appropriate entity within the organisation, will need to identify through a risk assessment process, differences between scheduled and actual flight times, duty periods and rest periods that will be considered significant within the context of their specific operations.

For example, identified significant differences may include:

1. for a particular city pair, any occasion where actual flight time exceeds planned flight time by 30 minutes;
2. for a particular trip, any occasion where actual duty time exceeds planned duty time by 60 minutes;
3. for a particular layover, any occasion where the rest period is reduced from the planned rest period by 60 minutes.

As a result, the significant deviations should be used as indicators to help identify potential fatigue hazards (discussed in Chapter Four) and may also be used to monitor the performance of the FRMS itself (Chapter Five). Further, the Fatigue Safety Action Group will also be responsible for establishing a process for monitoring such significant deviations and documenting any subsequent actions taken.

Such definitions will need to be provided to the regulator for their acceptance and it will be important that there is a clear understanding between the regulator and the operator as to what constitutes a significant deviation. The regulator may also use these to identify criteria for when the operator must notify them immediately.

3.4.1 Example of Terms of Reference for a Fatigue Safety Action Group

This example is designed to cover the needs of a large operator. This is not a template. Not all the items suggested here will be needed by every operator. Each operator needs to consider its operational and organizational profile in deciding the composition of the Fatigue Safety Action Group, its activities, and its interactions with other parts of the operator's organization.

[Insert Company Name] Terms of Reference: Fatigue Safety Action Group (FSAG)

Purpose

The Fatigue Safety Action Group (FSAG) is responsible for coordinating all fatigue risk management activities at [insert Company name]. This includes responsibility for gathering, analyzing, and reporting on data that facilitates the assessment of fatigue-related risk among flight crewmembers. The FSAG is also responsible for ensuring that the FRMS meets the safety objectives defined in the FRMS Policy, and that it meets regulatory requirements. The FSAG exists to improve safety, and does not get involved in industrial issues.

Terms of Reference

The FSAG is directly responsible to the Senior VP Flight Operations and reports through the Departmental Safety organization. Its membership will include at least one representative of each of the following groups: management, scheduling, and crewmembers, with other specialists as required.

The tasks of the FSAG are to:

- develop, implement, and monitor processes for the identification of fatigue hazards;
- ensure that comprehensive risk assessment is undertaken for fatigue hazards;
- develop, implement, and monitor controls and mitigations as needed to manage identified fatigue hazards;
- develop, implement, and monitor effective FRMS performance metrics;
- cooperate with the Safety Department to develop, implement and monitor FRMS safety assurance processes, based on agreed safety performance indicators and targets;
- be responsible for the design, analysis, and reporting of studies that measure crewmember fatigue, when such studies are needed for the identification of hazards, or for monitoring the effectiveness of controls and mitigations (such studies may be contracted out but the FSAG is responsible for ensuring that they are conducted with the highest ethical standards, meet the requirements of the FRMS, and are cost-effective);
- be responsible for the development, updating, and delivery of FRMS education and training materials (these activities may be contracted out but the FSAG is responsible for ensuring that they meet the requirements of the FRMS and are cost-effective);
- ensure that all relevant personnel receive appropriate FRMS education and training, and that training records are kept as part of the FRMS documentation;
- develop and maintain strategies for effective communication with all stakeholders;
- ensure that crewmembers and others receive response to their fatigue reports;
- communicate fatigue risks and the performance of the FRMS to senior management;
- develop and maintain the FRMS intranet site;
- develop and maintain the FRMS documentation;
- ensure that it has adequate access to scientific and medical expertise as needed, and that it documents recommendations made by these specialist advisors and the corresponding actions taken;
- keeps informed of scientific and operational advances in fatigue risk management principles and practice;
- cooperate fully with the regulator in relation to FRMS auditing; and
- manage effectively and be accountable for FRMS resources.

The FSAG will meet monthly. Minutes will be taken during meetings and distributed within 10 working days after each meeting. The FSAG will present an annual budget request in [designated part of the financial cycle] and an annual report of all expenditures.

4.0 FATIGUE RISK MANAGEMENT (FRM) PROCESSES

4.1 INTRODUCTION TO FRM PROCESSES

This Chapter works through the basic steps for setting up FRM safety risk management processes, which are very similar to SMS safety risk management processes[3]. The main difference is that SMS processes are designed to address all types of risks. FRM processes within an FRMS are specifically designed to manage the risks related to crewmember fatigue.

FRM processes (represented in the blue box in Figure 4.1 below) are one part of the day-to-day operations of the FRMS. They are designed to enable the operator to achieve the safety objectives defined in its FRMS Policy, and are managed by the Fatigue Safety Action Group (Figure 4.1).

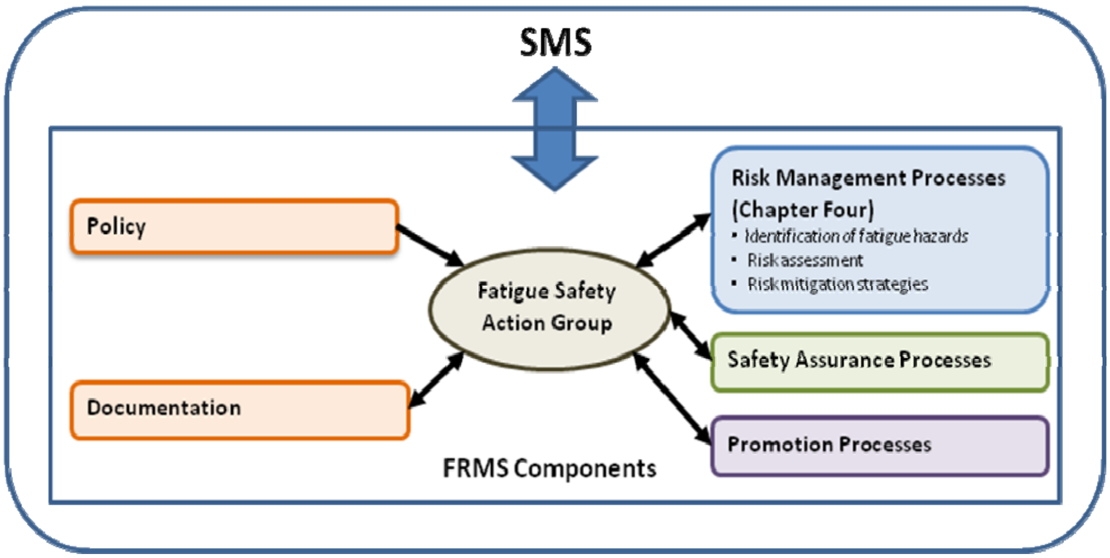


Figure 4.1 Linkages between FRM processes and other FRMS components

FRM processes need to:

1. identify where fatigue is a hazard; and
2. assess the level of risk that a given fatigue hazard represents; and
3. if necessary, put in place controls and mitigation strategies, and monitor to make sure that they manage the risk at an acceptable level.

3 See IATA Introduction to Safety Management Systems (SMS), 2nd Edition.

To do this, FRM processes require different sorts of data, including:

a) measures of the fatigue levels of crewmembers; and

b) measures of operational performance.

Examples of these types of measures are described later in this Chapter. The key is choosing the right combination of measures for each operation that is covered by the FRMS. However, just collecting data is not enough. Data analysis needs to be used to inform decisions made by the Fatigue Safety Action Group and others accountable for the FRM processes and for FRMS safety performance (Chapter Five). The ICAO requirements for FRM processes are as follows (Annex 6, Part I, Appendix 8).

Annex 6, Part I, Appendix 8

2. Fatigue risk management processes

2.1. Identification of hazards

An operator shall develop and maintain three fundamental and documented processes for fatigue hazard identification:

2.1.1. Predictive

The predictive process shall identify fatigue hazards by examining crew scheduling and taking into account factors known to affect sleep and fatigue and their effects on performance. Methods of examination may include but are not limited to:

a) operator or industry operational experience and data collected on similar types of operations;

b) evidence-based scheduling practices; and

c) bio-mathematical models

2.1.2. Proactive

The proactive process shall identify fatigue hazards within current flight operations. Methods of examination may include but are not limited to:

a) self-reporting of fatigue risks;

b) crew fatigue surveys;

c) relevant flight and cabin crew performance data;

d) available safety databases and scientific studies; and

e) analysis of planned versus actual time worked

2.1.3. Reactive

The reactive process shall identify the contribution of fatigue hazards to reports and events associated with potential negative safety consequences in order to determine how the impact of fatigue could have been minimized. At a minimum, the process may be triggered by any of the following:

a) fatigue reports;

b) confidential reports;

c) audit reports;

d) incidents; and

e) flight data analysis events

2.2. Risk assessment

An operator shall develop and implement risk assessment procedures that determine the probability and potential severity of fatigue-related events and identify when the associated risks require mitigation.

2.2.1. The risk assessment procedures shall review identified hazards and link them to:

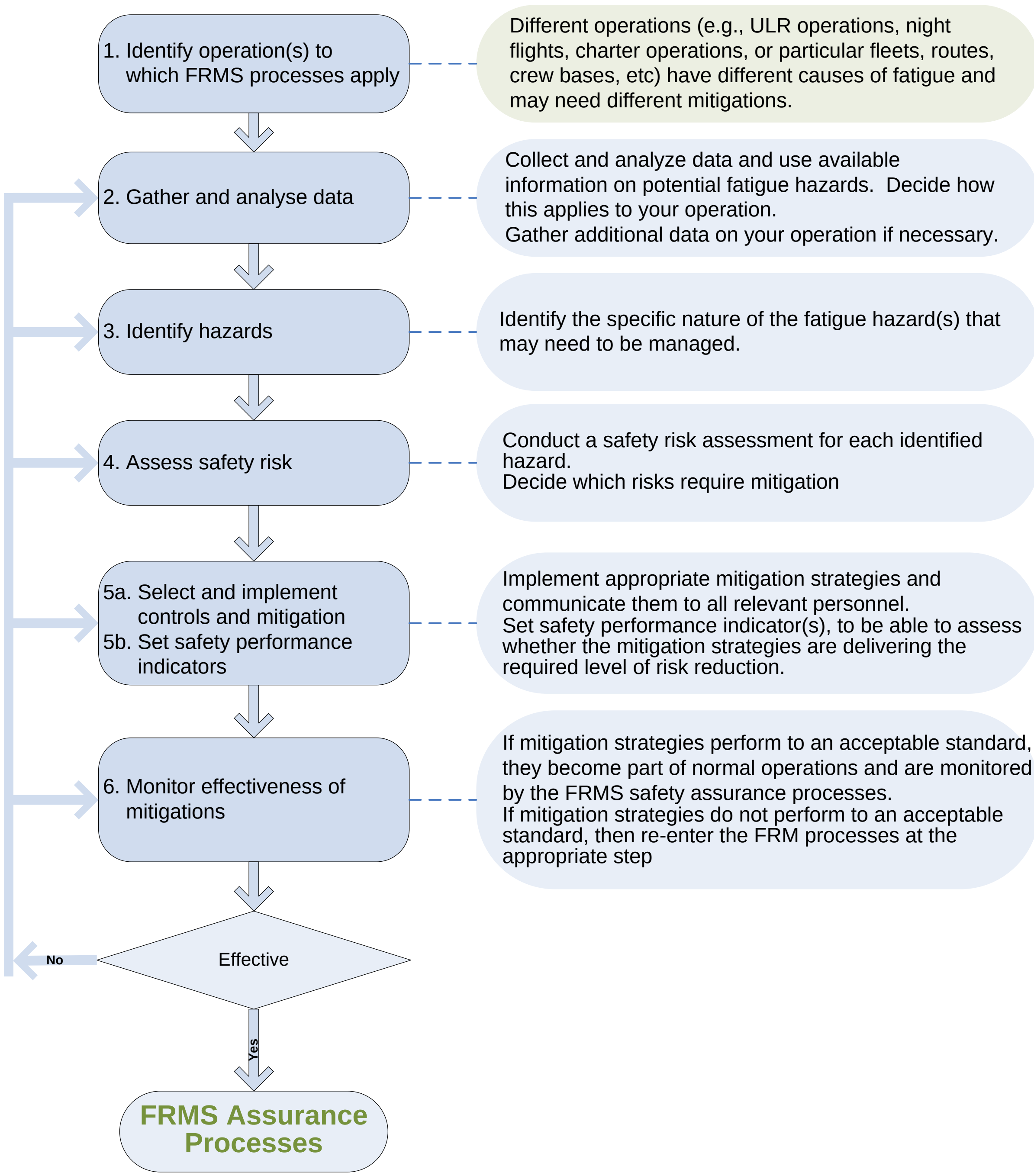
a) operational processes;
b) their probability;
c) possible consequences; and
d) the effectiveness of existing safety barriers and controls.

2.3. Risk mitigation

2.3.1. An operator shall develop and implement risk mitigation procedures that:

a) select the appropriate mitigation strategies;
b) implement the mitigation strategies; and
c) monitor the strategies' implementation and effectiveness.

Figure 4.2 – Summarizes the steps in FRM processes.



4.2 FRM PROCESSES STEP 1: IDENTIFY THE OPERATIONS COVERED

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.

Further, as described in Chapter 2, 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.

4.3 FRM PROCESSES STEP 2: GATHER DATA AND INFORMATION

In Step 2, 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 4.3 compares flight and duty times in daytime short haul, domestic night cargo, and long haul operations studied by the NASA Fatigue Program. [4]

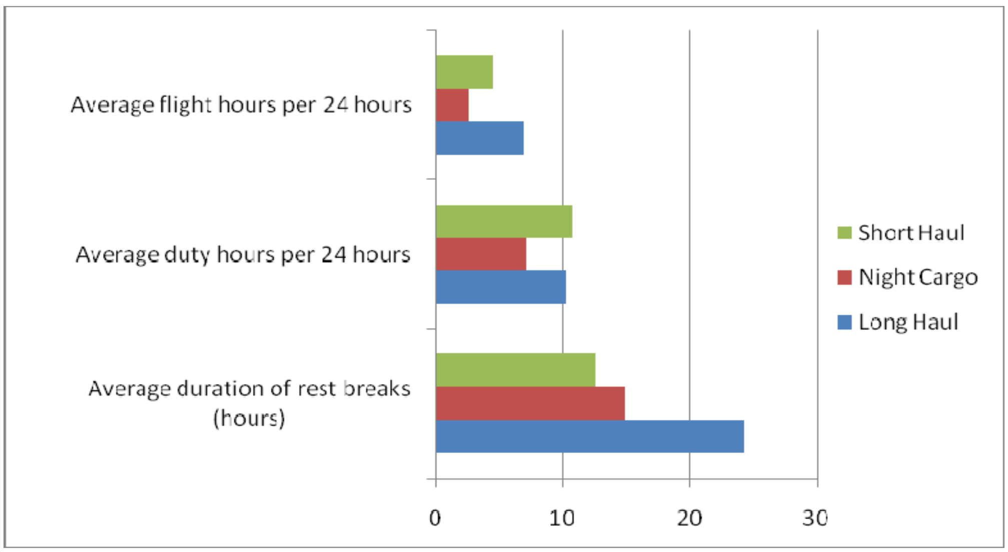


Figure 4.3:

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

[4] Gander PH, Rosekind MR, Gregory KB (1998). Flight crew fatigue IV: a synthesis. Aviation, Space and Environmental Medicine 69 (9): B49-B60.

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 pilots, 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 self-rated fatigue and mood were worst, and when additional effort would be required to maintain alertness and performance.

The long haul operations (2 pilots, 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.

Table 4.1 summarizes the different duty-related causes of fatigue identified in these studies. They pre-dated ULR flights and all involved scheduled operations. The very long duty days in ULR operations might be expected to cause fatigue, but the use of augmented crews and the availability of onboard crew rest facilities for in-flight sleep are important mitigation strategies. Unscheduled operations pose particular challenges, because it is hard to plan sleep when you do not know when you have to work, or for how long.

Table 4.1: Summary of Identified Work Related Fatigue Causes (from NASA field studies [18]

	Type of Operations		
Cause of Fatigue Hazard	Domestic Short Haul	Domestic Night Cargo	Long Haul
Restricted sleep due to short rest periods	X		
Restricted sleep due to early duty report times	X		
Multiple high workload periods across the duty day	X		
Multiple sectors	X	X	
High density airspace	X		
Long duty days	X		X
Extended wakefulness on duty days			X
High workload during circadian low		X	X
Shorter sleep periods at wrong times in the circadian cycle		X	X
Circadian disruption (due to night work)		X	X
Split sleep patterns and short sleep episodes on layovers		X	X
Circadian disruption (due to crossing multiple time zones)			X
Circadian drift (changes in circadian pattern) following extended patterns			X

Note: These are the causes of fatigue identified in these particular studies, not an exhaustive list.

Other potential causes of work-related fatigue include:

- additional tasks that are performed immediately prior to a flight or at intermediate points during a series of flights;
- high total duty time and flight time over specified periods (per month, per year), which increases the risk of cumulative fatigue;
- not having the opportunity for adequate recovery sleep after one trip (or set of consecutive duties) before starting the next trip; and
- other related tasks that crew members may be required to perform before or after flight duty, for example training activities, administrative duties, or baggage loading and unloading.

When FRM processes are being set up, it is not always necessary to go out and gather new data for Step 2. It may be possible to identify potential fatigue hazards based on information and operational experience from similar types of operations flown by the operator or other carriers, or from published scientific studies of fatigue in similar operations. This is illustrated at the end of the Chapter, in the example on how to set up FRM processes for a new ULR route.

For existing routes being moved into the FRMS, data that is already routinely collected by the operator can be analyzed to help identify fatigue hazards (from various sources), for example the use of captain's discretion, on-time performance, violations of prescriptive flight and duty time rules, level of sickness absences, and standby usage, or Aviation Safety Reports (ASR's) that mention fatigue. It should be noted that it is a requirement of the FRMS SARPs (Annex 6, Part I, Appendix 8, 1.2 g) that the operator collects data on significant deviations to scheduled and actual flight times and duty periods, with the reasons for these significant deviations (previously discussed in Chapter Three).

Once the FRM processes become fully operational, data collection and analysis are part of the operator's day-to-day function, so a range of data will be available routinely for Step 2. In addition, the Fatigue Safety Action Group may sometimes decide to undertake non-routine data collection to better understand specific fatigue hazards (for example, a one-off fatigue survey at a crew base, or a targeted monitoring study on a route where fatigue is identified as a concern). Different types of information and data that can be collected are described in the following sections and in Appendix B.

4.4 FRM Processes Step 3: Hazard Identification

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.

4.4.1 Predictive Hazard Identification Processes

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.

Note: See next page for expanded explanations of the above.

a) Previous Experience

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 (see the ULR example at the end of this Chapter).

b) Evidence-Based Scheduling Practices

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 self-rated 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.

c) Bio-Mathematical Models

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, bio-mathematical 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 (caffeine consumption, exercise, improved rest facilities, etc.);

- 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 bio-mathematical 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, evidence-based scheduling practices, and bio-mathematical models. In other words, none of these methods are required, and other methods may be used.

4.4.2 Proactive Hazard Identification Processes

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.

The Importance of Collaboration

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).

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 outside of duty hours.

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. Keep in mind that these are options - they are not all required all of the time.

a) Self-Reporting of Fatigue Risks

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. An example of a fatigue report form can be found in Appendix B.

[5] See ICAO Doc 9859 Safety Management Manual.

b) Crew Fatigue Surveys

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.

Appendix B describes 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 4.4 shows an analysis of the effects of time of day and duty length on fatigue ratings at top of descent (using the Samn-Perelli fatigue scale - see Appendix B). 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.

[6] Powell D, Spencer MB, Holland D, Petrie KJ (2008). Fatigue in two-pilot operations: implications for flight and duty time limitations. *Aviation, Space and Environmental Medicine* 79: 1047-1050.

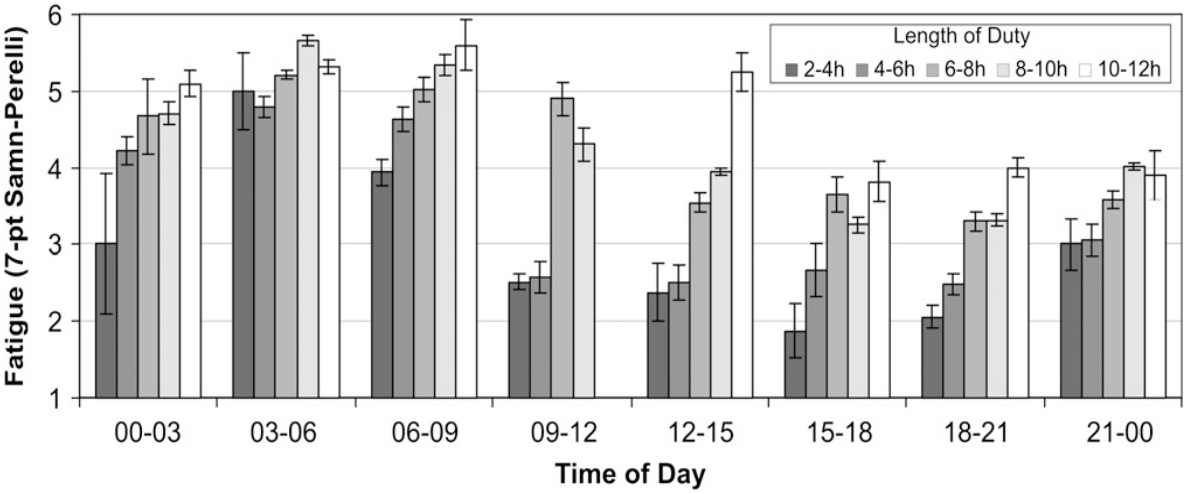


Figure 4.4: Effects of time of day and duty length on fatigue ratings at top of descent in short haul operations across a 3-month period

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.

c) Crew Performance Data

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. pilot 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 <u>during an operation</u>, 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?

Appendix B describes a performance test that is commonly used to measure crewmember fatigue – the Psychomotor Vigilance Task or PVT. [7]

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

d) Available Safety Databases and Scientific Studies

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.

A fairly large amount of scientific research has been undertaken on crewmember fatigue in flight operations. Some of this is available on the web, for example many studies from the NASA Fatigue Countermeasures Program can be downloaded fre

http://human-factors.arc.nasa.gov/zteam/fcp/FCP.pubs.html

[7] Balkin TJ, Bliese PD, Belenky G, Sing H, Thorne DR, Thomas M, Redmond DP, Russo M, Wesensten NJ (2004). Comparative utility of instruments for monitoring sleepiness-related performance decrements in the operational environment. *Journal of Sleep Research,* 13: 219-227.

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 papers have executive summaries or abstracts that outline the key findings.

e) Analysis of Planned versus Actual Time Worked

The planning of schedules and rosters based on fatigue science as well as operational requirements permits predictive identification of fatigue hazards (Section 4.4.1 above). However, numerous unforeseen circumstances can cause changes to planned schedules, for example weather conditions, volcanic ash, unexpected technical problems, or crewmember illness. Crewmember fatigue relates to what is actually flown, not what is planned. Thus another proactive approach for identifying fatigue hazards is to analyze actual schedules and rosters for factors such as on-time performance, exceedences of the flight and duty time limits specified in the FRMS, and schedule manipulation by individual crewmembers.

Monitoring Crewmembers' Sleep

Given the primary importance of sleep loss and recovery in the dynamics of crewmember fatigue, another valuable and commonly used method for proactive fatigue hazard identification is sleep monitoring.

Sleep can be monitored in a variety of ways, all of which have advantages and disadvantages (for details, see Appendix B).

- The simplest and cheapest method of monitoring sleep is to have crewmembers complete a daily sleep diary before, during, and after the trip(s) being studied. They are typically asked to record when they sleep, and to rate the quality of their sleep, as soon as possible after waking up. This can be done using a paper diary or an electronic device such as a Personal Data Assistant (PDA).
- A more objective measure of sleep/wake patterns can be obtained by continuously monitoring movement, using an "actigraph". This is a wristwatch-like device that is worn continuously (except when showering or bathing). Data on the amount of movement is recorded regularly (typically every minute) and is downloaded to a computer after several weeks, for subsequent analysis. Because actigraphs are not cheap (yet), usually only a sample of crewmembers on a given trip would have their sleep monitored in this way. Current systems also require a trained person to process and analyze the data.
- In rare cases, where the expected fatigue risk is high or uncertain (for example in new types of operations), portable polysomnographic recordings may be used to monitor sleep both in-flight and during layovers. This involves applying electrodes to the scalp and face to record electrical signals coming from the brain (electroencephalogram or EEG), eye movements (electro-oculogram or EOG) and chin muscles (electromyogram or EMG). Polysomnography is the "gold standard" method for evaluating sleep quality and quantity, but it is relatively invasive for participants and expensive both in terms of equipment and because it requires manual scoring and analysis by a trained technician.

Selecting Measures of Crewmember Fatigue

Several options have just been described for assessing crewmember fatigue levels in order to identify fatigue hazards. ICAO Annex 6, Part I, Appendix 8 is clear that the five methods it lists can be used – it does not say that they must be used, or that other methods cannot be used. The following general points are intended to help operators to decide which measures to use and when to use them.

1. Fatigue-related impairment affects many skills and has multiple causes, so there is no single measurement that gives a total picture of a crewmember's current fatigue level.
2. The most important thing to consider in choosing fatigue measures is the expected level of fatigue risk. All measures require resources (financial and personnel) for data collection and analysis. Limited resources need to be used effectively to identify fatigue hazards and to help the Fatigue Safety Action Group prioritize where controls and mitigations are most needed.
3. A core set of measures can be selected for routine monitoring. For example, crew fatigue reports and regular analysis of scheduling and rostering variations could be used for ongoing monitoring of fatigue hazards.
4. An additional range of measures can be available to be used if a potential hazard is indentified and the Fatigue Safety Action Group decides that it needs more information about that hazard. Again, the measures selected need to reflect the expected level of risk. For example:
   a) A series of complaints about a particular layover hotel prompts a brief on-line survey of crewmembers using that hotel, to see how widespread the problem is and whether it merits action.
   b) A series of fatigue reports is received about a tag flight on the end of a particular trip. This prompts monitoring of the sleep, sleepiness, and fatigue ratings of crewmembers flying that trip, using sleep dairies and subjective rating scales. Data collection continues for a month, followed by data analysis, so that within 3 months the Flight Safety Action Group will have the information it needs to reach a decision and plan any necessary controls and interventions (for example, having another crew take the tag flight).
   c) An operator with limited long haul experience gets the regulators' agreement to begin developing an FRMS in order to undertake ULR operations on a specified city pair. As part of gaining regulatory approval for the overall FRMS, the operator is required to undertake intensive monitoring of crewmember fatigue during the first 4 months of the operation. This includes monitoring sleep before, during, and after the trip using actigraphs and sleep diaries, as well as ratings of sleepiness and fatigue and PVT performance tests pre-flight, within 30 minutes of top of climb, before each in-flight rest period, within 30 minutes of top of descent, and post flight before leaving the aircraft. The regulator requires a report on the findings no later than 6 months after the launch of the operation.
5. Balance needs to be maintained between gathering enough data for the Fatigue Safety Action Group to be confident about its decisions and actions and the additional demands that data collection can place on crewmembers (sometimes described in science as 'participant fatigue').

4.4.3 Reactive Hazard Identification Processes

In an FRMS, reactive processes are designed to identify the contribution of crewmember fatigue to safety reports and events. The aim is to identify how the effects of fatigue could have been mitigated, and to reduce the likelihood of similar occurrences in the future. ICAO Annex 6, Annex 6, Part I, Appendix 8 lists five examples of triggers for reactive processes:

a) fatigue reports;
b) confidential reports;
c) audit reports;
d) incidents; and
e) Flight Data Analysis (FDA) events (also known as Flight Operations Quality Assurance or FOQA).

Depending on the severity of the event, a fatigue analysis could be undertaken by the Fatigue Safety Action Group, the operator's safety department, or an external fatigue expert. The findings of any fatigue investigation should be recorded as part of the FRMS documentation.

There is no simple test (such as a blood test) for fatigue-related impairment. To establish that fatigue was a contributing factor in an event, it has to be shown that;

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

To show that the person or crew were likely to be in a fatigued state, ideally you would have information about:

- how much sleep they need to feel fully rested; and
- how much sleep they had in the 24 hours before the accident (acute sleep loss); and
- how much sleep they had in the 72 hours before the accident (cumulative sleep debt); and
- how long they had been awake at the time of the event (extended wakefulness); and
- whether their workload was unusually heavy or light leading up to and during the event; and
- whether they were in a sleepy part of the circadian body clock cycle at the time of the event (early morning or mid-afternoon, body time); and
- when they last had the opportunity for full recovery from sleep debt (at least two nights of unrestricted sleep in a row, fully adapted to the local time zone).

This information generally has to be gathered after the event, based on the recall of the people involved, and should be confirmed where possible by anyone with whom they spent time leading up to the event. Where it is not possible to get this information, the duty history can give an idea of what opportunities the person or crew had for sleep.

There are no simple rules for interpreting this information (how much acute sleep loss do you need to be fatigue-impaired? how much cumulative sleep debt?). Transport Canada has proposed a method for fatigue investigation that provides useful guidance for answering these questions, and for deciding if the crewmember's actions or decisions are consistent with the type of behaviour expected of a fatigued person or crew, although it has not yet been validated in aviation operations. This method is summarized in Appendix B.

4.5 FRM PROCESSES STEP 4: RISK ASSESSMENT

Once a fatigue hazard has been identified, the level of risk that it poses has to be assessed and a decision made about whether or not that risk needs to be mitigated. Fatigue risk assessment follows SMS principles (combining risk probability and risk severity). It evaluates the potential for injury, equipment damage, or loss due to a fatigue hazard, and provides recommendations about management of that risk, as summarized in the following tables. [8]

Table 4.2a: Defining Fatigue Risk Probability

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

[8] IATA Introduction to Safety Management Systems (SMS), 2nd Edition. ICAO SMM (Doc 9859).

Table 4.2b: Defining Fatigue Risk Severity

Fatigue Risk Severity		
	Meaning	
Catastrophic	• Multiple deaths • Equipment destroyed	A
Hazardous	• A large reduction in safety margins, physical distress or a workload such that crewmembers cannot be relied upon to perform their tasks accurately or completely • Serious injury • Major equipment damage	B
Major	• A significant reduction in safety margins, a reduction in the ability of crewmembers to cope with adverse operating conditions as a result of increase in workload, or as a result of conditions impairing their efficiency • Serious incident • Injury to persons	C
Minor	• Nuisance • Operating limitations • Use of emergency procedures • Minor incident	D
Negligible	• No signficant consequences	E

Table 4.2C: Fatigue Risk Assessment Matrix

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

Table 4.2d: ICAO Risk Tolerability Matrix

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

However, it should be noted that these tables are provided as general examples only. In reality, each operator must develop their own criteria for levels of severity and probability. There are no right and wrong criteria, but whatever criteria are identified, they must be agreed upon and widely understood by the people who will then use them to make risk assessments. Depending on an operator's safety management structure, the Fatigue Safety Action Group may identify the severity and probability criteria, and then use these to assess the fatigue-related risks and the need for mitigation in an FRMS.

4.6 FRM PROCESSES STEP 5: RISK MITIGATION

When it is decided that a particular fatigue hazard requires action, then controls and mitigations must be identified and implemented. The specific expertise of the Fatigue Safety Action Group should be used in the selection of these controls and mitigations. All involved personnel need to clearly understand the hazard and the controls and mitigations designed to reduce the associated risk.

Table 4.3 provides some examples of organizational-level controls and mitigations for managing fatigue hazards. A control is a system defence designed to manage specific elements of fatigue risk. (ICAO SSM) Mitigation is the use of the defence. These are examples only, not exhaustive lists.

Fatigue Hazard	Controls	Mitigations
Back-to-back night flights	Scheduling rules do not permit back to-back night flights.	Software is programmed to prohibit scheduling of back-to-back night flights. Reserve crew available to cover exceptional circumstances
Lack of ULR crew in departure city base	All flights scheduled >12 hours require evaluation of staffing levels at crew base in departure city. Established crew staffing policies to support operation and monitor staffing levels to ensure that policy requirements are being met	Relocate additional crewmembers to departure city base. Ensure that sufficient reserve crews are available to support ULR flight schedules.
Lack of ULR crew in en-route divert base	Establish reserve crew staffing at en-route base to support diversions	Reserve crew call-out
Reports of inadvertent crew napping on the flight deck	Scheduling rules, trip construction, rostering, crew augmentation policies to enable in-flight rest, improved onboard crew rest facilities	Scheduling changes to improve layover sleep opportunities. Flight Operations Manual procedure for controlled flight deck napping developed
Crewmembers not getting enough sleep in onboard rest facilities	Pay attention to design of crew rest facilities when ordering aircraft. Retro-fit problem aircraft. Flight ops manual contains rules for organizing in-flight rest	Provide crewmembers with education on how to obtain optimal in-flight sleep Captain's discretion on the day allowed for organization of in-flight rest.
Interrupted sleep periods in crew hotels	Scheduling rules, trip construction, rostering	Internal procedures to restrict crew contacts during rest periods Hotels required to provide segregated crew rest hotel areas, minimizing noise
Landings at a confluence of circadian low, extended work period, and high work demands.	Scheduling rules, trip construction, rostering	Protocols for in-flight rest and controlled flight deck napping.

The effectiveness of implemented controls and mitigations must be assessed, which requires setting safety performance indicators such as the following.

Schedule-related indicators:

- Number of flight deviations (or flight completion not accomplished) on specific city pairings, due to fatigue, lack of staff, medical emergencies, etc.
- Number of bids for pairings identified as high fatigue risk (e.g. back-to-back night flights).
- Number of crew duty day exceedences into allowable excesses (as determined through risk assessment. For example, longer than 14 hours.)
- Number of flight duty periods determined to be "significantly" later than scheduled*. .
- Number of flight duty periods longer than a specified number of hours without a rest break within the duty.
- Number of flight times more than a specified number of minutes longer than planned (e.g., 30 or 60 minutes).
- Number of flight duty periods starting within window of circadian low (WOCL).
- Number of landings within the WOCL.
- Number of duty periods with more than a specified number of flight sectors.
- Number of duty periods with more than a specified number of aircraft changes.
- Number of successive early wakeups, especially combined with long "sits" between flights or long duty days.
- Number of reduced rest breaks within duties (by more than a specified number of minutes determined to be "significant")*.
- Number of reduced rest breaks between duties (by more than a specified number of minutes determined to be "significant")*.
- Number of reserve crew call-outs (on particular flights, at a particular crew base, etc).

Note: * This indicator is a specific requirement of an FRMS, (Section 1.2 f, Appendix 8, Annex 6, Part I), and is discussed in Chapter Three.

Proactive/reactive fatigue indicators:

- Measured data outside acceptable thresholds (e.g., sleepiness ratings, PVT scores, or inadequate layover sleep duration).
- Numbers of fatigue reports (sorted in many ways such as by crew base, seat, augmented flights, fleet types, operational types, etc).
- Number of fatigue-related incidents.
- Number of fatigue-related FOQA events associated with a particular schedule for which fatigue reports have been received.
- Absenteeism/fatigue calls.

The implications of such safety performance indicators need to be considered within the context of the entire operation, to distinguish between acceptable and unacceptable risk.

If the controls and mitigations perform to an acceptable standard (i.e., they bring the risk into the tolerable region – see Table 4.2d), they become part of normal operations and are monitored by the FRMS safety assurance processes. If the controls and mitigations do not perform to an acceptable standard, then it will be necessary to re-enter the FRM processes at the appropriate step. As indicated in Figure 4.2, this could require: gathering of additional information and data; and/or re-evaluation of the fatigue hazard and the associated risks;

and / or identification, implementation, and evaluation of new or revised controls and mitigations.

4.7 EXAMPLE: SETTING UP FRM PROCESSES FOR A NEW ULR ROUTE

In 2005, recommended guidelines for ULR operations were developed by a Flight Safety Foundation consortium group– the Ultra Long Range Crew Alertness Steering Committee. This group identified ULR operations as scheduled operations that exceed 16 hours. This 16-hour distinction for ULR operations has since become broadly accepted.

This example works through FRMS processes that could be used for establishing a new ULR operation (scheduled flight times in excess of 16 hours). It is developed from an actual safety case for a new ULR route that received regulatory approval, but it is an example not a recipe. The accepted approach for ULR operations is to evaluate each city pair to be flown. [9] Figure 4.5 summarizes the FRM processes, which are explained in more detail in the text.

4.7.1 Step 1 – Identify the Operation

The operation to which these FRM processes apply is a new ULR route between City A and City B (described here as the A-B-A route).

4.7.2 Step 2 – Gather Data and Information

Information and data are potentially available from two types of existing operations: long-haul operations that are similar but have flight times under 16 hours; and ULR operations already being flown by other operators. The relevance of the available information depends on how closely the existing operations resemble the proposed new ULR operation. The following factors need to be considered.

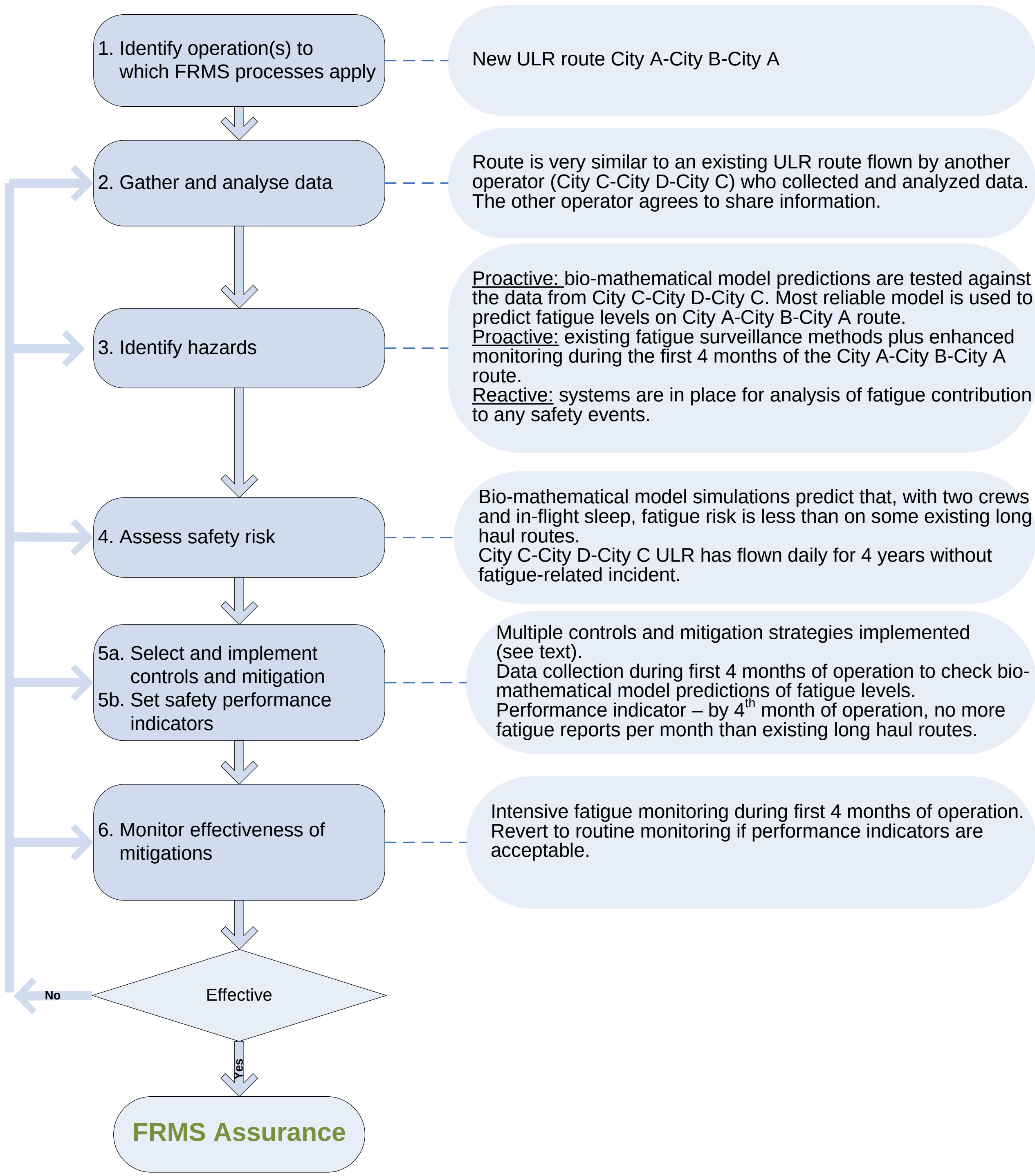
- Crew complement and facilities for in-flight rest.
- Crew domicile (if crewmembers are domiciled in the departure city and they have had sufficient time off since their last trans-meridian flight, it can be assumed that their circadian body clocks are adapted to domicile time).
- Departure time of the outbound flight (local time and likely body clock time).
- Outbound flight duration and time zones crossed.
- Arrival time of the outbound flight (local time and likely body clock time).
- Duration of the layover.
- Departure time of the return flight (local time and likely body clock time).
- Return flight duration and time zones crossed.
- Arrival time of the return flight (local time and likely body clock time).
- Depending on the actual city pairs being served, it may also be relevant to compare winter and summer schedules for take-off and landing times and flight durations.

In this case, another operator has been flying a ULR trip between City C and City D. This existing operation has the same crew complement and similar departure times, flight durations, layover durations, and patterns of time zone crossings as the A-B-A route. As part of the regulatory approval process for the C-D-C route, the operator was required to conduct a 6-month operational validation, which included intensive monitoring of crewmember sleep and fatigue.

[9] Flight Safety Foundation (2005). Flight Safety Digest 26.

The operator generously makes these findings available for use in the A-B-A safety case, through an independent scientific team who were involved in the C-D-C data collection and analysis. (The expertise of the scientific team ensures that the findings are interpreted and applied to the A-B-A route in an appropriate manner.)

Figure 4.5: FRM Processes in Setting up a New ULR route



4.7.3 Step 3 – Identify Hazards

Predictive Processes

The operator already has experience with several long haul routes using the same aircraft and crew complement and with similar departure times and time zone crossings to the A-B-A route, but that remain under the 16-hour flight time limit that is used to define ULR. This experience has guided development of the operational plan for the A-B-A ULR route.

Two bio-mathematical models are available that can be used to predict the likely levels of crewmember fatigue or alertness on the A-B-A route. The data collected on the C-D-C route are used to test how well these models can predict the sleep and fatigue of crewmembers before, during, and after ULR operations.

One model (which has not been validated for aviation operations, but is sold for this use) makes the following predictions for the C-D-C route: that crewmember fatigue levels increase significantly across both the outbound and return flights; that layover sleep is too short to enable recovery before the return flight; and that fatigue levels are potentially unsafe by the end of both flights. These predictions are directly contradicted by PVT performance data and subjective sleepiness and fatigue ratings collected during the first 6 months of the C-D-C operation, which has flown daily without major incident for four years. The operational data and experience are considered more reliable than these bio-mathematical model predictions.

On the other hand, the second model reliably predicts the duration of in-flight sleep on the C-D-C route (to within the range of variability seen among the crewmembers monitored). This model is chosen to predict crewmember alertness on the A-B-A route.

Proactive Processes

The following proactive processes for identifying fatigue hazards are proposed for intensive monitoring during the first 4 months of the new operation, to validate the predictions about fatigue levels and fine tune the mitigation strategies, as needed.

- Crewmembers are reminded about and encouraged to use existing fatigue reporting forms.
- For the first month of the operation, a senior flight crewmember will be present in the Flight Operations Centre for the first and last few hours of every flight on the A-B-A route, to ensure rapid and appropriate management response to any fatigue-related issues arising.
- For the first month of the A-B-A operation, a subset of crewmember volunteers is asked to complete a sleep and duty diary (with fatigue and sleepiness ratings) before, during, and after an A-B-A trip. These data will be compared with the same measures collected during the C-D-C operational validation.

Other proactive fatigue monitoring processes that could be used include:

- Asking all crewmembers to complete fatigue and sleepiness ratings at the top of descent on each flight, for the first month of the A-B-A operation.
- Surveying all crewmembers after the A-B-A operation has been flown for 3 months, to obtain an overview of their experience of fatigue and the effectiveness of different mitigation strategies (scheduling, in-flight rest facilities, layover hotels, etc).

- Having a subset of crewmember volunteers who wear actigraphs and complete sleep diaries before, during, and after a complete trip on the A-B-A route. In addition they would complete fatigue and sleepiness scales and undertake PVT performance tests at key times across each flight. These data would be compared with the same measures from the C-D-C operational validation.

Reactive Processes

The operator has systems in place for analyzing the contribution of fatigue to safety reports and events, and for determining how to reduce the likelihood of similar events occurring in future. Special attention will be paid to ensuring that any fatigue reports or incidents from the A-B-A operation are analyzed quickly and appropriate action taken.

4.7.4 Step 4 – Assess Safety Risk

The bio-mathematical model used to predict crewmember alertness on the A-B-A route has previously been used to predict alertness on a range of 2-person and 3-person long haul routes. These predictions indicate that minimum alertness levels on the A-B-A route are likely to be higher than on some existing long haul routes, notably 3-person westward return night flights with duty periods of about 14 hours, and long overnight flights with 2-person crews.

Two sets of operational experience support the prediction that the A-B-A route does not pose excessive fatigue hazards: 1) the safety record of the C-D-C operation which has flown daily for four years; and 2) the A-B-A operator's experience with similar long haul routes using the same aircraft and crew complement, but remaining under the 16-hour flight time limit.

4.7.5 Step 5 – Select and Implement Controls and Mitigations

In this example, the following controls and mitigation strategies are proposed for the A-B-A operation.

- The aircraft chosen for the route has the best available on-board crew rest facilities.
- All crewmembers flying the new operation are domiciled in the departure city.
- All crewmembers flying the new operation receive specific education on personal and organizational strategies for managing fatigue on the A-B-A operation. This includes discussion on how to make best use of in-flight and layover sleep opportunities.
- All crewmembers have protected time off duty to enable two full nights of sleep in the departure city time zone, so that they have the opportunity to begin the A-B-A operation fully rested.
- There is a clear policy defining on-call arrangements and the provisioning of relief crew.
- The flight crew includes 2 captains and 2 first officers, so that a single captain does not have sole command responsibility for entire ULR flights. This is in accordance with the Flight Safety Foundation ULR recommendations.
- There is a clear policy on the distribution of in-flight rest opportunities, so that crewmembers can plan how best to use them.
- Each crewmember has two rest opportunities per flight, to ensure that they have at least some rest time overlapping their normal sleep time and that they have a second opportunity to get some sleep if, for any reason, they are unable to sleep during their first in-flight rest period.

- Meals are available for flight crew on the flight deck if they wish, in order to maximize the amount of time during in-flight rest periods that is available for sleep.
- The layover hotel has been carefully vetted to ensure that it provides excellent facilities for sleep, eating, and exercise.
- A procedure is implemented between Flight Operations and the layover hotel to provide notification of delays without having to wake crewmembers.
- There are clear procedures on the management of flight delays.
- There are clear procedures on the management of flight diversions.
-
- The following safety performance indicators are identified:
- Data collected during the first 4 months of the A-B-A operation will be compared with model predictions and with the same measures from the C-D-C validation, to establish whether crewmember fatigue and alertness levels are in the range predicted.
- By the fourth month of the A-B-A operation, the fatigue reporting rate (reports/flight segment) and average fatigue report risk level should be comparable to existing long haul routes. No ''intolerable" fatigue reports should be received (see Table 4.2.d).

4.7.6 Step 6 – Monitor Effectiveness of Controls and Mitigations

There is a defined validation period for the first four months of the operation that involves more intensive monitoring. The Fatigue Safety Action Group will have regular oversight of all data and fatigue reports coming in and will act in a timely manner when issues arise.

At the end of the validation period, a report will be compiled and routine processes will be defined for fatigue risk monitoring and management on the A-B-A route. This report will be available to all interested parties. If the performance indicators are acceptable, the A-B-A operation will revert to routine monitoring.

4.7.7 Linking to FRMS Safety Assurance Processes

Normally, the FRM processes do not operate in isolation from the FRMS safety assurance processes (described in detail in the next Chapter). However, when setting up FRMS in an organization, or for a new type of operation, the data needed for FRMS safety assurance processes are not available before the operation(s) begin flying. This means that it is necessary to have a staged approach to FRMS implementation, which is described in Chapter Seven.

5.0 FRMS SAFETY ASSURANCE PROCESSES

5.1 INTRODUCTION TO FRMS SAFETY ASSURANCE PROCESSES

The FRM processes described in Chapter Four are the part of the day-to-day FRMS operations that focuses on identifying fatigue hazards, assessing safety risks, putting in place controls and mitigation strategies, and monitoring their effectiveness.

This Chapter works through the basic steps in FRMS safety assurance processes, which form another layer in an operator's defenses against fatigue-related risk. FRMS safety assurance processes are also part of the routine operation of the FRMS, and they monitor how well the entire FRMS is functioning. They:

- check that the FRMS is functioning as intended;
- check that it is meeting the safety objectives defined in the FRMS policy;
- check that it is meeting regulatory requirements;
- identify where changes in the operating environment have the potential to increase fatigue risk; and
- identify areas for improvement in the management of fatigue risk (continuous improvement of the FRMS).

To do this, FRMS safety assurance processes use a variety of data and information as safety performance indicators that can be measured and monitored over time. Having a variety of safety performance indicators, plus a safety target for each, is expected to give better insight into the overall performance of the FRMS than having a single measure. Safety performance targets must fall in the tolerable region defined in the risk assessment process (see Section 4.5), and they may need to be revised as operational circumstances change. [10]

Figure 5.1 outlines the linkages between the FRMS safety assurance processes and other components of the FRMS. The information, data, and safety performance indicators from the FRM processes provide a source of information for the FRMS safety assurance processes. In addition, the FRMS safety assurance processes:

1. use information and expertise from other sources, both from within the operator's organization and external to it, to evaluate the functioning of the FRMS; and
2. evaluate trends in safety performance indicators to identify emerging or changed hazards and refer these back to the FRM processes; and
3. identify changes in the operating environment that could affect fatigue risk and refer these back to the FRM processes; and
4. provide input about ways to improve the operation of the FRMS.

[10] See IATA Introduction to Safety Management Systems (SMS), 2nd Edition.

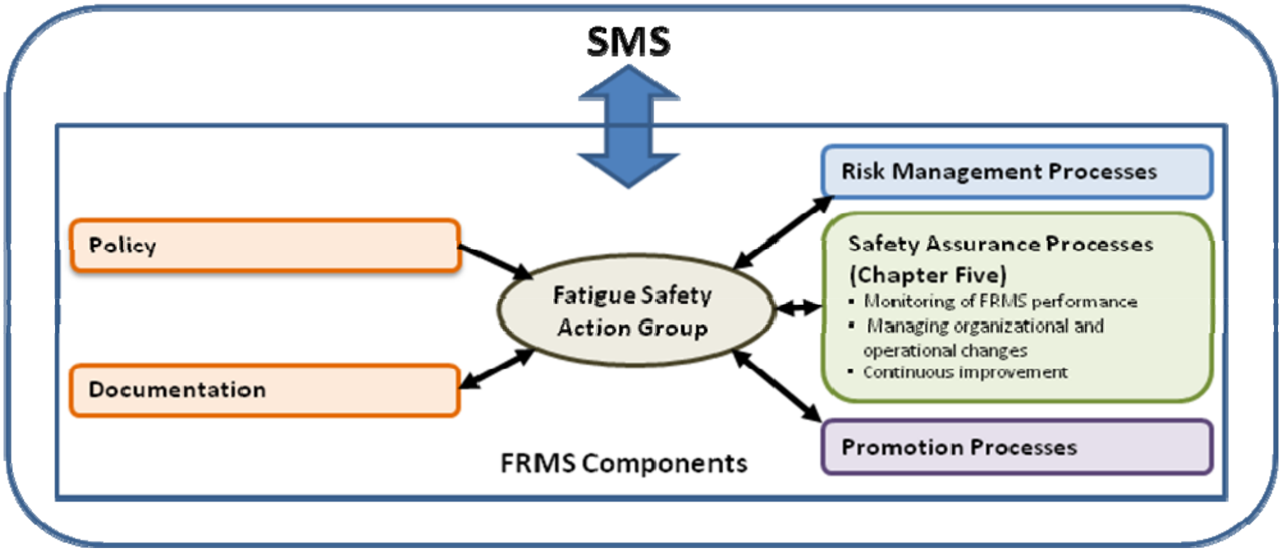


Figure 5.1: Linkages between FRMS assurance processes and other FRMS components

Some of the FRMS safety assurance processes can be undertaken by the Fatigue Safety Action Group, while others (for example audits of the FRMS) would normally be undertaken by other units within the operator's organization. The responsibility for different FRMS safety assurance activities may be distributed differently, depending on the size of the organization. For example, larger operators may have a separate FRMS safety assurance team and/or a designated FRMS safety assurance manager. Communication (in both directions) between the FRMS safety assurance processes and the SMS is necessary, since the safety performance of the FRMS will impact on overall safety performance.

The ICAO requirements for FRMS safety assurance processes are as follows.

Appendix 8:
3. FRMS Safety Assurance Processes

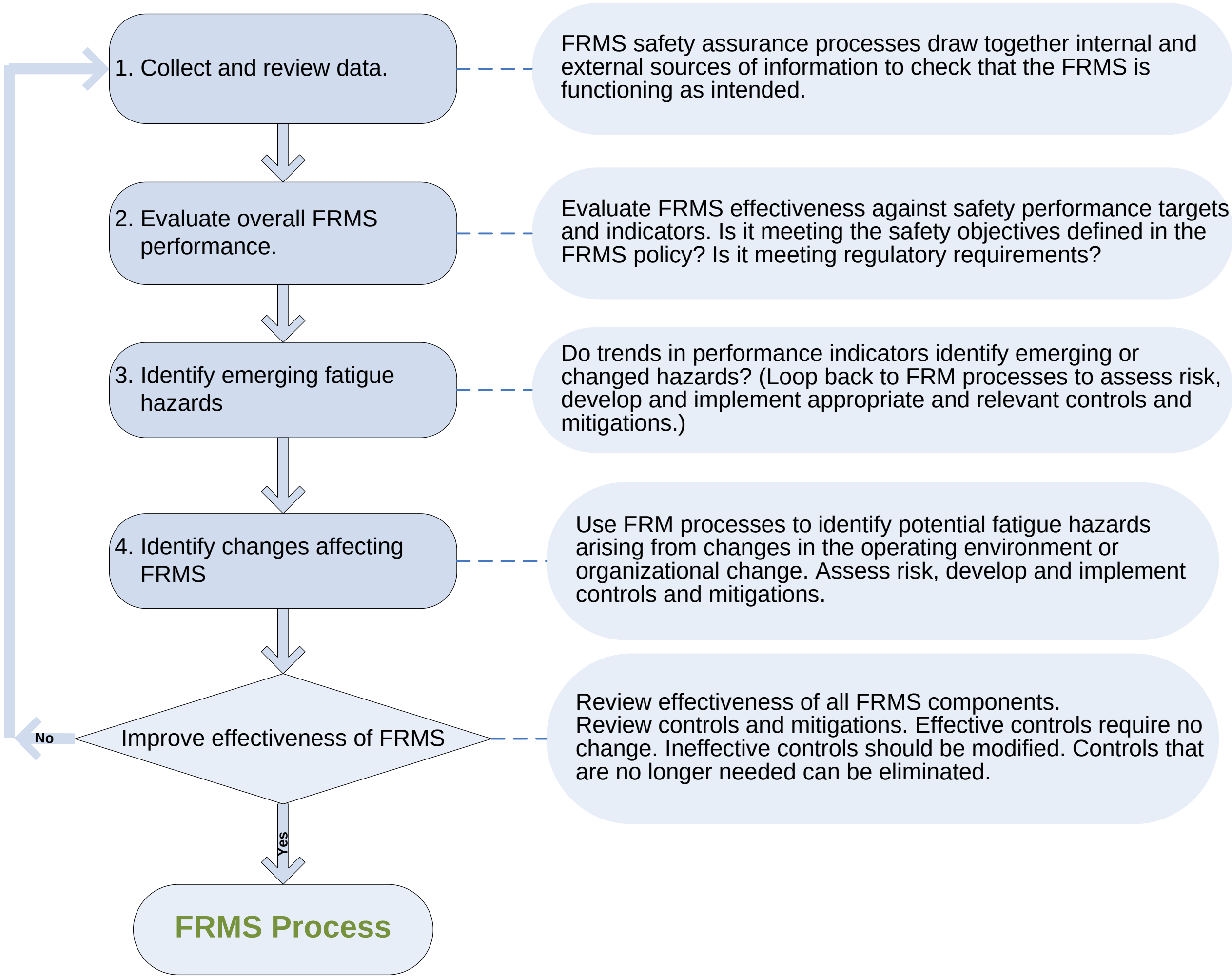
3.1 The operator shall develop and maintain FRMS safety assurance processes to:

a) provide for continuous FRMS performance monitoring, analysis of trends, and measurement to validate the effectiveness of the fatigue safety risk controls. The sources of data may include, but are not limited to:
   1) hazard reporting and investigations;
   2) audits and surveys; and
   3) reviews and fatigue studies;

b) provide a formal process for the management of change which shall include but is 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; and

c) provide for the continuous improvement of the FRMS. This shall include but is not limited to:
   1) the elimination and/or modification of risk controls have had unintended consequences or that are no longer needed due to changes in the operational or organizational environment;
   2) routine evaluations of facilities, equipment, documentation and procedures; and
   3) the determination of the need to introduce new processes and procedures to mitigate emerging fatigue-related risks.

Figure 5.2: FRMS Safety Assurance Processes



5.2 FRMS Safety Assurance Processes Step 1: Collect and Review Data

Step 1 involves bringing together and reviewing information gained through the FRM processes to examine the overall performance of the FRMS. Performance of the FRMS should be examined through indentifying a variety of safety performance indicators. These should include those specific to the FRMS as well as SMS safety performance indicators. Examples of safety performance indicators specific to an FRMS will include measures obtained through the FRM processes, such as:

- The number of exceeded maximum duty days in operations covered by the FRMS;
- The number of voluntary fatigue reports per month;
- The average "fatigue call" rate by flight crews on a specific pairing (trip);
- The ratio of fatigue reports from ULR operations covered by the FRMS to fatigue reports from the long haul operations covered by the prescriptive flight and duty time regulations.
- Attendance at FRMS training sessions;
- Results on FRMS training assessments;
- The level of crew member participation in fatigue-related data collection;
- The number times fatigue is identified as an organizational factor contributing to an event.

ICAO Annex 6, Part I, Appendix 8 indicates that sources of data for monitoring the safety performance of the FRMS may include (but are not limited to):

1. hazard reporting and investigations;
2. audits and surveys; and
3. reviews and fatigue studies.

1. Hazard Reporting and Investigations

Trends in voluntary fatigue reports by crewmembers and others can provide valuable insights into the effectiveness of the FRMS. Safety events in which crewmember fatigue has been identified as a contributing factor will be less common than fatigue reports. However, regular review of these events may also highlight areas where functioning of the FRMS could be improved. The value of both these sources of information depends on using appropriate methods for analyzing for the role of fatigue (see Chapter 4 and Appendix B).

2. Audits and Surveys

Audits and surveys can provide measures of the effectiveness of the FRMS without having to rely on fatigue levels being high enough to trigger fatigue reports or fatigue-related safety events (both of which are relatively rare events).

Audits focus on the integrity of, and adherence to, the FRM processes. These audits should answer questions such as:

- are all departments implementing the recommendations of the Fatigue Safety Action Group?
- are crewmembers using mitigation strategies as recommended by the Fatigue Safety Action group?
- is the Fatigue Safety Action Group maintaining the required documentation of its activities?

Audits can also periodically assess the effectiveness of the FRMS, for example by looking at the status of FRMS safety performance indicators and targets.

Audits are 'external' to the Fatigue Safety Action Group, but may still be internal to the operator, i.e., conducted by other units within the organization. In addition, feedback from regulatory audits can provide useful information for FRMS safety performance monitoring. Another type of audit that can be used in this context is to have an independent scientific review panel that periodically reviews the activities of the Fatigue Safety Action Group, and the scientific integrity of their decisions. A scientific review panel can also provide the Fatigue Safety Action Group with periodic updates on new scientific developments relevant to the FRMS.

Surveys can provide information on the effectiveness of the FRMS. For example they can document how schedules and rosters are affecting crewmembers, either by asking about their recent experiences (retrospective) or tracking them across time (prospective). Surveys for this purpose should include validated measures, such as standard rating scales for fatigue and sleepiness, and standard measures of sleep timing and quality (see Chapter 4 and Appendix B). Remember that a high response rate (ideally more than 70%) is needed for survey results to be considered representative of the entire group, and response rates tend to decline when people are surveyed too frequently ('participant fatigue').

3. Reviews and Fatigue Studies

In general, safety reviews are used to ensure that safety performance is adequate during times of change, [11] for example during the introduction of a new type of operation or a significant change to an existing operation covered by the FRMS.

A review would start by identifying the change (for example, moving a trip to a crew base in a different time zone, changes in on-board crew rest facilities, significant changes in the total trip, a change of equipment being used for the trip, etc). It would then evaluate the appropriateness and effectiveness of the FRMS activities relating to the change (for example, proposed methods for fatigue hazard identification, the risk assessment process, proposed controls and mitigations to address the fatigue hazard(s), and measures of their effectiveness to be used during the implementation of the change).

Fatigue studies as part of FRMS safety assurance processes are undertaken when an operator is concerned about a broad fatigue-related issue for which it is appropriate to look at external sources of information. These could include the experience of other operators, industry-wide or State-wide studies, and scientific studies. These sources of information can contribute in situations when safety arguments based on the limited experience and knowledge within that operator may not be enough. Fatigue studies in this context are mainly used for gathering information about large-scale issues in FRMS, rather than for identifying specific fatigue hazards.

FRMS Safety Performance Indicators

Trends in FRMS safety performance indicators are also an important source of information about the effectiveness of the FRMS. These may include indicators identified by the Fatigue Safety Action Group as part of the FRM processes (see Section 4.6). They may also include indicators that capture more global aspects of the safety performance of the FRMS, for example safety performance metrics within the operator's SMS.

[11] See ICAO Doc 9859 Safety Management Manual.

5.3 FRMS Safety Assurance Processes Step 2: Evaluate FRMS Performance

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 in Step 1 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 (see Section 4.5); 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 (for additional examples see Section 5.8 below).

- 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 at Step 2 or beyond (see Figure 4.2). 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 5.3 tracks a measure of the effectiveness of the Air New Zealand FRMS across time[12]. It shows that the percentage of pilots reporting duty-related fatigue occurring at least once a week has declined across a series of surveys conducted between 1993 and 2006.

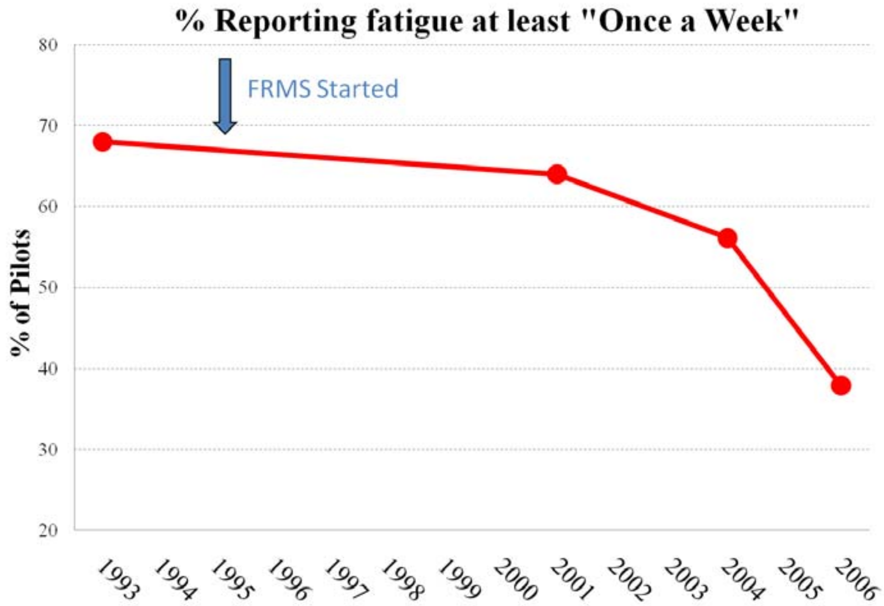


Figure 5.3: Declining reports of crewmember fatigue across successive Air New Zealand surveys

12 Figure 5.3 is used by kind permission of Dr David Powell.

5.4 FRMS SAFETY ASSURANCE PROCESSES STEP 3: IDENTIFY EMERGING HAZARDS

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).

5.5 FRMS SAFETY ASSURANCE PROCESSES STEP 4: IDENTIFY CHANGES AFFECTING FRMS

In our dynamic aviation environment changes are a normal part of flight operations. They may be driven by external factors (for example, new regulatory requirements, changing security requirements, or changes to air traffic control) or by internal factors (for example, management changes, new routes, aircraft, equipment, or procedures). Changes can introduce new fatigue hazards into an operation, which need to be managed. Changes may also reduce the effectiveness of controls and mitigations that have been implemented to manage existing fatigue hazards. Step 4 of the FRMS safety assurance processes aims to identify when new hazards may be a result of change.

ICAO 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[1]. 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.

5.6 FRMS Safety Assurance Processes Step 5: Improve Effectiveness of FRMS

Ongoing evaluation by the FRMS safety assurance processes not only enables the FRMS to be adapted to meet changing operational needs, it also allows the FRMS to continuously improve the management of fatigue risk. In doing so, risk controls that have unintended consequences or that are no longer needed due to changes in the operational or organizational environment can be identified, then modified or eliminated through the FRM processes. Examples include:

1. routine evaluations of facilities, equipment, documentation and procedures; and
2. the determination of the need to introduce new processes and procedures to mitigate emerging fatigue-related risks.

It is important that changes made to the FRMS are documented by the Fatigue Safety Action Group so that they are available for internal and regulatory audit.

5.7 Assigning Responsibility for FRMS Safety Assurance Processes

To deliver effective oversight of the functioning of the FRMS, and to examine its functioning in relation to the SMS, the FRMS safety assurance processes need to operate in close communication with the Fatigue Safety Action Group, but with a degree of independence from it. The aim is to avoid the Fatigue Safety Action Group reviewing its own performance. Figure 5.4 describes an example of how responsibility for the FRMS safety assurance processes might be assigned in a large organization.

In this example, the Fatigue Safety Action Group is accountable to the Safety Team for Flight Operations. The Safety Team for Flight Operations is accountable in turn to the Executive Safety Team. In Figure 5.4, these lines of accountability are indicated by heavy arrows. (In a large organization, there might eventually be separate FRMSs and Fatigue Safety Action Groups for flight operations, maintenance, ground operations, and in-flight services.) The thin lines represent information flows.

Primary responsibility for the FRMS safety assurance processes is assigned to a Quality Assurance person or team that is accountable to the Executive Safety Team and:

- maintains close communication with the Fatigue Safety Action Group;
- makes recommendations to the Safety Team for Flight Operations, as needed to improve the functioning of the FRMS;
- makes recommendations to the Safety Team for Maintenance, as needed to improve the functioning of the FRMS;
- makes recommendations to the Safety Team for Ground Operations, as needed to improve the functioning of the FRMS;
- makes recommendations to the Safety Team for In-Flight Services, as needed to improve the functioning of the FRMS; and
- monitors changes in the regulatory environment and the operating environment that may affect the functioning of the FRMS.

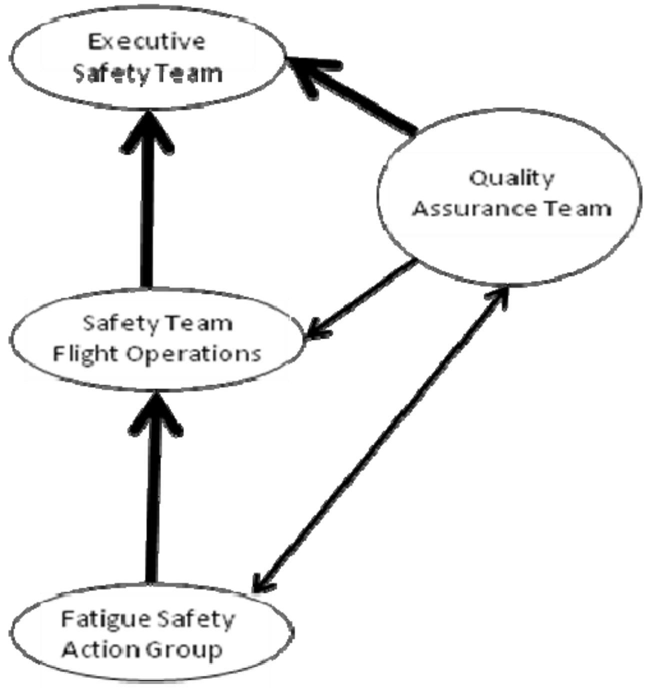


Figure 5.4: Example of assignment of responsibility for FRMS safety assurance processes in the flight operations department of a large organization

In a smaller operator, responsibility for the FRMS safety assurance processes might reside with an individual rather than a team. This individual may also have a variety of other quality assurance responsibilities. A single safety team might be responsible for flight operations, in-flight services, ground operations and maintenance.

5.8 EXAMPLES OF FRMS SAFETY ASSURANCE PROCESSES INTERACTING WITH FRM PROCESSES

Figure 5.5 summarizes interactions between the FRM processes and the FRMS safety assurance processes. Together, these two sets of processes form the “engine” of the FRMS. Both function in a dynamic way in response to the information and data collected and each is responsive to changes in the other.

The following examples illustrate some FRMS safety assurance processes and describe the specific ways in which they interact with the FRM processes.

Figure 5.5: Interactions between FRM processes and FRMS safety assurance processes

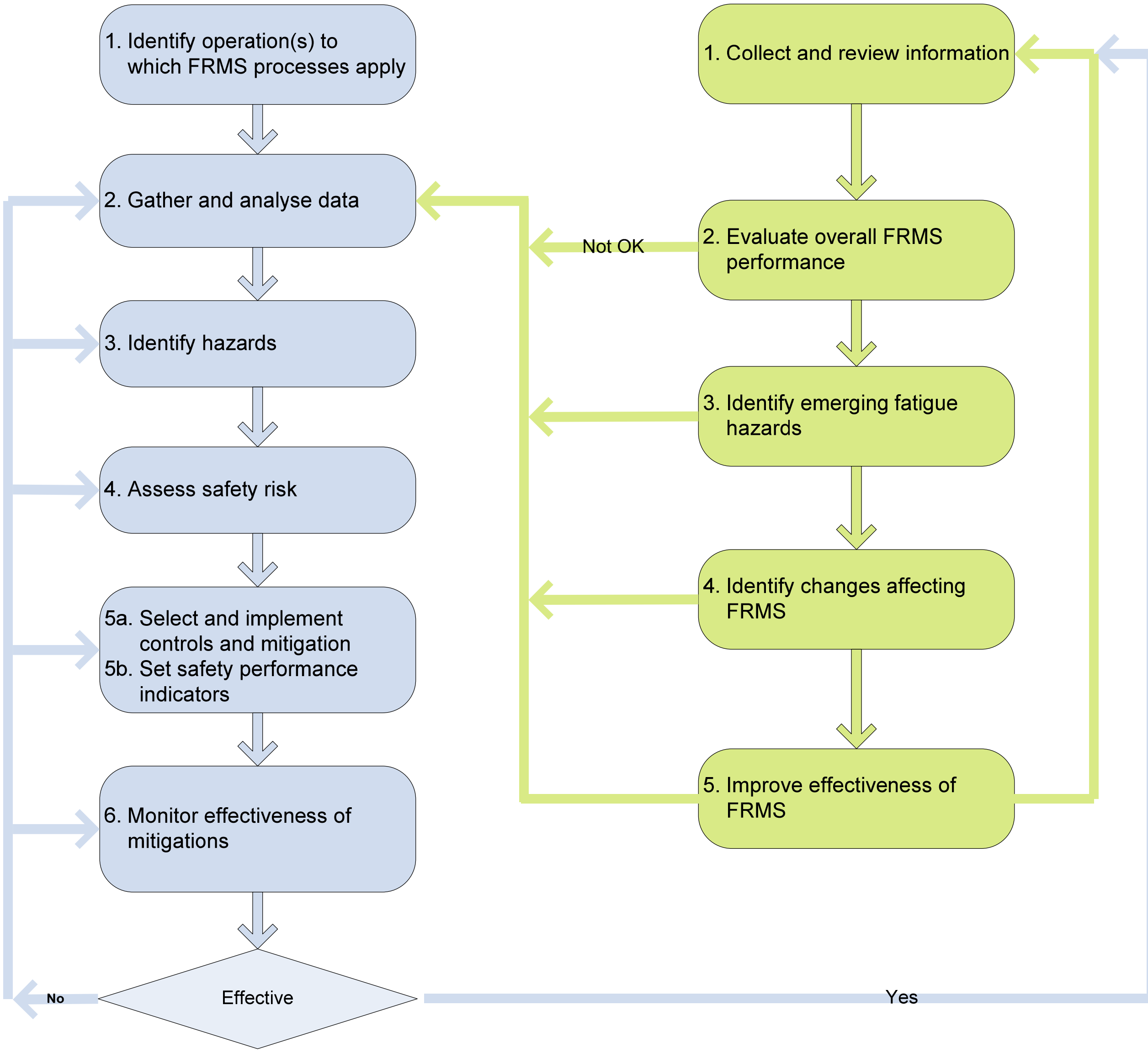
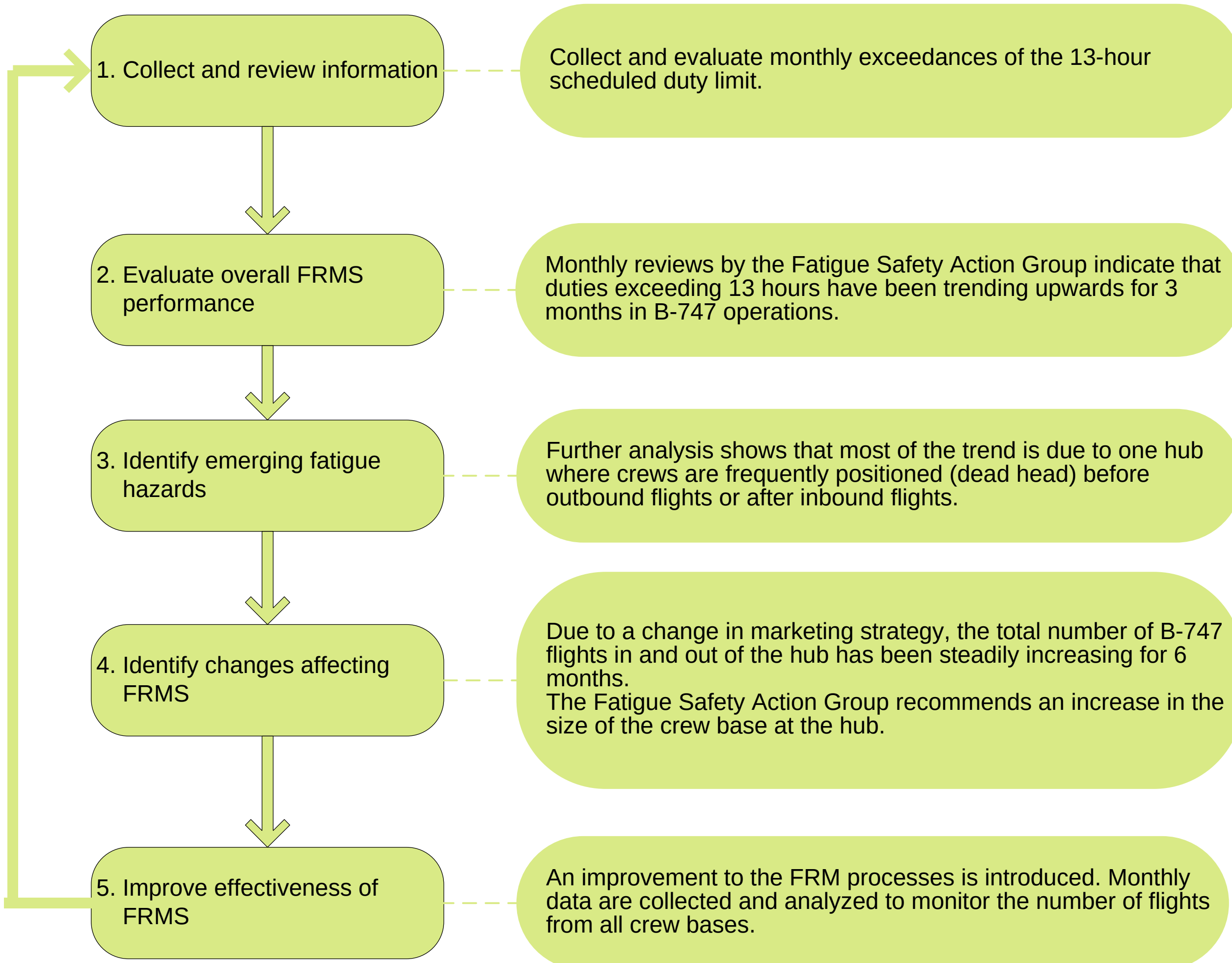


Figure 5.6: FRMS Safety Assurance Processes Example 1



In the example in Figure 5.6, as the result of a risk assessment (FRM processes Step 4), the Fatigue Safety Action Group sets a duty length of 13 hours as one of its FRMS safety performance indicators (SPIs). The target is to have no more than two instances of duties in excess of 13 hours per week in B-747 operations. It collects and assesses monthly data on scheduled and actual exceedences of the 13-hour duty limit across all its B-747 flights in and out of the hub. For 3 consecutive months, there is an increasing trend in exceedences.

A short haul example is described in Figure 5.7. Here, the use of captain's discretion is tracked as an FRMS safety performance indicator. (Most State regulations allow for maximum flight duty periods to be increased on the day of operation at the discretion of the relevant captain.)

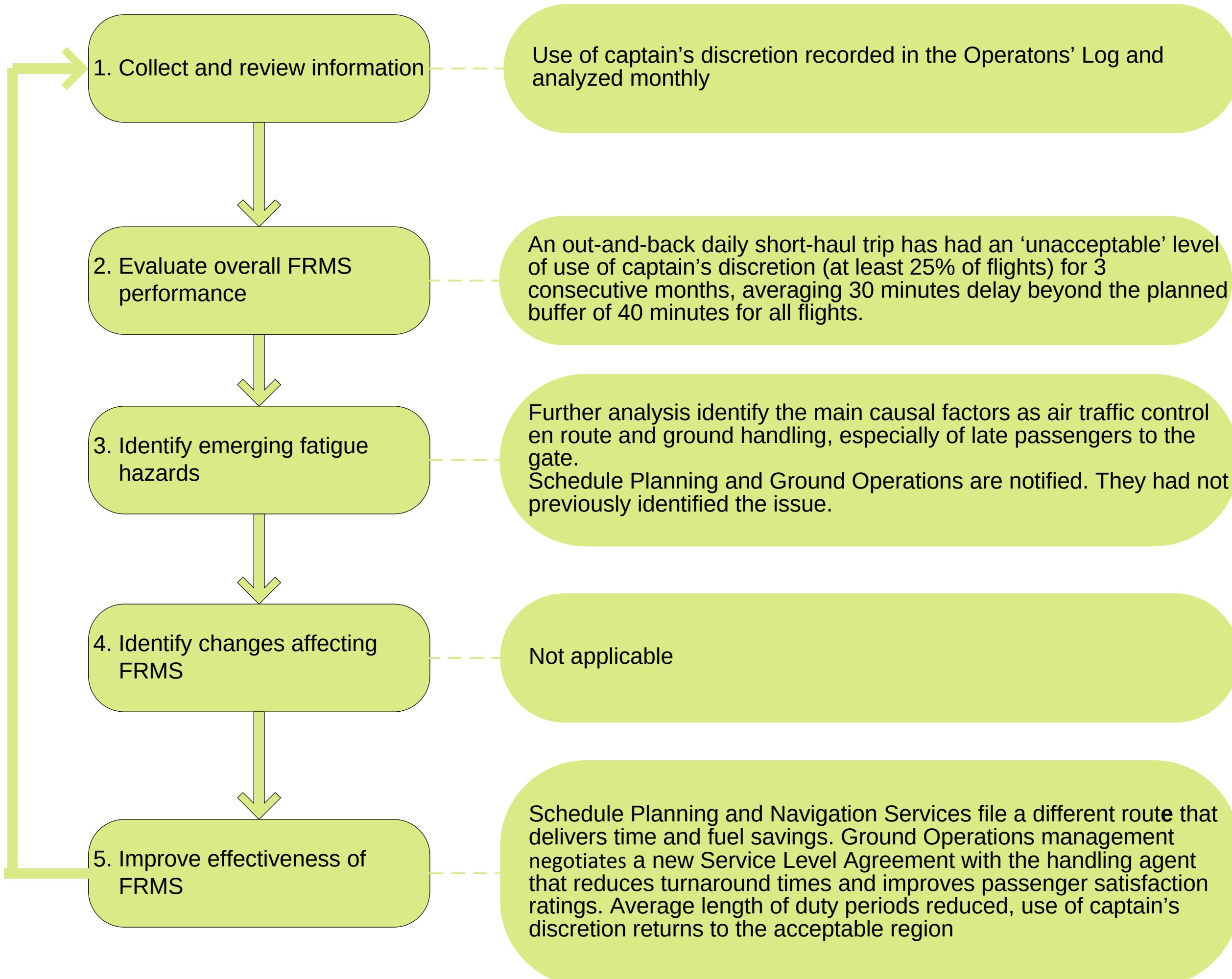
In this example, in the FRMS processes, the Fatigue Safety Action Group has conducted a risk assessment (see Table 4.2 d) and decided to set the following thresholds for short haul flights:

- intolerable region - discretion used on at least 25 % of flight duty periods in a two month period;
- tolerable region - discretion used on 10-25 % of flight duty periods in a two month period;
- acceptable region - discretion used on less than 10% of flight duty periods in a two month period.

In addition, delays of more 2 hours must be logged and presented to the Fatigue Safety Action Group.

Data on use of discretion are collected in a log generated by the operator's crew management system. The Fatigue Safety Action Group analyzes this data monthly, to ensure that the trips being created by the scheduling software are realistic, given the usual operating conditions. The data are sorted by trip (sequence of consecutive flight duty periods), distinguishing between regular scheduled trips (that recur for several roster periods, e.g., monthly bid lines) and trips that are introduced temporarily to cover variations in scheduling or crewmember availability at a particular crew base. Data are also analyzed by crewmember rank, category, and qualifications to see, for example, if trips with more frequent use of discretion are avoided by more senior crewmembers).

Figure 5.7: FRMS Safety Assurance Processes Example 2



The next example (Figure 5.8) looks at an operator whose FRMS uses scheduled maximum values for planning purposes that are well within the established risk-assessed, regulator-approved, outer boundaries of the FRMS. In this example, on a particular day at a particular crew base, the maximum value of scheduled duty time periods defined in the FRMS have been exceeded multiple times.

Every exceedance of the scheduled duty times requires submission of a report to the Fatigue Safety Action Group, which is added to the FRMS documentation for regulatory audit. In addition, the FRMS safety assurance processes require that the reasons for each exceedance are investigated and that, if required, corrective action is taken. In this example, the functions of FRMS safety assurance are undertaken by the SMS team as part of their broader SMS safety assurance functions. This is to ensure that the management of fatigue risks does not result in unintended consequences in overall risk management, that the actions taken by the Fatigue Safety Action Group are not self-monitored, and that there is appropriate distribution of resources across both the FRMS and the SMS.

The monthly review of exceedences by the SMS team responsible for FRMS safety assurance processes identifies a cluster of exceedences occurring on the same day in the same place. They notify the Fatigue Safety Action Group. The Fatigue Safety Action Group contacts the line manager responsible for crewing resources on the day and asks him to interview the staff on duty on that day. The investigation reveals that there were a series of problems that coincided on that particular day, which combined to produce the outcome of multiple exceedences of the scheduled duty time limits. It is unlikely that this same combination of problems would recur. However, the effectiveness of the FRMS is improved by a series of measures that improves the management of staff in the crewing office in times of unexpected high workload.

Monthly analysis of exceedences of the scheduled duty time limits specified in the FRMS could consider:

- the areas of the organization involved in exceedences;
- causes and extenuating circumstances; and
- patterns of overdue submission of reports on exceedences.

The Fatigue Safety Action Group is responsible for developing and implementing any recommended mitigations, in consultation with the team responsible for the FRMS safety assurance processes.

Figure 5.8: FRMS Safety Assurance Processes Example 3

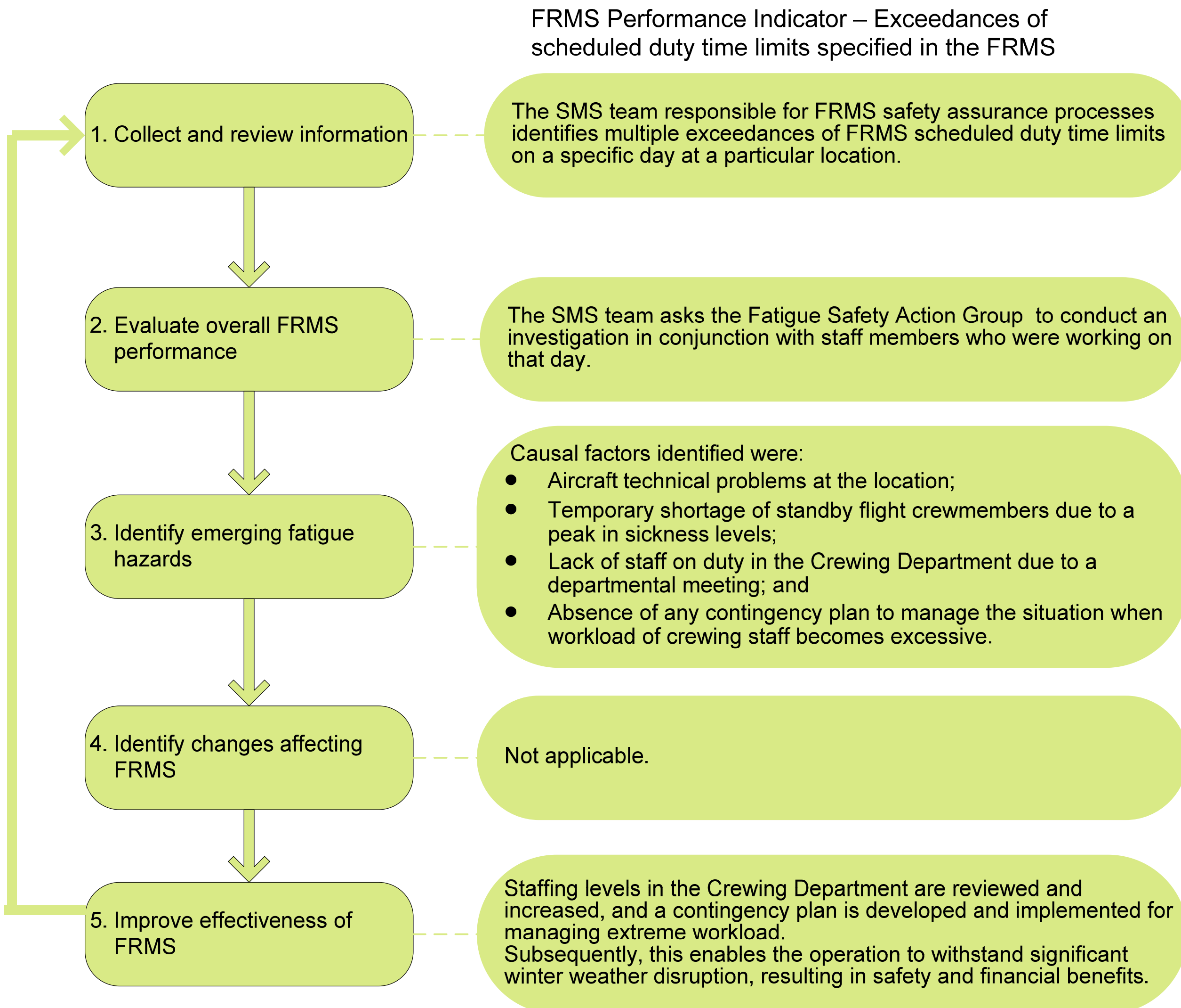


Figure 5.9 describes an example that uses another type of FRMS safety performance indicator **-** a code incorporated in the rostering software that indicates when a crewmember is approaching the limit for maximum allowable monthly flight hours. If the code is set to trigger below the flight hours limit defined in the FRMS policy, then this provides a buffer that enables some flexibility and reduces the risk of exceedences.

Each month, the Fatigue Safety Action Group analyzes how often the code is activated, i.e., how often crewmembers are approaching the maximum monthly flight hours, and where this is happening. An increasing trend in code indicates increasing workload for flight crewmembers, and can be due to an increasing number of flights being scheduled or a reduced number of crewmembers available to fly them, or both. Seasonal analyses are also undertaken to indicate whether this is a normal cyclical pattern that requires short-term remedial action, or a separate upward trend that requires long term remedial action.

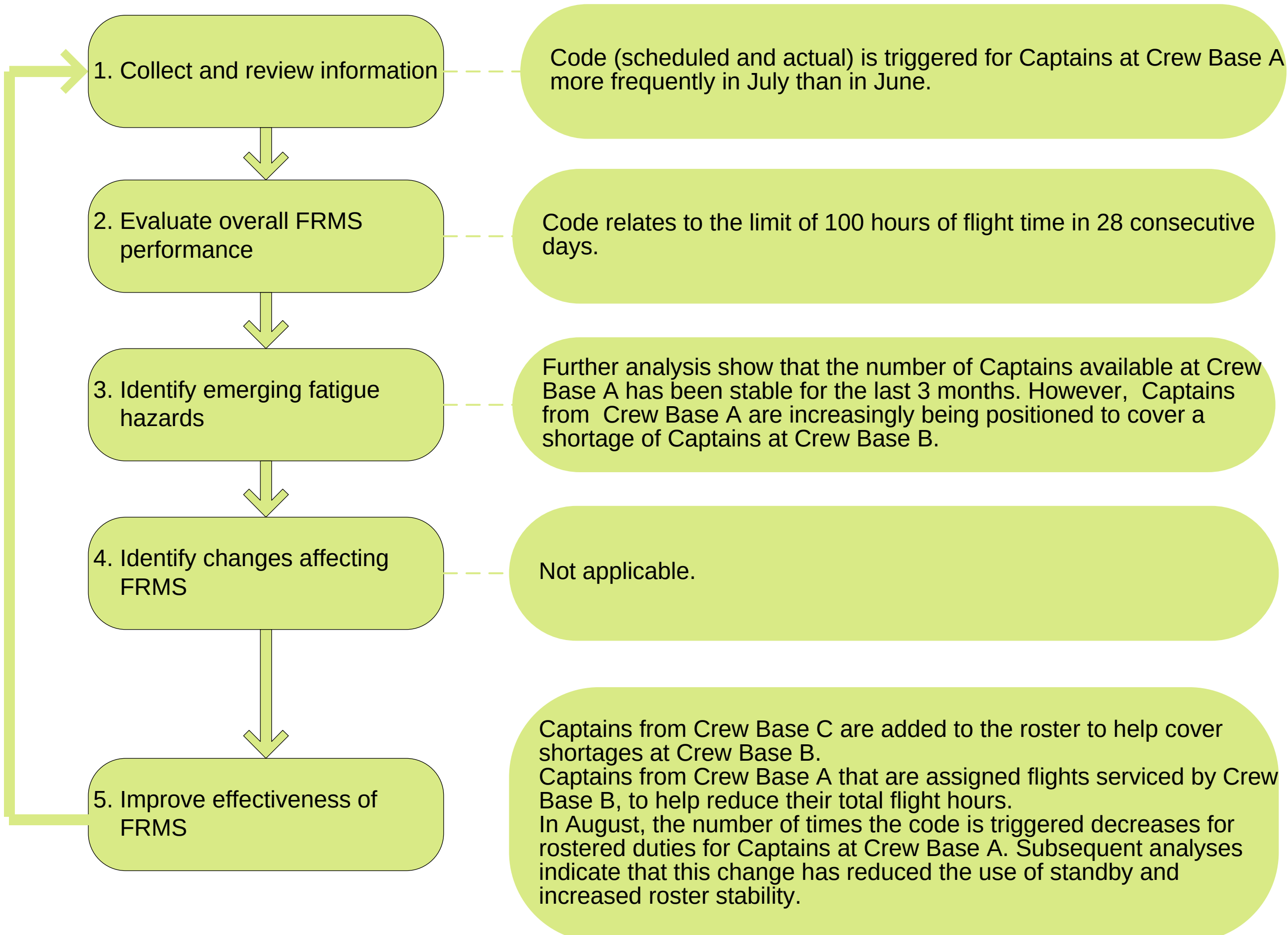
In this example, monthly analyses by the Fatigue Safety Action Group have revealed that occurrences of scheduled and actual flight hours triggering the code have increased in July compared with June, for Captains at a particular crew base.

Note: It is possible to incorporate a variety of codes in the rostering software to track when different rostering parameters are approaching limits specified in the FRMS. These codes can be separated into categories, for example by fleet, crewmember rank and crew base, and analyzed in a variety of ways, including:

- number of times that codes occur for actual versus rostered schedules;
- analysis of which duty or flight hours limit is most frequently approached, and in which part of the operation this is most likely to occur;
- month-by-month trends in numbers of codes occurring;
- rolling 13-month trends (recalculated each month for the last 13 months, to cover a full cycle of seasonal changes);
- longer-term trends, for example 3-yearly trends by crewmember rank.

Figure 5.9: FRMS Safety Assurance Processes Example 4

FRMS Performance Indicator – Code Tracking High Monthly Flight Hours



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6.0 FRMS PROMOTION PROCESSES

6.1 INTRODUCTION TO FRMS PROMOTION PROCESSES

This Chapter works through the requirements for FRMS promotion processes that include training programs and a communication plan. Figure 6.1 outlines the linkages between the FRMS promotion processes and other FRMS components. Along with the FRMS policy and documentation, the FRMS promotion processes support the core operational activities of the FRMS (FRM processes and FRMS safety assurance processes).

FRMS training should ensure that all involved personal are trained and competent to undertake their responsibilities in the FRMS, and standards for initial and recurrent training should be specified in the FRMS documentation. A special feature of FRMS training is that key principles of fatigue science - managing sleep and understanding the effects of the circadian body clock – are relevant not only to people's roles in the FRMS but also to their lives outside of work, for example in safe motor vehicle driving and in staying healthy. Thus FRMS training covers issues that everyone can identify with personally, and this can help promote the concept of shared responsibility in an FRMS.

Like SMS, FRMS relies on effective communication throughout the operator's organization[13]. On the one hand, there needs to be regular communication about the activities and safety performance of the FRMS to all stakeholders. Depending on the structure of the organization, this may come from the Fatigue Safety Action Group, the SMS, or from an accountable executive responsible for the FRMS communication plan. On the other hand, crewmembers and other stakeholders need to communicate promptly and clearly about fatigue hazards to the Fatigue Safety Action Group or other relevant management.

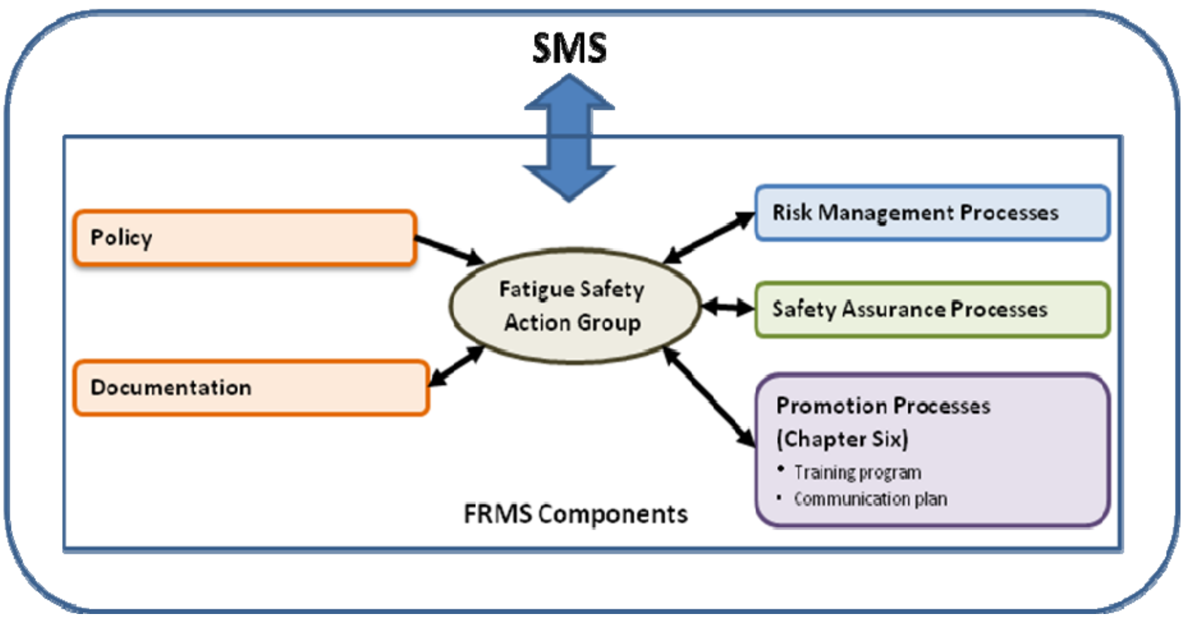

Figure 6.1: Linkages between FRMS promotion processes and other FRMS components

13 ICAO Safety Management Manual (Doc 9859. IATA Introduction to Safety Management Systems (SMS), 2nd Edition, Section 5.2.

Annex 6, Part I, Appendix 8

4. FRMS promotion processes

4.1 FRMS promotion processes support the ongoing development of the FRMS, the continuous improvement of its overall performance, and attainment of optimum safety levels. The following shall be established and implemented by the operator as part of its FRMS:

a) training programs to ensure competency commensurate with the roles and responsibilities of management, flight and cabin crew, and all other involved personnel under the planned FRMS; and

b) an effective FRMS communication plan that:
1) explains FRMS policies, procedures and responsibilities to all relevant stakeholders; and
2) describes communication channels used to gather and disseminate FRMS-related information.

6.2 FRMS Training Programs

In addition to the above requirements, ICAO Annex 6, Part I, Appendix 8 requires that an operator maintain documentation that describes and records FRMS training programs, training requirements, and attendance records. It further recommends that regulators have competency requirements for FRMS training instructors, who may be part of an operator's internal training department or external contractors.

6.2.1 Who Needs to be Trained

For an FRMS to be effective, all personnel who contribute to FRMS safety performance need to have appropriate training. This includes crewmembers, crew schedulers, dispatchers, operational decision-makers, all members of the Fatigue Safety Action Group, and personnel involved in overall operational risk assessment and resource allocation. It also includes senior management, in particular the executive accountable for the FRMS and senior leadership in any department managing operations within the FRMS.

6.2.2 Curriculum

The content of training programs should be adapted according to the knowledge and skills required for each group to play their part effectively in the FRMS. All groups require basic education about the dynamics of sleep loss and recovery, the effects of the daily cycle of the circadian body clock, the influence of workload, and the ways in which these factors interact with operational demands to produce fatigue (see Chapter 2). In addition, it is useful for all groups to have information on how to manage their personal fatigue and sleep issues.

Crewmembers

The ICAO SMS guidance (Doc 9859) recommends a 'building-block' approach to training. Applying this approach to FRMS, training for crewmembers could address the following areas.

- An overview of the FRMS structure and how it works in the operator's organization.
- Their responsibilities and those of the operator, in the FRMS.
- Causes and consequences of fatigue in the operation(s) in which they work.
- FRM processes in which they play a vital role, particularly in the use of fatigue reporting systems and implementing mitigations.
- The importance of accurate fatigue data (both subjective and objective).

- How to identify fatigue in themselves and others.
- Personal strategies that they can use to improve their sleep at home and to minimize their own fatigue risk, and that of others, while they are on duty.
- Basic information on sleep disorders and their treatment, where to seek help if needed, and any requirements relating to fitness to fly.

Crew Scheduling

FRMS training for personnel involved in crew scheduling could address the following areas.

- An overview of the FRMS structure and how it works in the operator's organization, including the concepts of shared responsibility and an effective reporting culture.
- A robust understanding of how scheduling affects sleep opportunities and can disrupt the circadian biological clock cycle, the fatigue risk that this creates, and how it can be mitigated through scheduling.
- Comprehensive training in the use and limitations of any scheduling tools and bio-mathematical models or other algorithms that may be used to predict the levels of crewmember fatigue across schedules and rosters.
- Their role in the FRMS in relation to fatigue hazard identification and risk assessment.
- Processes and procedures for assessing the potential fatigue impact of planned scheduling changes, and for ensuring that the Fatigue Safety Action Group is engaged early in the planning of changes with significant potential to increase fatigue risk.
- Processes and procedures for implementing scheduling changes recommended by the Fatigue Safety Action Group.
- How to identify fatigue in themselves and others.
- Personal strategies that they can use to improve their sleep at home and to minimize their own fatigue risk, and that of others, while they are at work.
- Basic information on sleep disorders and their treatment, and where to seek help if needed.

Fatigue Safety Action Group

FRMS training for members of the Fatigue Safety Action Group, and for others with responsibility for safety decision-making that affects FRMS performance, could address (at least) the following areas.

- A full understanding of all FRMS components and elements (policy and documentation; processes for hazard identification, risk assessment, mitigation, and monitoring; safety assurance processes for monitoring FRMS performance, managing change, and for continuous improvement of the FRMS; and FRMS promotion processes, including training and communication).
- The responsibilities and accountabilities of different stakeholders in the FRMS.
- Linkages between the FRMS and other parts of the operator's overall safety management system.
- Linkages between the FRMs and other parts of the organization, for example the scheduling department, flight operations, medical department, etc.

- Regulatory requirements for the FRMS.
- How to identify fatigue in themselves and others.
- Personal strategies that they can use to improve their sleep at home and to minimize their own fatigue risk, and that of others, while they are at work.
- Basic information on sleep disorders and their treatment, and where to seek help if needed.

Senior Management

FRMS training for senior management could address the following areas.

- An overall understanding of crewmember fatigue and the safety risk that it represents to the organization.
- An overview of the FRMS structure and how it works, including the concepts of shared responsibility and an effective reporting culture, and the role of the Fatigue Safety Action Group.
- The responsibilities and accountabilities of different stakeholders in the FRMS, including themselves.
- An overview of the types of fatigue mitigation strategies being used by the organization.
- FRMS safety assurance metrics used by the organization.
- Linkages between the FRMS and other parts of the operator's safety management system.
- Linkages between the FRMS and other parts of the organization, for example the scheduling department, flight operations, medical department, etc.
- Regulatory requirements for the FRMS.
- How to identify fatigue in themselves and others.
- Personal strategies that they can use to improve their sleep at home and to minimize their own fatigue risk, and that of others, while they are at work.
- Basic information on sleep disorders and their treatment, and where to seek help if needed.

Examples of training materials developed by the NASA Fatigue Countermeasures Program for flight crew in different types of operations are freely available on the internet. [14]

- The original generic training package 'Crew Factors in Flight Operations X: Alertness Management in Flight Operations Education Module' is available at: http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20020078410_2002126547.pdf
- The training package 'Crew Factors in Flight Operations XIV: Alertness Management in Regional Flight Operations Education Module' is available at: http://human-factors.arc.nasa.gov/zteam/PDF_pubs/REGETM_XIV.pdf
- The training package 'Crew Factors in Flight Operations XV: Alertness Management in General Aviation Education Module' is available at: http://humanfactors.arc.nasa.gov/publications/B_Flight_Ops_XV_GAETM1.pdf

[14] Web addresses accurate as of August 2, 2010

These training packages draw on fatigue-related safety data and scientific research. Each package includes a slide presentation with explanatory text. They are designed to be used as a personal resource by crewmembers, and/or as a live presentation that lasts at least an hour. In addition, the Regional and General Aviation Modules include summaries from a number of NASA studies and safety reports. It should be noted that these materials date from 2001-2002 and need to be updated to include more recent safety and scientific data, and to reflect current operating conditions. Nevertheless, they provide useful examples of the type and level of information that can be used in initial FRMS training, particularly for flight crew. They are useful examples, but each operator will need to look at how relevant the training materials are for their particular operational needs.

Table 6.1 provides some examples of personal fatigue mitigation strategies that might be covered in FRMS training for flight crew.

Table 6.1: Examples of Fatigue Hazards and Personal Mitigation Strategies (Not an Exhaustive List)

Fatigue Hazard	Personal Mitigation Strategies
Sleep at home disturbed by new baby	• Move to a quiet part of the house for final sleep before departure. • Maximize sleep in 24 hours before departure. • Controlled flight deck napping, maximize sleep during in-flight rest periods (if available). • Strategic use of caffeine in flight
In-flight sleepiness on non-augmented flights	• Maximize sleep in 24 hours before departure. • Controlled flight deck napping, strategic use of caffeine in flight.
Difficulty sleeping in onboard crew rest facilities	• Maximize sleep in 24 hours before departure. • Use eye mask, ear plugs, arrange a suitable wakeup call. • Avoid caffeine for 3-4 hours before trying to sleep. • Strategic use of caffeine after in-flight rest period.
Difficulty sleeping in noisy, poorly-curtained rooms in layover hotel	• Submit a fatigue report to the Fatigue Safety Action Group. • Use eye mask, ear plugs, arrange a suitable wakeup call. • Avoid caffeine for 3-4 hours before trying to sleep.
Non-restorative sleep	• See a sleep disorders specialist. • Comply fully with recommended treatment

Table 6.1 continued

Fatigue Hazard	Personal Mitigation Strategies
Unpredictable call-outs	• Ensure that sleep environment is dark and quiet, and use sleep hygiene measures to maximize sleep quality. • Maximise recovery sleep on off-duty days. • When feeling sleepy while waiting for call-out, attempt sleep (prioritise sleep over other activities). • Controlled flight deck napping, maximize sleep during in-flight rest periods (if available). • Strategic use of caffeine in flight
A specific city pairing results in landing when extremely fatigued.	• Submit a fatigue report to the Fatigue Safety Action Group. • Controlled flight deck napping. • Maximize sleep during in-flight rest periods (if available). • Strategic use of caffeine in flight.
Extended commute prior to scheduled flight duty period.	• Arrive at duty location with sufficient time to allow adequate sleep, ensuring fitness for duty.

6.2.3 FRMS Training Formats and Frequency

There are a variety of ways in which FRMS training can be delivered, each of which has strengths and limitations. Live training sessions with a trained instructor have the advantage that crewmembers can ask questions about their specific issues or concerns, and can learn from each other's experiences. Face-to-face contact with different stakeholders in the FRMS can facilitate building the safety culture. However, live training requires coordinating a time and place that groups of participants can attend, and involves time getting to and from the venue, in addition to the time required for the actual training session.

Web-based learning or distributed training (for example, using DVDs) allows greater flexibility in the time and place that training occurs. Individual participation allows participants to proceed at their own pace through the training materials. In web-based learning, sessions can be networked so that multiple participants can join in with a tutor on-line. Material can also be made interactive (a task has to be completed, for example a short quiz answered, before the participant can move on to the next part of the training). Participants and tutors can interact via designated 'chat rooms'. Web-based learning programs can also direct participants to explore a variety of other resources available on the internet. On the other hand, it is harder to eliminate 'cheating' when learning assessments are completed on-line than when they are completed in a classroom. This may be important for training evaluation (see below).

Providing different materials and formats for recurrent training can help to maintain interest. For example, recent fatigue reports or Fatigue Safety Action Group interventions can be used as case studies to illustrate and revise concepts covered in the initial training material. Recurrent training can also cover changes to the operations or the FRMS, and scientific and regulatory updates. The frequency and nature of recurrent training needs to be decided by the Fatigue Safety Action Group, in consultation with professional trainers (internal or external to the operator) as needed. Many regulators may also prescribe requirements on the frequency of FRMS training.

6.2.4 FRMS Training Evaluation

The effectiveness of FRM training and education programs should be periodically evaluated. Examples of evaluation tools can include the following.

- To evaluate immediate knowledge transfer from a training session, participants can be given a short quiz assessing fatigue knowledge, to be completed before and after the training session (for an example, see the text box below).
- To evaluate the amount of knowledge retained, crewmembers' use of suggested countermeasure strategies, and perceived usefulness of training, a survey can be conducted at a fixed time after training (for example, 6 months).
- Findings from the quiz and surveys can be used to:
    a) revise the content of the training package, to improve the training on topics which a significant proportion of crewmembers have not fully understood;
    b) provide feedback to trainers on areas where they may need to change or improve their teaching approaches; and
    c) identify areas that need to be reviewed or added in recurrent training.

QUIZ (for use before and after initial training)

Are these ideas true or false? ***Please tick one box for each question.***

1.	Sleep is a time when your brain switches off.	☐ True	☐ False
2.	Dreaming sleep is better for you than non-dreaming sleep.	☐ True	☐ False
3.	In the end, the only way to get rid of sleepiness is to get some sleep.	☐ True	☐ False
4.	You can always beat sleepiness, if you try hard enough.	☐ True	☐ False
5.	As you get sleepier, your reaction time slows down.	☐ True	☐ False
6.	Napping is a sign of laziness.	☐ True	☐ False
7.	The circadian body clock adapts easily to sleeping during the day.	☐ True	☐ False
8.	There are two times of day when your circadian body clock makes you feel most sleepy, around 3-5 am and 3-5 pm.	☐ True	☐ False
9.	Having a regular routine at bedtime can help you to fall asleep more easily.	☐ True	☐ False
10.	A dark, quiet room helps you sleep better.	☐ True	☐ False
11.	If you drink too much coffee and can't sleep, you should drink some alcohol to help you relax.	☐ True	☐ False
12.	Even if you are not sleepy, you should start each flight with a cup of coffee, to fight fatigue.	☐ True	☐ False
13.	You are on the flight deck and you feel incredibly sleepy. The best thing to do is not to tell anyone, and to try extra hard to stay focused.	☐ True	☐ False
14.	Fatigue would not be a problem if the schedules were properly designed.	☐ True	☐ False

6.2.5 FRMS Training Documentation

ICAO Annex 6, Part I, Appendix 8 requires that an operator keep documentation that describes and records FRMS training programs, training requirements, and attendance records.

6.2.6 FRMS Communications Plan

ICAO Annex 6, Part I, Appendix 8 requires an operator to have an FRMS communication plan that:

1. explains FRMS policies, procedures and responsibilities to all stakeholders; and
2. describes communication channels used to gather and disseminate FRMS-related information.

The FRMS training programs are clearly an important part of the communication plan. However, training generally occurs at fairly long intervals (for example annually). In addition, there needs to be ongoing communication to stakeholders about the activities and safety performance of the FRMS, to keep fatigue 'on the radar' and encourage the continuing commitment of all stakeholders. A variety of types of communication can be used, including electronic media (websites, on-line forums, e-mail), newsletters, bulletins, seminars, periodic poster campaigns in strategic locations, etc.

Communications about the activities and safety performance of the FRMS (from the Fatigue Safety Action Group or other designated management) need to be clear, timely and credible, i.e., consistent with the facts and with previous statements. The information provided also needs to be tailored to the needs and roles of different stakeholder groups, so that people are not swamped by large quantities of information that has little relevance to them.

Communications from crewmembers are vital for fatigue hazard identification, for feedback on the effectiveness of controls and mitigations, and in providing information for FRMS safety performance indicators (for example, by participating in surveys and fatigue monitoring studies). For these communications to be open and honest, all FRMS stakeholders need to have a clear understanding of the policies governing data confidentiality and the ethical use of information provided by crewmembers. There also needs to be clarity about the thresholds that separate non-culpable fatigue-related safety events from deliberate violations that could attract penalties.

Timely feedback to crewmembers who submit fatigue reports is vital. Feedback does not require completion of a full investigation. Every crewmember should receive a timely response to their report with some indication of the planned follow-up activity. For example - “To Capt Smyth; thank you for your fatigue report yesterday regarding flight 123 from AA to ZZ. This report has been forwarded to the Fatigue Safety Action Group, which is currently investigating an adverse trend in fatigue reports associated with this trip and is evaluating a number of potential mitigation strategies”.

The communication plan needs to be described in the FRMS documentation and assessed periodically as part of FRMS safety assurance processes

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7.0 FRMS IMPLEMENTATION

7.1 INTRODUCTION TO FRMS IMPLEMENTATION

There is no 'off-the-shelf' version of an FRMS that will suit all operators. Each operator needs to develop an FRMS that is appropriate to its organisation and operations and the nature and level of the fatigue risk(s).

The implementation of an FRMS can be done in stages, as is recommended for SMS. [15] The idea is to have a series of manageable steps so that resources and workload can be allocated over a period of time, rather than having to have everything available before implementation can begin. Having a staged approach is also a way to manage the complexity of the task, focusing on one step at a time. Figure 7.1 summarises a staged approach to FRMS implementation, based on the SMS model.

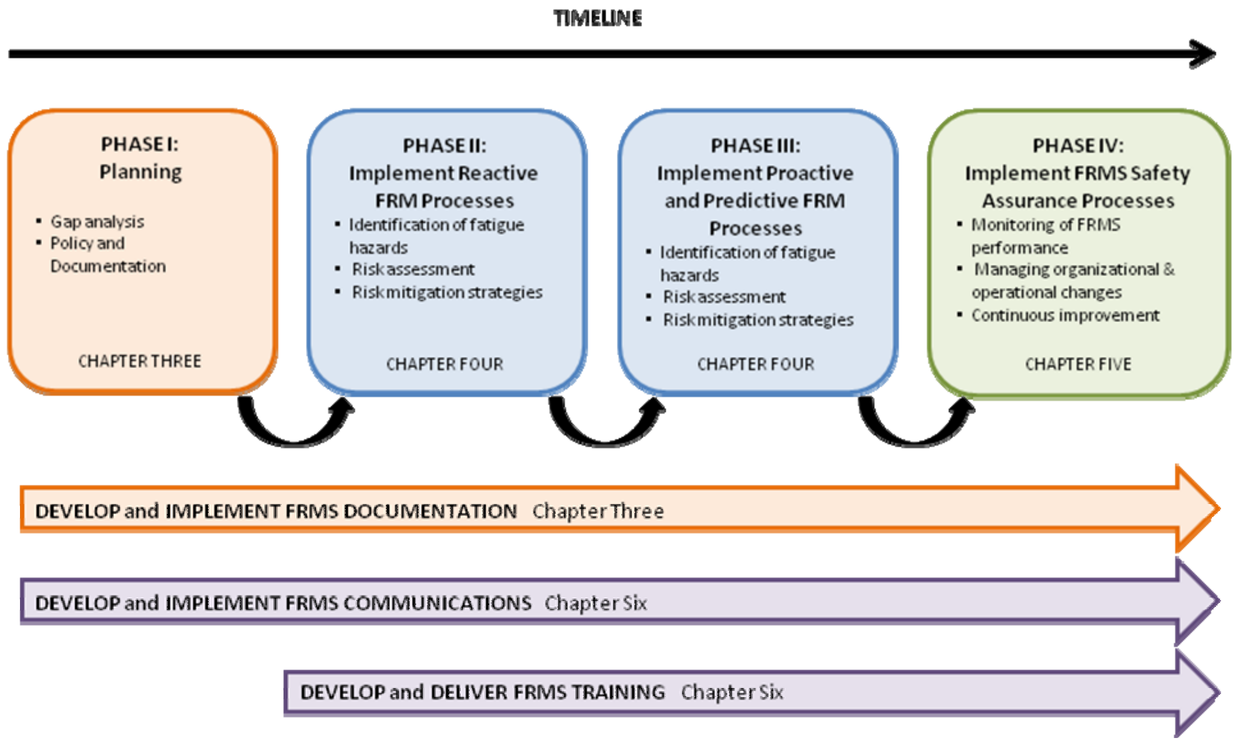

Figure 7.1: Stage approach to FRMS implementation

Once an operator has decided to implement an FRMS, and has reviewed the regulators requirements, they should notify the regulator that they wish to proceed. Full implementation of an FRMS involves four phases, each of which shoud to be reviewed by the regulator before the next phase begins. At the end of the fourth phase, the operator can seek regulatory approval for the full FRMS.

[15] ICAO Safety Management Manual (Doc 9859) Chapter 10. IATA Introduction to Safety Management Systems (SMS), 2nd Edition, Section 8.

7.2 PHASE I: PLANNING

The objective of Phase I is to arrive at an overall plan of how the FRMS will function, how it will be integrated with other parts of the operator's organization, who will be accountable for the FRMS, and who will be accountable for making sure that FRMS implementation is successfully completed.

Gap Analysis and Developing an Implementation Plan

Many elements needed for an FRMS may already be in place in an operator's organization. One of the first steps in FRMS implementation is therefore to undertake a gap analysis to:

- identify elements of the FRMS that are already available in existing systems and process; and
- identify existing systems and process that could be modified to meet the needs of FRMS (to minimize 're-inventing the wheel'); and
- identify where new systems and processes need to be developed for the FRMS.

For example, an operator may already have a confidential safety reporting system as part of its SMS. Existing report forms may (or may not) need to be modified to include the information needed to analyze the role of fatigue in safety events. Additional training may (or may not) be needed for the staff responsible for analyzing safety data, to ensure that they know how to analyze for the role of fatigue in events. A procedure will need to be added for information on fatigue-related events to be communicated on a regular basis to the Fatigue Safety Action Group. Fatigue reports may also be used as an FRMS safety performance indicator. In this case, a procedure would need to be added for this information to be evaluated regularly as part of the FRMS safety assurance processes.

Data on scheduled and actual flight and duty times are required to be collected under the fatigue management regulations. An operator that is moving some of its operations into an FRMS could add a variable to the existing flight and duty time databases to identify the operations covered by the FRMS, so that this information can be analyzed separately as required for the FRMS (Annex 6, Part I, Appendix 8). Procedures will need to be added for this information to be communicated to the Fatigue Safety Action Group and recorded as required in the FRMS documentation.

Rostering-related data may already be available for FRMS performance indicators, for example monthly significant exceedences on duty limits, use of captain's discretion, or use of extended duties. A procedure will need to be added for this information to be evaluated regularly as part of the FRMS safety assurance processes.

It may be efficient to schedule FRMS training to coincide with other training activities that already bring the target groups together.

The ICAO SMS Guidance (SMM Chapter 7, Appendix 2) provides a detailed checklist for a gap analysis that works systematically through all the elements of an SMS. This could be modified to work though the elements of an FRMS as identified in Figure 3.1 (Chapter Three, this manual).

The results of the gap analysis are used to inform the development of the FRMS implementation plan - a road map describing how the implementation will proceed, including timelines.

By the end of Phase I, the following steps need to be accomplished.

- Gap analysis.
- FRMS Policy Statement signed by the accountable executive. Developing the policy at the beginning of the FRMS implementation process will assist in defining the scope of the FRMS.
- FRMS implementation plan.
- FRMS documentation plan. This can be expected to evolve as the FRMS becomes operational.
- FRMS communication plan. This can be expected to evolve as the FRMS becomes operational.
- Allocation of financial and human resources. The Accountable Executive for the FRMS needs to have the authority and control to ensure that this happens. [16]
- Fatigue Safety Action Group (or equivalent) established. The stage at which the Fatigue Safety Action Group is established will vary, according to the size and complexity of the organization and the FRMS, and whether there are suitably qualified people in other parts of the organization who are available to begin the Phase I activities.

7.3 PHASE II: IMPLEMENT REACTIVE FRM PROCESSES

Phase II implements the (first version) of the FRM processes, based on reactive hazard identification (Chapter Four). It does this by gathering and analyzing existing sources of information and data that are relevant to the operations covered by the FRMS. Types of information that may be available include confidential safety reports, accident reports and incident investigations, audits, and historical rostering data (for example, data on scheduled and actual flight and duty times, exceedences, etc.). In effect, Phase II activities consolidate existing fatigue risk management processes and procedures in the organization, and introduce controls and mitigations to manage identified deficiencies in the existing system.

By the end of Phase II, the following steps need to be accomplished.

- FRM processes based on reactive hazard identification are operational, including risk assessment and the development, implementation, and monitoring of appropriate controls and mitigations.
- FRMS documentation processes are established to support the current version of the FRMS.
- FRMS training activities are established to support the current version of the FRMS. (Stakeholders need training to ensure that they are competent to undertake their responsibilities in the FRMS as the implementation plan rolls out).
- FRMS communication processes are established to support the current version of the FRMS.
- The operator is ready to undertake coordinated safety analyses of this first version of the FRMS (ICAO SMM 10.4).

[16] IATA Introduction to Safety Management Systems (SMS), 2nd Edition, Section 8.4.

Phase III adds proactive and predictive fatigue hazard identification processes (discussed in Chapter Four) into the FRMS processes established in Phase II.

By the end of Phase III, the following steps need to be accomplished.

- FRM processes based on reactive, proactive, and predictive hazard identification are operational, including risk assessment and the development, implementation, and monitoring of appropriate controls and mitigations.
- FRMS documentation processes are established to support the current version of the FRMS.
- FRMS training activities are established to support the current version of the FRMS. (A single program to the level required for the full FRMS implementation may be more efficient than part-training at each Phase of the implementation.)
- FRMS communication processes are established to support the current version of the FRMS.
- The operator is ready to undertake coordinated safety analyses of this version of the FRMS, similar to the process used when implementing SMS (ICAO SMM 10.4).

7.5 PHASE IV: IMPLEMENT FRMS SAFETY ASSURANCE PROCESSES

Phase IV activates the FRMS safety assurance processes (Chapter Five of this manual). By the end of Phase IV, the following steps need to be accomplished.

- Roles and responsibilities for assuring the safety performance of the FRMS are established.
- The necessary authorities and communication channels are active.
- FRMS safety performance indicators have been developed and agreed on.
- The procedures and processes for periodic evaluation of the safety performance indicators are established.
- Appropriate feedback is established between the FRM processes and the FRMS safety assurance processes.
- FRMS documentation processes are fully implemented.
- FRMS training processes are fully implemented.
- FRMS communication processes are fully implemented.

In other words, by the end of Phase IV, the FRMS should be fully functional and integrated with the operator's SMS and other parts of the organization as appropriate. It should be continuously improving and able to respond to changes in the organization and the operating environment. Having an FRMS has been described by one operator as making his organization 'nimble', in the sense of being able to respond quickly when market opportunities arise (for example new routes that become viable when aircraft capabilities change).

Regulatory approval for the full FRMS is sought at the end of Phase IV.

7.6 OPERATIONAL EXAMPLE OF STAGED FRMS IMPLEMENTATION

Operator A is a major airline that flies primarily long range, trans-oceanic flights with multi-national crews. It has been flying for 20 years with an excellent safety record. Operator A is interested in starting an FRMS for both of its long range fleets. The CEO decides to implement FRMS for the entire operation to enhance safety and efficiency.

This example works through the steps that Operator A could follow to implement a fully operational FRMS. It assumes that management at Operator A are familiar with information in this Implementation Guide and are ready to start implementation.

Phase I

1. Responsibility for FRMS implementation assigned to a designated FRMS manager.
2. FRMS manager assembles an implementation team, and organizes training for the team on FRMS basics and fatigue science.
3. Accountable Executive for the FRMS allocates resources and authority to support FRMS development.
4. FRMS manager identifies internal stakeholders (department representatives).
5. FRMS policy statement is drafted.
6. Gap analysis undertaken by FRMS manager and implementation team.
7. FRMS documentation plan developed and first draft established.
8. FRMS communication plan developed and first draft established.
9. Implementation plan developed, with initial timeline.
10. Fatigue Safety Action Group established with required stakeholder membership and meets regularly with the implementation team (if different employees) to discuss progress.

Phase II

11. Fatigue Safety Action Group works through the FRM process diagram (Chapter 4), using existing information and data for <u>reactive fatigue hazard identification</u>.
    a) Step 1 - decide whether domestic, international long haul and ULR operations require different FRM processes. Carry out the following steps for each set of FRM processes.
    b) Step 2 –collect and analyze available data and information (for example confidential safety reports, accident reports and incident investigations, audits, and historical rostering data).
    c) Step 3 – Identify fatigue hazards(s)
    d) Step 4 – establish risk assessment processes and procedures. Clarify linkages to SMS risk assessment and processes for prioritization of risks to be mitigated. (In this large airline example, the FRMS policy statement indicates that the Fatigue Safety Action Group is responsible for prioritizing fatigue risks, and for developing, implementing, and monitoring fatigue controls and mitigations. It is required to provide monthly reports of these activities to the SMS Review Board, with the intent that this report will become part of the FRMS safety assurance process in the overall FRMS.)
    e) Step 5 – select and implement controls and mitigations. Set safety performance indicators.
    f) Step 6 – set up processes for monitoring the effectiveness of controls and mitigations

12. Perform training to ensure that stakeholders are competent to undertake their roles and responsibilities in the FRMS. In this example, it is decided to undertake training to support the full FRMS. Communication channels are set up to provide training updates and reminders when Phases III and IV of the FRMS implementation become active.
13. FRMS communication channels established.
14. Fatigue Safety Action Group provides a coordinated safety analysis of the existing FRMS to the SMS Review Board. (The SMS Review Board is responsible for the FRMS safety assurance functions, in this example).

Phase III

15. For each set of FRMS processes established in Phase II, the Fatigue Safety Action Group identifies appropriate tools for proactive and predictive fatigue hazard identification.
    a) Proactive fatigue identification tools are used for assessing routine and complex hazards.
16. Proactive and predictive fatigue hazard identification are integrated in to the FRM processes established in Phase II.
17. All stakeholders have received suitable training and are competent to undertake their roles and responsibilities in the FRMS.
18. FRMS communication channels are operational.
19. Fatigue Safety Action Group provides a coordinated safety analysis of the existing FRMS to the SMS Review Board.

Phase IV

20. FRMS safety performance indicators are decided collaboratively by the Fatigue Safety Action Group and the SMS Review Board and approved by the Accountable Executive for the FRMS.
    a) Decide which information that will be analyzed for trends (e.g., fatigue reporting rates between similar city pairs, operations, or fleets)
    b) Develop criteria for comparing performance with safety objectives (for example, is the overall risk level increasing, is the number of higher risk events increasing, are safety objective in the FRMS policy being achieved, are regulatory requirements being met).
    c) Decide how emerging fatigue hazards are identified. For example, set triggers to identify when action is needed (at what level do adverse trends in performance indicators trigger an investigation of the causes of the trend).
21. Processes are established for identifying changes that could impact the FRMS.
22. Processes are established for evaluating how well Fatigue Safety Action Group recommendations are implemented in other parts of the organization, for example in scheduling and flight operations.

23. The following safety assurance processes are established.
    a) Monthly reporting by the Fatigue Safety Action Group to the SMS Review Board. To include updates on fatigue hazards identified and on the status of agreed safety performance indicators.
    b) SMS Review Board able call for special reports from the Fatigue Safety Action Group, for example after significant operational changes such as a newly established route.
    c) Quarterly review of trends in confidential crew reports relating to fatigue, to be undertaken by the Fatigue Safety Action Group and reported to the SMS Review Board.
    d) Quarterly review of exceedences of flight and duty time limits specified in the FRMS Policy, to be undertaken by the Fatigue Safety Action Group and reported to the SMS Review Board.
    e) Quarterly review of trends in FRMS safety performance indicators identified in the FRMS policy, to be undertaken by the Fatigue Safety Action Group and reported to the SMS Review Board.
    f) Annual review of fatigue hazard identification and mitigation activities of the Fatigue Safety Action Group by an independent FRMS Scientific Advisory Group.
    g) Internal audit of the FRMS by a team selected by the SMS Review Board.
    h) Annual report of the Fatigue Safety Action Group to the SMS Review Board and the Accountable Executive for the FRMS, to include the recommendations of the independent FRMS Scientific Advisory Group, findings of audits, and actions taken in response to them.
24. First quarterly audit of FRMS safety performance by the team selected by the SMS Review Board. If audits are satisfactory for one year, internal audit will revert to every 6 months.
25. FRMS documentation fully implemented.
26. FRMS training fully implemented.
27. FRMS communications fully implemented.

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APPENDIX A: GLOSSARY

***** denotes an ICAO definition.

Actigraph (or Actiwatch).

A wristwatch-like device containing an accelerometer to detect movement. Activity counts are recorded per unit time, for example every minute. The patterns of movement can be analyzed using purpose-built software to estimate when the wearer of the actiwatch was asleep, and to provide some indication of how restless a sleep period was (i.e., sleep quality). Actigraphs are designed to record continuously for several weeks so they are valuable tools for monitoring sleep patterns, for example before, during, and after a trip

Actigraphy.

Use of actiwatches to monitor sleep patterns. For actigraphy to be a reliable measure of sleep, the computer algorithm that estimates sleep from activity counts must have been validated against polysomnography, which is the gold standard technology for measuring sleep duration and quality. The main weakness of actigraphy is that an actigraph cannot differentiate between sleep and still wakefulness (since it measures movement).

Afternoon Nap Window

A time of increased sleepiness in the middle of the afternoon. The precise timing varies, but for most people it is usually around 15:00-17:00. This is a good time to try to nap. On the other hand, it is also a time when it is more difficult to stay awake, so unintentional micro-sleeps are more likely, especially if recent sleep has been restricted

Augmented Flight Crew

A flight crew that comprises more than the minimum number required to operate the aeroplane so that each crewmember can leave his or her assigned post to obtain in-flight rest and be replaced by another appropriately qualified crewmember.

Augmented Long Range Operations

Flights where the flight duty period is extended through the use of augmented crews, allowing crewmembers the opportunity for in-flight rest.

Bio-mathematical Model

A computer programme designed to predict crewmember fatigue levels, based on scientific understanding of the factors contributing to fatigue. All bio-mathematical models have limitations that need to be understood for their appropriate use in an FRMS. An optional tool (not a requirement) for predictive fatigue hazard identification (ICAO Annex 6, Part 1, Appendix 8, Section 2.1.)

Chronic fatigue

In fatigue risk management, chronic fatigue refers to the sleepiness and performance impairment that accumulate when sleep is restricted day after day. These effects can be reversed by obtaining adequate recovery sleep (also see cumulative sleep debt).

Chronic Fatigue Syndrome

Medical condition for which the diagnosis requires a person must meet two criteria:

1. Have severe chronic fatigue for at least 6 months or longer that is not relieved by rest and not due to medical or psychiatric conditions associated with fatigue as excluded by clinical diagnosis; and
2. Concurrently have four or more of the following symptoms: self-reported impairment in short-term memory or concentration severe enough to cause substantial reduction in previous levels of occupational, educational, social, or personal activities; sore throat that is frequent or recurring; tender lymph nodes in the neck or armpits; muscle pain; multi-joint pain without swelling or redness; headaches of a new type, pattern, or severity; unrefreshing sleep; and post-exertional malaise (extreme, prolonged exhaustion and sickness following physical or mental activity) lasting more than 24 hours.

   The fatigue and impaired memory or concentration must have impaired normal daily activities, along with other symptoms that must have persisted or recurred during 6 or more consecutive months of illness and must not have predated the fatigue. http://www.cdc.gov/cfs/general/case_definition/index.html

Circadian Body Clock

A neural pacemaker in the brain that monitors the day/night cycle (via a special light input pathway from the eyes) and determines our preference for sleeping at night. Shift work is problematic because it requires a shift in the sleep/wake pattern that is resisted by the circadian body clock, which remains 'locked on' to the day/night cycle. Jet lag is problematic because it involves a sudden shift in the day/night cycle to which the circadian body clock will eventually adapt, given enough time in the new time zone.

Controls

System-level defensive strategies designed to minimize fatigue risk on an ongoing basis. Examples include: scheduling rules, monitoring staffing levels at crew bases, selection of appropriate in-flight crew rest facilities, and protocols for in-flight rest and controlled rest on the flight deck.

Controlled flight deck napping

An effective mitigation strategy to be used as needed in response to fatigue experienced during flight operations. Recommended procedures for controlled flight deck napping can be found in Appendix C. It should not be used as a scheduling tool, i.e., as a planned strategy to enable extended duty periods

Countermeasures

Personal mitigation strategies that crewmembers can use to reduce their own fatigue risk. Sometimes divided into strategic countermeasures (for use at home and on layovers, for example good sleep habits, napping before night duty), and operational countermeasures for use in flight, for example controlled rest on the flight deck.

***Crewmember**

A person assigned by an Operator to duty on an aircraft during a flight duty period

Crew Pairing

A set of scheduled flights on which a crewmember is rostered for one or more days.

Cumulative sleep debt

Sleep loss accumulated when sleep is insufficient for multiple nights (or 24-hr days) in a row. As cumulative sleep debt builds up, performance impairment and objective sleepiness increase progressively, and people tend to become less reliable at assessing their own level of impairment

***Duty**

Any task that crew members are required by the Operator to perform, including, for example, flight duty, administrative work, training, positioning and standby when it is likely to induce fatigue

***Duty Period**

A period which starts when a flight or cabin crew member is required by an Operator to report for or to commence a duty and ends when that person is free from all duties.

Evening Type

A person whose natural sleep time is later than average as a result of the characteristics of their circadian biological clock. There is also a developmental trend to become more evening-type across puberty, which reverses for most people in adulthood.

Evening Wake Maintenance Zone

A period of several hours in the circadian body clock cycle, just before usual bedtime, when it is very difficult to fall asleep. Consequently, going to bed extra early usually results in taking a longer time to fall asleep, rather than getting extra sleep. Can cause restricted sleep and increased fatigue risk with early duty start times.

***Fatigue**

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.

FRMS Training

Competency-based training programs designed to ensure that all stakeholders are competent to undertake their responsibilities in the FRMS.

Fatigue Safety Action Group (FSAG)

A group comprised of representatives of all stakeholder groups (management, scheduling, crew representatives) together with specialist scientific, data analysis, and medical expertise as required), that is responsible for coordinating all fatigue management activities in the organisation.

Fatigue Risk Management

The management of fatigue in a manner appropriate to the level of risk exposure and the nature of the operation, in order to minimise the adverse effects of fatigue on the safety of operations.

Fatigue Risk Management System Policy

A required component of an FRMS (ICAO Annex 6, Part 1, Appendix 8, Section 1.1). THE FRMS Policy must: identify the elements of the FRMS and its scope; reflect the shared responsibility of all stakeholders in the FRMS; state the safety objectives of the FRMS; be signed by the accountable executive of the organisation; be communicated throughout the organisation; declares management commitment to effective safety reporting, to providing adequate resourcing for the FRMS, and to continuous improvement of the FRMS; identify clear lines of accountability for the functioning of the FRMS; and require periodic reviews of the FRMS.

***Fatigue Risk Management System (FRMS).**

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 Safety Assurance

FRMS safety assurance processes monitor the entire FRMS to check that it is functioning as intended and meeting the safety objectives in the FRMS policy and regulatory requirements. FRMS safety assurance processes also identify operational and organizational changes that could potentially affect the FRMS, and identify areas where the safety performance of the FRMS could be improved (continuous improvement).

***Flight data analysis (FDA)**

A process of analyzing recorded flight data in order to improve the safety of operations.

***Flight duty period**

A period which commences when a crew member is required to report for duty that includes a flight or a series of flights and which finishes when the aeroplane finally comes to rest and the engines are shut down at the end of the last flight on which he/she is a crew member.

***Flight time – aeroplanes**

The total time from the moment an aeroplane first moves for the purpose of taking off until the moment it finally comes to rest at the end of the flight.

Homeostatic Sleep Pressure

See Sleep Homeostatic Process

Internal Alarm Clock

A time in the circadian body clock cycle when there is a very strong drive for waking and it is difficult to fall asleep or stay asleep. Occurs about 6 hours after the **Window of Circadian Low** in the late morning to early afternoon and can cause restricted sleep and increased fatigue risk after night duty.

Jet Lag

Desynchronization between the circadian body clock and the day/night cycle caused by transmeridian flight (experienced as a sudden shift in the day/night cycle). Also results in internal desynchronization between rhythms in different body functions. Common symptoms include wanting to eat and sleep at times that are out of step with the local routine, problems with digestion, degraded performance on mental and physical tasks, and mood changes. Resolves when sufficient time is spent in the new time zone for the circadian body clock to become fully adapted to local time

Micro-sleep

A short period of time (seconds) when the brain disengages from the environment (it stops processing visual information and sounds) and slips uncontrollably into light non-REM sleep. Micro-sleeps are a sign of extreme physiological sleepiness.

Mitigations

System-level interventions designed to reduce a specific identified fatigue risk. Examples include: increasing the number of crewmembers at a base, use of reserve crew, educating crewmembers on how to obtain optimal in-flight sleep, Captain's discretion to re-organize in-flight rest arrangements on the day of flight in response to crewmembers' fatigue levels and operational conditions, etc.

Morning Type

A person whose natural sleep time is earlier than average as a result of the characteristics of their circadian biological clock. There is also a developmental trend to become more morning-type across adulthood.

Nap

A brief period of sleep, usually defined as less than half of a full night time sleep period. Naps as short as 5 minutes have been shown to provide (temporary) relief from the cumulative effects of sleep loss – also see controlled flight deck napping

Non-Rapid Eye Movement Sleep (Non-REM Sleep)

A type of sleep associated with gradual slowing of electrical activity in the brain (seen as brain waves measured by electrodes stuck to the scalp, known as EEG). As the brain waves slow down in non-REM sleep, they also increase in amplitude, with the activity of large groups of brain cells (neurons) becoming synchronized. Non-REM sleep is usually divided into 4 stages, based on the characteristics of the brainwaves. Stages 1 and 2 represent lighter sleep. Stages 3 and 4 represent deeper sleep and are also known as slow-wave sleep.

Non-REM/REM Cycle

Regular alternation of non-REM sleep and REM sleep across a sleep period, in a cycle lasting approximately 90 minutes

Rapid Eye Movement Sleep (REM Sleep)

A type of sleep during which electrical activity of the brain resembles that during waking. However, from time to time the eyes move around under the closed eyelids – the 'rapid eye movements' – and this is often accompanied by muscle twitches and irregular heart rate and breathing. People woken from REM sleep can typically recall vivid dreaming. At the same time, the body cannot move in response to signals from the brain, so dreams cannot be 'acted out'. The state of paralysis during REM sleep is sometimes known as the 'REM block'.

Recovery Sleep

Sleep required for recovery from the effects of acute sleep loss (in one 24-hour period) or cumulative sleep debt (over multiple consecutive 24-hour periods). Recovery sleep may be slightly longer than usual, but lost sleep is not recovered hour-for-hour. Two nights of unrestricted sleep (when a crewmember is fully adapted to the local time zone) are typically required for recovery of normal sleep structure (non-REM/REM cycles). Recent laboratory research suggests that recovery of optimal waking function may take more than two nights of recovery sleep.

***Rest Period**

A continuous and defined period of time subsequent to and/or prior to duty, during which flight or cabin crew members are free of all duties.

Roster/Rostering

Assignment of crewmembers to a schedule.

Safety Management

The systematic management of the operational risks associated with flight, engineering and ground activities in order to achieve as high a level of safety performance as is reasonably practicable.

***Safety Management System (SMS)**

A systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures.

Safety Performance

The level of safety achieved in a risk controlled environment measured against a safety level deemed as low as reasonably practicable.

Schedule

Sequence of flights designed to meet operational requirements and effectively manage resources including crewmembers.

Shift Work

Any work pattern that requires a crewmember to be awake at a time in the circadian body clock cycle that they would normally be asleep. Problematic because the circadian body clock is sensitive to light and tends to remain 'locked on' to the day/night cycle rather than adapting to the work pattern. Shift work is usually associated with sleep restriction, together with a requirement to work during times in the circadian body clock cycle when performance and alertness are sub-optimal (for example, through the Window of Circadian Low).

Sleep

A reversible state in which conscious control of the brain is absent and processing of sensory information from the environment is minimal. The brain goes "off-line" to sort and store the day's experiences and replenish essential systems depleted by waking activities. A complex series of processes characterized by alternation between two different brain states: non-REM sleep and REM sleep

Sleep Debt

See Cumulative sleep debt

Sleep Disorders

A range of problems that make it impossible to obtain restorative sleep, even when enough time is spent trying to sleep. More than 80 different sleep disorders have been identified, that can cause varying amounts of sleep disruption. Examples include obstructive sleep apnea, the insomnias, narcolepsy, and periodic limb movements during sleep

Sleep Homeostatic Process

The body's need for **slow-wave sleep** (non-REM stages 3 and 4), that builds up across waking and discharges exponentially across sleep

Sleep Inertia

Transient disorientation, grogginess and performance impairment that can occur as the brain progresses through the process of waking up. Sleep inertia can occur on waking from any stage of sleep but may be longer and more intense on waking from slow-wave sleep (non-REM stages 3 and 4), or after sleep periods or naps containing a high proportion of slow-wave sleep.

Sleep Need

The amount of sleep that is required on a regular basis to maintain optimal levels of waking alertness and performance. Very difficult to measure in practice because of individual differences. In addition, because many people live with chronic sleep restriction, when they have the opportunity for unrestricted sleep, their sleep may be longer than their theoretical 'sleep need' due to recovery sleep.

Sleep Quality

Capacity of sleep to restore waking function. Good quality sleep has minimal disruption to the non-REM/REM cycle. Fragmentation of the non-REM/REM cycle by waking up, or by brief arousals that move the brain to a lighter stage of sleep without actually waking up, decreases the restorative value of sleep.

Sleep Restriction

Obtaining less sleep than needed ('trimming' sleep) across at least two consecutive nights. The effects of sleep restriction accumulate, with performance impairment and objective sleepiness increasing progressively. The need for sleep will eventually build to the point where people fall asleep uncontrollably (see micro-sleep).

Slow-Wave Sleep

The two deepest stages of non-REM sleep (stages 3 and 4), characterized by high amplitude slow brainwaves (EEG dominated by 0.5-4 Hz).

Standby/standby duty

A defined period of time, at the airport, at the hotel, or at home, during which a flight or cabin crew member is required by the Operator to be available to receive an assignment for a specific duty without an intervening rest period.

Transient fatigue

Impairment accumulated across a single duty period, from which complete recovery is possible during the next rest period.

Trip

A scheduling expression describing the time from when a crewmember initially reports for duty until he/she returns home from the sequence of flights and is released from duty. A trip may include multiple flights and many days of travel.

Ultra long range operations (ULR)

Augmented long range operations involving any sector between a specific city pair in which the planned flight time exceeds 16 hours, taking into account mean wind conditions and seasonal changes (as defined by the Ultra long range Crew Alertness Steering Committee, Flight Safety Foundation (2005). Flight Safety Digest 26.)

Unforeseen operational circumstance

An unplanned event, such as unforecast weather, equipment malfunction, or air traffic delay that is beyond the control of the operator. In order to be considered unforeseen, the circumstance would occur or become known to the operator after the flight has begun (after the moment the aeroplane first moves for the purpose of taking off)

Unrestricted sleep

Sleep which is not restricted by duty demands. Sleep can begin when a crewmember feels sleepy, and does not have to be delayed because of duty demands. In addition, the crewmember can wake up spontaneously and does not have to set the alarm to be up in time for duty.

Window of Circadian Low (WOCL)

Time in the circadian body clock cycle when subjective fatigue and sleepiness are greatest and people are least able to do mental or physical work. The WOCL occurs around the time of the daily low point in core body temperature - usually around 03:00-05:00 when a person is fully adapted to the local time zone. However, there is individual variability in the exact timing of the WOCL, which is earlier in morning-types (larks) and later in evening-types (owls), and may move a few hours later after consecutive night shifts.

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APPENDIX B: MEASURING CREWMEMBER FATIGUE

FRM Processes (Chapter 4) and FRMS safety assurance processes (Chapter Five) sometimes require the measurement of crewmember fatigue. There is no single measurement that is the 'gold standard', because fatigue-related impairment affects many skills and has multiple causes. A wide variety of fatigue measures are used in scientific research. The measures described here are examples that have been chosen because:

- they have been shown to be sensitive for measuring what they claim to measure (i.e., they have been scientifically validated);
- they do not jeopardize crewmembers' ability to perform their operational duties; and
- they have been widely used in aviation, so data can be compared between different types of operations.

New ways to measure fatigue and sleep are always being developed and some will become valuable tools to add to the list below, once they have been validated for use in aviation operations. Meanwhile, in an FRMS it is important to use measures that are accepted by regulators, operators, crewmembers, and scientists as being meaningful and reliable. This avoids the unnecessary cost and inconvenience of collecting data that is of doubtful value.

Fatigue measurements can be based on crewmembers' recall or current impressions of fatigue (subjective measures) or on objective measurements, such as performance tests and different types of physical monitoring.

Each type of measure has strengths and weaknesses. To decide which types of data to collect, the most important consideration should be the expected level of fatigue risk.

B1 CREWMEMBERS' RECALL OF FATIGUE

B1.1 Fatigue Reporting Forms

Fatigue reports allow individual crewmembers to give vital feedback on fatigue risks where and when they occur in an operation. Crew members are encouraged to do this through an effective safety reporting system (ICAO Doc 9859, SMS Manual). It is necessary to provide a clear understanding of the line between acceptable performance (which can include unintended errors) and unacceptable performance (such as negligence, recklessness, violations or sabotage). This provides fair protection to reporters but does not exempt them from punitive action where it is warranted. Crewmembers also need to be confident that reports will be acted on, which requires feedback from the Fatigue Safety Action Group, and need to be assured that the intent of the reporting process is to improve safety, not to attribute blame. A series of fatigue reports on a particular route can be a trigger for further investigation by the Fatigue Safety Action Group.

Fatigue report forms need to be easy to access, complete, and submit. Consideration should be given to making fatigue report forms available for completion electronically, for example on lap top computers or smart phones (I-Pod, Blackberry, etc). The following example is adapted from a form that has been routinely used in an operator's FRMS for more than 10 years.

When fatigue report forms are first introduced, or other activities that raise fatigue awareness are launched, there is likely to be an increase in fatigue reporting. This 'spike' does not necessarily represent an increase in fatigue occurrences or risk. It may simply be due to people being more likely to report. Other FRMS safety performance indicators may need to be evaluated, to decide whether the increase in reporting should trigger further action by the Fatigue Safety Action Group.

Fatigue Report Form

If confidentiality required tick here ○

Name		Employee No.		Pilot/CCM	(circle)

WHEN DID IT HAPPEN? Local report date ______ Time of event (local report time) ______

Duty description (trip pattern) ______

Sector on which fatigue occurred — From ______ To ______

Hours from report time to when fatigue occurred ______ Disrupt? Yes / No

Aircraft type ______ Number of crew ______

WHAT HAPPENED?

Describe how you felt (or what you observed) ______

Please circle how you felt

1	Fully alert, wide awake	5	Moderately let down, tired
2	Very lively, somewhat responsive, but not at peak		
3	OK, somewhat fresh	6	Extremely tired, very difficult to concentrate
4	A little tired, less than fresh	7	Completely exhausted

Please mark the line below with an 'X' at the point that indicates how you felt

alert --- drowsy

WHY DID IT HAPPEN?

Fatigue prior to duty?	Yes / No	How long had you been awake when the event happened?		hrs mins
Hotel	Yes / No			
Home	Yes / No	How much sleep did you have in the <u>24 hrs</u> before the event?		hrs mins
Duty itself	Yes / No			
In-flight rest	Yes / No	How much sleep did you have in the <u>72 hrs</u> before the event?		hrs mins
Disrupt	Yes / No			
Personal	Yes / No	flight deck nap?	Yes / No	If yes, when: start end

Other comments ______

WHAT DID YOU DO? Actions taken to manage or reduce fatigue (for example, flight deck nap)

WHAT COULD BE DONE? Suggested corrective actions

B1.2 Retrospective Surveys

Retrospective surveys are a comparatively cheap way to obtain information from a group of crewmembers on a range of topics such as:

- demographics (age, flying experience, gender, etc);
- amount and quality of sleep at home and on trips;
- experience of fatigue on duty; and
- views on the causes and consequences of fatigue on duty.

Wherever possible, validated scales and standard questions should be used for gathering information on common topics such as sleep problems. This enables the responses of crewmembers to be compared across time, or with other groups. [17] For example, the Epworth Sleepiness Scale is a validated tool for measuring the impact of sleepiness on daily life. It is widely used clinically, to evaluate whether an individual is experiencing excessive sleepiness, [18] and information is available on its distribution in large community samples. [19] Figure B1 shows the Epworth Sleepiness scale. The crewmember is asked to rate each situation from 0='would never doze' to 3 'high chance of dozing', for a total possible score of 24. Scores above 10 are generally considered to indicate excessive sleepiness. Scores above 15 are considered to indicate extreme sleepiness.

How likely are you to doze off or fall asleep in the following situations, in contrast to feeling just tired? This refers to your usual way of life in recent times.PLEASE TICK ONE BOX ON EACH LINE

	would never doze	**slight chance**	**moderate chance**	**high chance**
Sitting and reading	0 ☐	1 ☐	2 ☐	3 ☐
watching TV	0 ☐	1 ☐	2 ☐	3 ☐
Sitting inactive in a public place (eg. theatre, meeting)	0 ☐	1 ☐	2 ☐	3 ☐
As a passenger in a car for an hour without a break	0 ☐	1 ☐	2 ☐	3 ☐
Lying down in the afternoon when circumstances permit	0 ☐	1 ☐	2 ☐	3 ☐
Sitting and talking to someone	0 ☐	1 ☐	2 ☐	3 ☐
Sitting quietly after a lunch without alcohol	0 ☐	1 ☐	2 ☐	3 ☐
In a car, while stopped for a few minutes in traffic	0 ☐	1 ☐	2 ☐	3 ☐

Figure B1: The Epworth Sleepiness Scale

[17] Note that some measures, for example the Karolinska Sleepiness Scale and the Samn-Perelli Crew Status Check are not designed to be used retrospectively. They are meant to be answered in relation to how you feel now.

[18] Johns MW (1994). Sleepiness in different situations measured by the Epworth Sleepiness Scale. *Sleep* 17:703-710.

[19] Gander PH, Marshall NS, Harris R, Reid P (2005). The Epworth sleepiness score: Influence of age, ethnicity and socioeconomic deprivation. *Sleep* 28:249-253

Retrospective surveys can also be used to track the effectiveness of an FRMS across time (i.e., as an FRMS safety assurance process – see Figure 5.3).

Strengths and Weaknesses of Retrospective Surveys

Retrospective surveys are a comparatively cheap way to gather a range of information. However, time and costs are involved in developing and distributing the survey questionnaire, entering the information into databases and analyzing it.

A limitation of retrospective surveys is that the information gathered is subjective, and therefore its reliability is open to question. Reliability is a particular issue when crewmembers are asked to accurately recall details of past events, feelings, or sleep patterns. This is not to question crewmembers' integrity – inaccurate recall of past events is a common and complex human problem. Concerns about whether some crewmembers might exaggerate in their responses, for personal or industrial reasons, should be minimal in a just reporting culture as is required for FRMS. In addition, extreme ratings are obvious when compared with group averages.

Crewmembers' confidence in the confidentiality of their data is likely to be a very important factor in their willingness to participate in surveys and to provide complete information on questionnaires. Despite limitations, retrospective surveys from time-to-time can be a useful source of information in an FRMS.

B2 MONITORING CREWMEMBER FATIGUE DURING FLIGHT OPERATIONS

B2.1 Subjective Fatigue and Sleepiness Ratings

The following things should be considered when choosing rating scales for monitoring crewmember fatigue and sleepiness during flight operations.

1. Is the scale quick and easy to complete?
2. Is it designed to be completed at multiple time points, e.g., across a flight?
3. 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?
4. Is it predictive of objective measures such as performance or motor vehicle crash risk?
5. Has it been used in other aviation operations, and are the data available to compare fatigue levels?

The following two scales meet these criteria.

The Karolinska Sleepiness Scale (KSS)

This scale asks people to rate how sleepy they feel right now[20]. Any of the values from 1-9 can be ticked, not only those with a verbal description.

1 = extremely alert
2
3 = alert
4
5 = neither sleepy nor alert
6
7 = sleepy, but no difficulty remaining awake
8
9 = extremely sleepy, fighting sleep

Figure B3: The Karolinska Sleepiness Scale (KSS)

[20] Åkerstedt T, Gillberg M. Subjective and objective sleepiness in the active individual. Int J Neurosci 52: 29-37, 1990.

Gillberg M, Kecklund G, Åkerstedt T. Relations between performance and subjective ratings of sleepiness during a night awake. Sleep 17(3): 236-241, 1994.

Harma M, Sallinen M, Ranta R, Mutanen P, Muller K. The effect of an irregular shift system on sleepiness at work in train drivers and railway traffic controllers. J Sleep Res 11(2):141-151, 2002.

Gillberg M. Subjective alertness and sleep quality in connection with permanent 12-hour day and night shifts. Scand J Work Environ Health 24 (Suppl 3): 76-80, 1998.

Reyner LA, Horne JA. Evaluation of 'in-car' countermeasures to sleepiness: cold air and radio. Sleep 21(1): 46-50, 1998.

Figure B4 shows KSS ratings from 25 flight crewmembers across ultra-long range flights from Singapore to Los Angeles. [21].

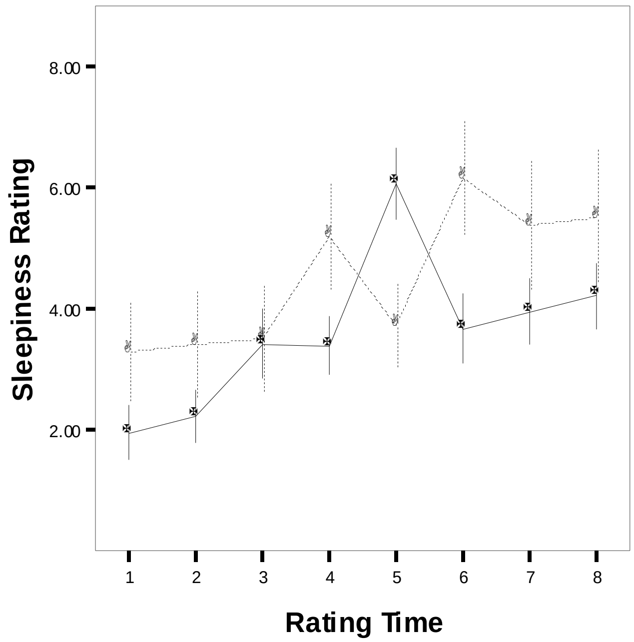

Figure B4: KSS sleepiness ratings on flights from Singapore to Los Angeles

Solid line – data for the command crew

Dotted line – data for the relief crew

[21] Flight Safety Foundation (2006). Flight Safety Digest 24 (8-9).
Signal TL, van den Berg M, Travier N, Gander PH (2004). Phase 3 ultra-long range validation: in-flight polysomnographic sleep and psychomotor performance. Wellington, New Zealand: Massey University, Sleep/Wake Research Centre Report.

Each flight had two crews (two captains, two first officers). The command crew (solid line) flew both the take off and the landing and was allocated the 2nd and 4th in-flight rest periods. The relief crew (dotted line) was allocated the 1st and 3rd in-flight rest periods (they became the command crew for the return flight).

Ratings were made at the following times:

- rating 1 - pre-flight;
- rating 2 - at top of climb;
- rating 3 - before each crewmember's 1st in-flight rest period;
- rating 4 - after each crewmember's 1st in-flight rest period;
- rating 5 - before each crewmember's 2nd in-flight rest period;
- rating 6 – after each crewmember's 2nd in-flight rest period;
- rating 7 - at top of descent; and
- rating 8 - post-flight before departing the aircraft.

The command and relief crews have different patterns in their sleepiness ratings across the flight, partly as a result of their different in-flight rest periods.

The Samn-Perelli Crew Status Check

This scale asks people to rate their level of fatigue right now, and is a simplified version of the Samn-Perelli Checklist.[22].

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

Figure B5: The Samn-Perelli Crew Status Check

[22] Samn SW, Perelli LP. Estimating aircrew fatigue: A technique with implications to airlift operations. Brooks AFB, TX: USAF School of Aerospace Medicine. Technical Report No. SAM-TR-82-21, 1982.

Samel A, Wegmann HM, Vejvoda M, Drescher J, Gundel A, Manzey D, Wenzel J. Two-crew operations: Stress and fatigue during long-haul night flights. Aviat Space Environ Med 68: 679-87, 1997.

Samel A, Wegmann HM, Vejvoda M. Aircrew fatigue in long-haul operations. Accid Anal & Prev 29(4); 439-452, 1997.

Figure B6 shows Samn-Perelli ratings for the same ULR crewmembers on the same flights as in Figure B4.

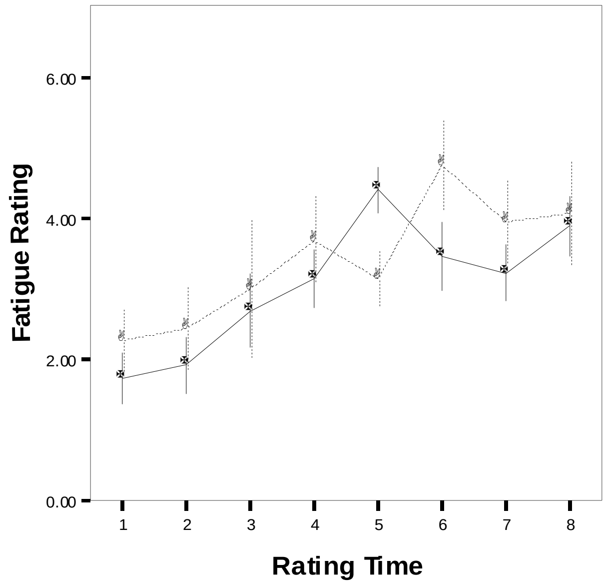

Figure B6: Samn-Perelli fatigue ratings on flights from Singapore to Los Angeles

Solid line – data for the command crew

Dotted line – data for the relief crew

Strengths and Weaknesses of Subjective Ratings

Subjective sleepiness and fatigue ratings are relatively cheap and easy to collect and analyze. Furthermore, how a crewmember feels is likely to influence their decisions about when to use personal fatigue countermeasure strategies. On the other hand, subjective ratings do not always reliably reflect objective measures of performance impairment or sleep loss, particularly when a person has been getting less sleep than they need (sleep restriction) across several consecutive nights.

Concerns about some crewmembers exaggerating on subjective fatigue and sleepiness ratings, for personal or industrial reasons, should be minimal in a just reporting culture as is required for FRMS. In addition, extreme ratings are obvious when compared with group averages.

In an FRMS, subjective sleepiness and fatigue ratings are particularly useful for:

- gathering information from large groups of crewmembers;
- where data are needed fairly quickly to decide whether more in-depth monitoring is warranted or if additional fatigue risk mitigation strategies are needed; and
- among a range of measures when more intensive monitoring is undertaken in an FRMS (for example during validation of a new route), because they provide valuable insights on crewmembers' experience of fatigue.

Decision-making by the Fatigue Safety Action Group can be guided by comparing average (and/or extreme) ratings with data gathered on other operations.

B2.2 Objective Performance Measurement

A range of objective performance tests are used in laboratory studies, but they usually measure very specific aspects of performance (for example, reaction time, vigilance, short-term memory, etc), not the complex combinations of skills needed by crewmembers in the course of flight duties. Laboratory tests usually also measure the performance of individuals, not the combined performance of the crew. Nevertheless, some simple performance tests are considered 'probes' or indicators of a crewmember's capacity to carry out his or her duties.

The following things should be considered when choosing performance tests for monitoring crewmember fatigue and sleepiness during flight operations.

1. How long does the test last?
2. Can it be completed at multiple time points (e.g., a number of times across a flight), without compromising a crewmember's ability to meet duty requirements?
3. 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?
4. Is it predictive of more complex tasks, e.g., crew performance in the simulator or during an in-flight emergency? (Unfortunately, there is very little research addressing this question at present.)
5. Has it been used in other aviation operations, and are the data available to compare fatigue levels?

One performance test that meets these criteria is the Psychomotor Vigilance Task or PVT. [23] In the most widely used version of the PVT, the test lasts for 10 minutes and is carried out on a purpose-built hand-held device. However, some recent studies [24] and large aviation field studies currently in progress are using a 5-minute version of the PVT programmed on a Personal Data Assistant (PDA) device.

Figure B7 shows mean reaction times on the PVT for the same ULR crewmembers on the same flights as in Figures B4 and B6. In this study, the 10-minute version of the test was used. PVT tests were done at the following times:

- test 1 - close to top of climb;
- test 2 - at the start of the second in-flight rest opportunity;
- test 3 - close to top of descent; and
- test 4 post-flight, before departing the aircraft.

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[23] Dinges, D. F. and Powell, J. P. (1985). Microcomputer analysis of performance on a portable, simple visual RT task during sustained operation. Behavior Research Methods, Instruments, and Computing, **17**: 652-655

Balkin, T. J., Bliese, P. D., Belenky, G., Sing, H., Thorne, D. R., Thomas, M., Redmond, D. P., Russo, M. and Wesensten, N. J. (2004). Comparative utility of instruments for monitoring sleepiness-related performance decrements in the operational environment. Journal of Sleep Research, **13**: 219-227.

[24] Lamond N, Petrelli, R, Dawson D, Roach GD. The impact of layover length on the fatigue and recovery of long-haul flight crew. Proceedings of the Fatigue in Transportation Conference (Session 13c), Seattle, September 11-25, 2005. US Department of Transport.

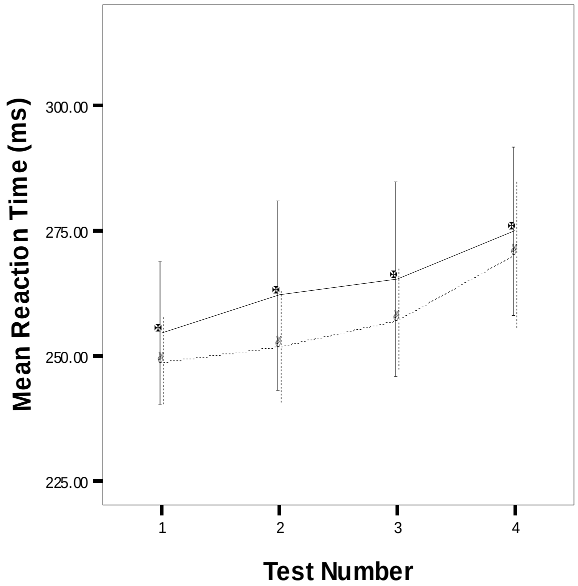

Figure B7: Mean Reaction Time on the PVT Task on Flights from Singapore to Los Angeles

Solid line – data for the command crew

Dotted line – data for the relief crew

Strengths and Weaknesses of the PVT

The PVT requires a crewmember's constant attention during the test. In the study in Figure B7, for example, this meant that crewmembers were required to be out of the operational control loop for a total of 30 minutes during the flight. This is an even greater challenge when crews are not augmented.

In the study in Figure in B7, crewmembers were asked to complete PVT tests on the flight deck and there were clearly occasions when their attention was distracted by operational events. This increased the variability of performance on the PVT test across the group and made it more difficult to find statistically significant changes in PVT performance across the flight. Only the post-flight test (Test 4) in Figure B7 is significantly different from any of the others.

The PVT does not measure important skills such as situation awareness and decision-making. On the other hand, more complex tests to measure these types of skills usually require many practice trials before they can be considered fully learnt and ready to be used for measuring changes due to fatigue. The PVT does not require practice trials, except to make sure that crewmembers know how to operate the testing device.

B2.3 Monitoring Sleep

Sleep loss is a key contributing factor to fatigue. In addition, crewmembers need to get recovery sleep to return to their optimum level of waking function. Sleep can be monitored during flight operations using subjective sleep diaries and/or by objective measures such as actigraphy or polysomnography. Each of these is described in more detail below.

Sleep Diaries

Sleep diaries ask crewmembers to record the following information about each sleep period:

- where they sleep (home, layover hotel, in flight in a crew rest facility or a business class seat, etc);
- what time they go to bed and get up;
- how much sleep they think they get; and
- how well they think they sleep.

Crewmembers may also be asked to rate their sleepiness and fatigue before and after planned sleep periods. When sleep is being monitored during flight operations, crewmembers are also asked to record actual duty times.

Diaries can have different layouts and they are often adapted to include specific information for a given study (for example, reminders about when to do performance tests or workload rating scales). Paper-based diaries are still more common, but electronic versions are also used (e.g., programmed on a PDA). Different layouts may be required for different parts of a study, for example pre-trip, during flights, and during layovers.

Figure B8 shows an example of an in-flight sleep diary designed to be used during ultra-long range flight when crews have multiple in-flight rest periods (courtesy of the Sleep/Wake Research Centre). This example includes Karolinska Sleepiness and Samn-Perelli ratings before and after each sleep period, as well as a sleep quality rating scale for each sleep period.

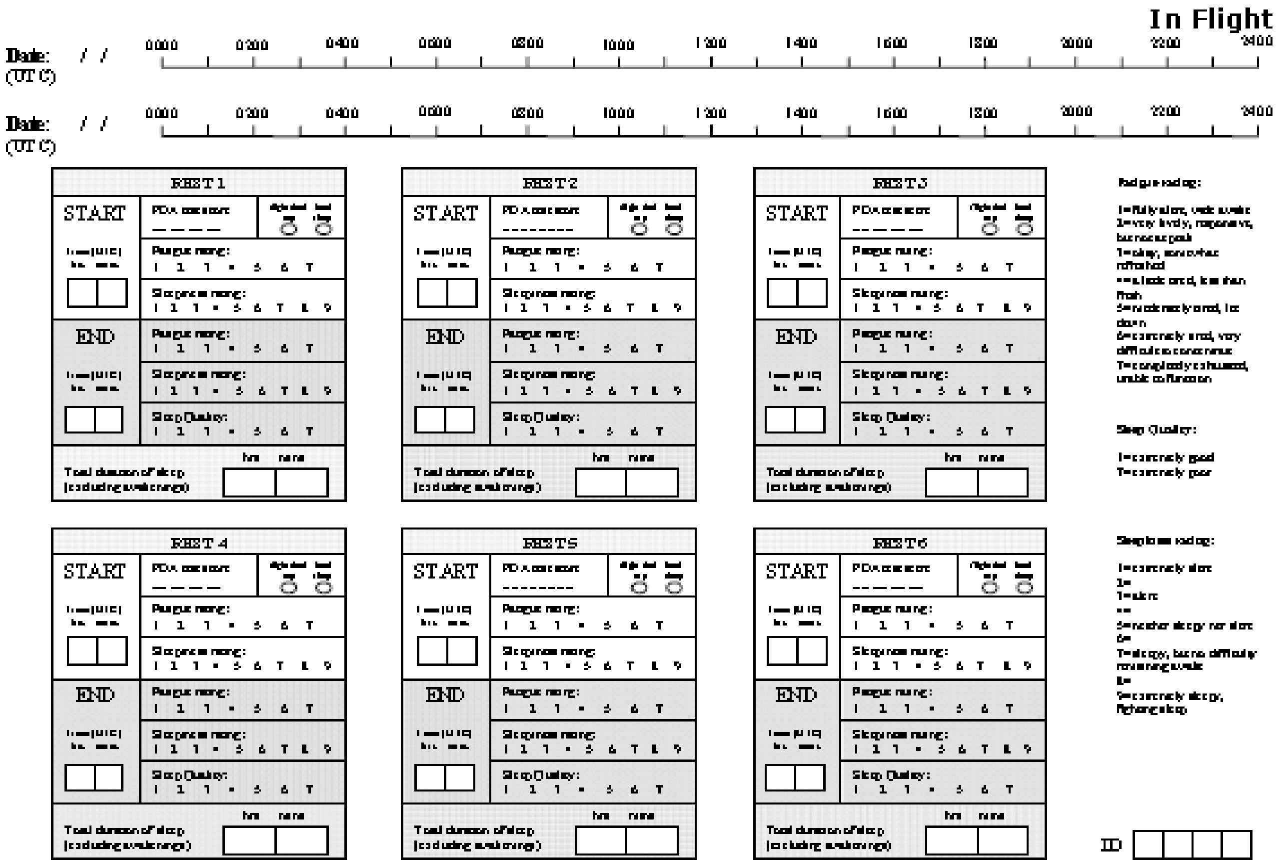

Figure B8: Example of an in-flight sleep diary for ULR operations

Strengths and Weaknesses of Sleep Diaries

Sleep diaries are cheap compared to objective forms of sleep monitoring. However, information from paper diaries needs to be manually entered into databases, which can slow down the process of getting answers to a particular operational question, and analysis of diary data has costs associated.

Sleep diaries are known to be less reliable than objective sleep monitoring. One study has compared sleep diaries and objective sleep measures from 21 B-777 flight crewmembers in a layover hotel and in flight. [25] For in-flight sleep:

- average sleep durations from diaries were similar to those recorded using polysomnography (the accepted gold standard for recording sleep); but
- the variability among individuals was high. Some crewmembers over-estimated how long they slept, and others underestimated; and
- crewmembers' estimates of how long they took to fall asleep, and their ratings of sleep quality were not reliably related to polysomnography measures.

[25] Signal, T.L., Gale, J., and Gander, P.H. (2005) Sleep Measurement in Flight Crew: Comparing Actigraphic and Subjective Estimates of Sleep with Polysomnography. *Aviation Space and Environmental Medicine* 76(11):1058-1063

Thus diaries alone may be useful for measuring the sleep duration of groups but cannot be considered accurate for estimating the sleep duration of any one individual. In addition, diaries are not generally considered reliable for measuring sleep quality. (However, some very new research suggests that people's reports of their sleep quality may be related to changes in parts of the brain that are not detected by polysomnography, so scientific opinion about the value of self-reported sleep quality may change).

Despite these limitations, sleep diaries are a relatively cheap way of gathering reasonable information on the average amount of sleep obtained by groups of crewmembers. They are also used to help interpret objective sleep data, as described below.

Actigraphy

An actigraph is a small device worn on the wrist that contains an accelerometer to measure movement and a memory chip to store 'activity counts' at regular intervals (for example every minute). Depending on the amount of memory available, they can be worn for weeks to months before the data need to be down-loaded to a computer for analysis. Figure B9 shows an example of an older style actigraph.

There are a number of manufacturers of actigraph devices, and each type comes with custom software that scans through the activity record and decides (based on a validated algorithm), whether the person was asleep or awake in each recorded epoch (for example every minute). Some devices have light sensors and some also have a regular watch face so that the wearer does not need to wear a normal watch as well, to keep track of time.

Figure B10 shows an actigraphy record from a crewmember before, during, and after a Singapore-Los Angeles-Singapore ULR trip. Each vertical gray bar indicates an hour, with 24 hours (from midnight to midnight) plotted across the diagram. Consecutive days are shown down the page. The vertical black bars indicate the level of activity for each minute of the recording (higher bars indicate more movement). Periods with minimal movement (short, scattered black bars) correspond to times when the crewmember was asleep.

Figure B9: an example of an actigraph

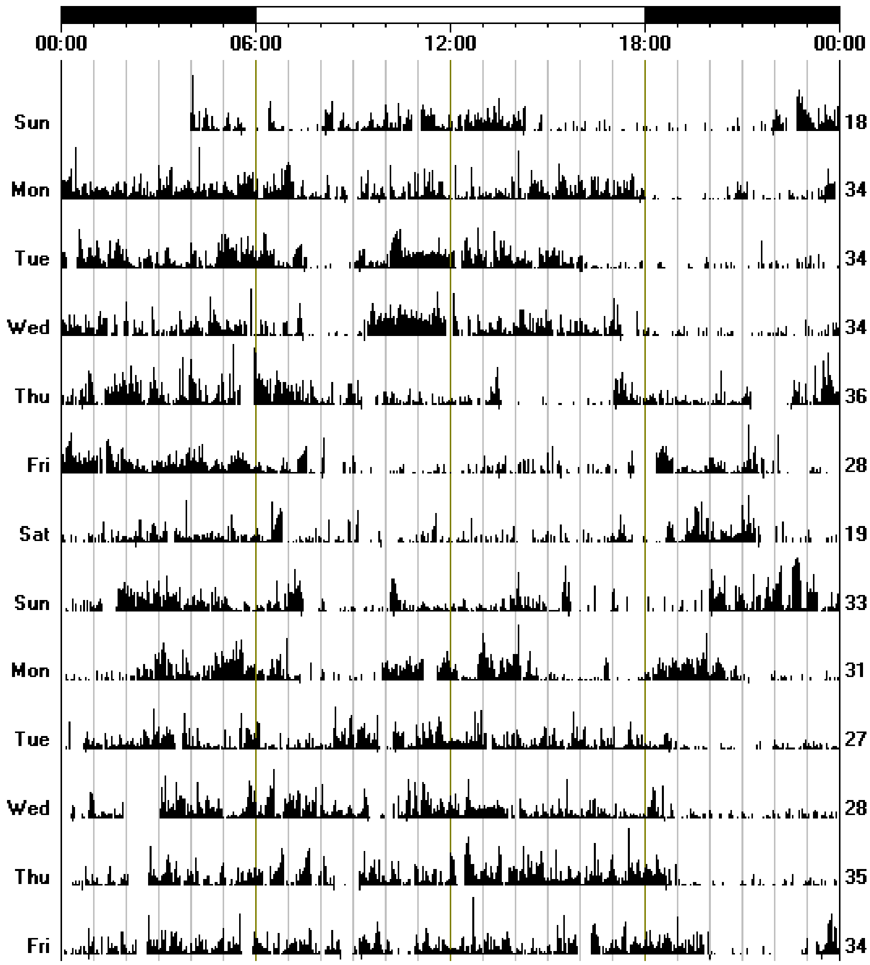

Figure B10 : Actigraphy record of a crewmember

before, during, and after a Singapore-Los Angeles-Singapore ULR trip

On the first Thursday, the crewmember in Figure B10 flew as a relief crewmember on the SIN-LAX segment, during which he had three in-flight rest opportunities (1 hr 30 mins, 4 hrs, and 2 hrs), but (according to his diary) he only went to the crew rest facility for the 2nd of these. The actigraphy scoring algorithm calculated that he obtained 2hrs 55 mins of sleep during the 2nd rest period, and 1 hr 12 mins of sleep during his 3rd rest period, which he took in a passenger cabin. His sleep diary indicated that he also spent 44 minutes trying to sleep during his 1st rest period, but the algorithm could not (at that time) score such a short sleep period.

The following Sunday, he flew as a command crewmember on the LAX-SIN segment and had two in-flight rest opportunities (195 minutes and 300 minutes), both of which he took in the crew rest facility. According to the actigraphy scoring algorithm, he obtained 2 hrs 14 min of sleep in his 1st rest period and 4 hrs 3 min in his 2nd rest period.

Strengths and Weaknesses of Actigraphy

As Figure B10 illustrates, actigraphy is very useful for obtaining objective records of the sleep/wake patterns of crewmembers across multiple days. This is currently the most practical and reliable way to look at whether a crewmember accumulates a sleep debt across a line of flying, compared to the amount of sleep they average when off duty. Actigraphy can also provide useful information on recovery sleep after a trip.

Actigraphs are small and unobtrusive to wear, and actigraphy is cheap compared to polysomnography. The main limitation of actigraphy is that it monitors activity (not sleep) and it cannot distinguish between someone being asleep versus being awake but not moving.

The study described previously [9] also compared actigraphy and polysomnographic sleep recordings from the 21 B-777 flight crewmembers. For both hotel sleep and bunk sleep:

- average sleep durations calculated from actigraphy were similar to those recorded using polysomnography; but
- for individual crewmembers, actigraphy could overestimate or underestimate polysomonographic sleep duration by more than an hour. This amount of inaccuracy is particularly problematic for in-flight sleep periods, which tend to be short; and
- comparing actigraphy and polysomnography minute-by-minute, the study concluded that actigraphic estimates of how long crewmembers took to fall asleep, and of how often they woke up during a sleep period (sleep quality), were not reliably related to polysomnographic measures.

On the positive side, the study demonstrated that actigraphy was not significantly contaminated by in-flight factors such as turbulence or aircraft movement, and that it is reliable for estimating the average sleep duration of groups of crewmembers, both in the air and on the ground.

Actigraphs are currently not particularly cheap, although some manufacturers are working on new generation devices that may push costs down. Not all actigraphs on the market have been validated (by comparing their algorithms for estimating sleep quantity and quality with polysomnography), and some have not yet been demonstrated to be robust and reliable for sleep monitoring during flight operations (battery life can be a problem in some devices).

At present, the accepted standard for analyzing actigraphy records is to use a sleep diary to identify when a crewmember was trying to sleep (as opposed to just sitting still or not wearing the watch). The sections of the record where the crewmember was trying to sleep are then analyzed for sleep duration and quality. This type of analysis requires a trained person to work through actigraphy records manually, which is time consuming and fairly costly. Several manufacturers and research groups are looking at ways to bypass the need for this manual scoring, which would make actigraphy much cheaper and faster to analyze. However, the reliability of these new approaches for estimating sleep quantity and quality (compared to polysomography) remains to be demonstrated.

Some operators may choose to develop the capacity in-house to collect and analyze actigraphy. As part of the FRMS Assurance Processes, an external scientific advisory group could be convened periodically to review the actigraphy analyses and the resulting decisions made by the Flight Safety Action Group.

Polysomnography

Polysomnography is the accepted gold standard for monitoring sleep and is currently the only method that gives reliable information on the internal structure of sleep and on sleep quality. It involves sticking removable electrodes to the scalp and face and connecting them to a recording device, to measure three different types of electrical activity: 1) brainwaves (electroencephalogram or EEG); 2) eye movements (electroculogram or EOG); and 3) muscle tone (electromyogram or EMG).

In addition to monitoring sleep, polysomnography can be used to monitor waking alertness, based on the dominant frequencies in the brainwaves, and patterns of involuntary slow rolling eye movements that accompany sleep onset. Figure B11 shows a flight crewmember on the flight deck wearing polysomnography electrodes, which the researcher is connecting to a portable recording device.

Figure B11: Polysomnographic recording in flight

Figure B12 shows an analysis of the polysomnography record of the 1st in-flight sleep period on the SIN-LAX flight for the same crewmember whose actigraphy record is shown in Figure B10 (times in UTC). Figure B12 is a graph created by a trained sleep technician who has gone through the entire polysomnographic recording and, using an internationally agreed set of rules, has decided for each 30 seconds whether the crewmember was awake, or in which type of sleep he spent most of that 30 seconds. Figure B12 shows that he took 13 minutes to fall asleep and then spent a total of 17.5 minutes in light non-REM sleep (S1 and S2). However, he woke up 6 times across the sleep period. He did not enter deep non-REM sleep (S3 and S4), or Rapid Eye Movement (REM) sleep.

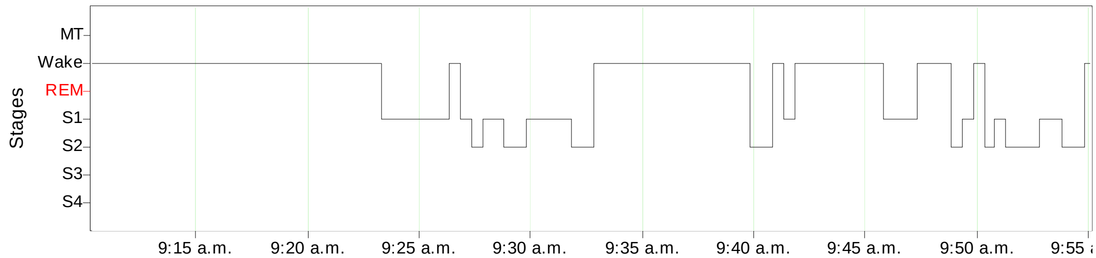

Figure B12: Polysomnographic record for the 1st in-flight rest period on the SIN-LAX flight (same crewmember as in Figure B10)

Figure B13 shows the polysomnographic record for the same crewmember during his 2nd in-flight rest period on the SIN-LAX flight. In this rest period (in the bunk), he fell asleep in 19.5 minutes and then slept for a total of 144.5 minutes, interrupted by numerous brief periods of waking which totaled 52 minutes. He spent 1.5 minutes in deep non-REM sleep (S3), 2 minutes in REM sleep, and the rest of the time in light non-REM sleep (S1 and S2).

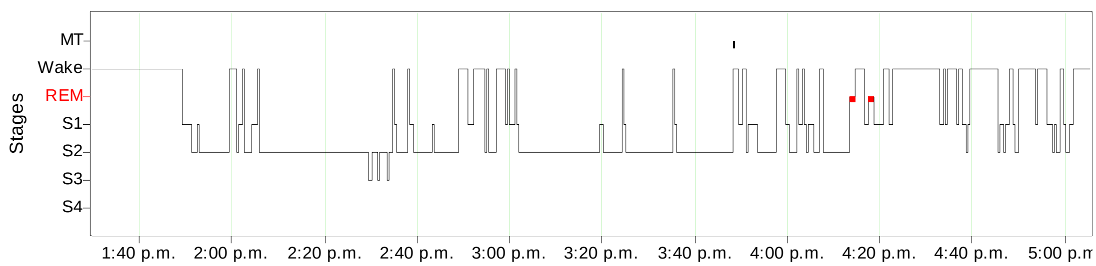

Figure B13: Polysomnographic record for the 2nd in-flight rest period on the SIN-LAX flight (same crewmember as in Figure B10)

Strengths and Weaknesses of Polysomnography

Figures B12 and B13 show the detailed information about sleep quality that can only be obtained from polysomnographic recordings. When it is important to be certain about the amount and type of sleep that crewmembers are obtaining, polysomnographic monitoring is the most trusted method.

On the other hand, polysomnography is relatively obtrusive and time-consuming. It takes a well-trained technician about 30 minutes to attach the recording electrodes to a person's scalp and face, and check that all the electrical connections are working. For in-flight recordings, the electrical contacts need to be checked periodically (for example before each in-flight rest period) to make sure that the signals are still clean. Crewmembers can be shown how to remove the electrodes themselves. However, the equipment is expensive and fragile and a technician is required to download the data from the recording device to a computer, and to clean the equipment. This means that it is usual for at least one technician to accompany crewmembers throughout a trip during which their sleep is recorded using polysomnography. This is costly.

As previously mentioned, the currently accepted standard for analyzing polysomnography is to have a trained sleep scoring technician work through the entire recording to decide for each 30 seconds whether the crewmember was awake, or in which type of sleep he/she spent most of that 30 seconds. For quality assurance, it is usual to have a second trained technician score at least some of the records to check the reliability of scoring between the two technicians. This is time consuming and relatively expensive. A number of groups are working on automated scoring systems for polysomnography, but as yet none of these are widely accepted by the sleep research and sleep medicine communities. Beyond the scoring process, it is necessary to have a qualified person to interpret that significance of diagrams such as Figures B12 and B13.

Despite these costs and inconveniences, there have been a number of studies of flight crew sleep that have used polysomnography and these have been very informative. While it is unlikely that any airline would need to develop in-house capacity to record and analyze polysomnography as a routine part of its FRMS, there are situations where the detailed information from polysomnography is needed. For example, in launching the first commercial passenger ULR flights, Singapore Airlines and the Singapore Civil Aviation Authority agreed that a subgroup of crewmembers would have their sleep monitored by polysomnography during the operational validation of the SIN-LAX route. The data in Figures B4, B6, B7, B10, B12, and B13 come from this validation and are used with the kind permission of the Singapore Civil Aviation Authority (Dr Jarnail Singh) and provided by the Sleep/Wake Research Centre at Massey University, New Zealand.

B2.4 Monitoring the Circadian Body Clock Cycle

The circadian body clock cycle is a key contributing factor to crewmember fatigue, but it is difficult to monitor during flight operations. *In the laboratory*, the cycle of the body clock is usually monitored by measuring two of the overt rhythms that it drives;

1. the daily rhythm in core body temperature; and
2. the daily rhythm in levels of the hormone melatonin, which is secreted by the pineal gland at night. Melatonin levels can be measured from blood, saliva, or urine samples collected at regular intervals.

During the 1980s, a number of research teams monitored the circadian body clocks of crewmembers by tracking the rhythm of core body temperature. Figure B14 shows the times of the daily temperature minimum of one participating B-747 crewmember across an 8-day long-haul trip pattern. [26]

At home in SFO prior to the trip, his temperature minimum (inverted triangle) occurred about 5 hours into his sleep period (black horizontal bar). During the trip, he repeatedly flew westward then back eastward across multiple time zones, spending around 24 hours in each location. The circadian temperature minimum could not follow this disrupted pattern (it shifted by no more than 2 hours from one day to the next). Across the trip pattern, it drifted progressively later, so that by the time the crewmember arrived back in SFO at the end of the trip, it had drifted about 6 hours later. Thus, when he got home, the crewmember's circadian body clock was 6 hours out of step with his home time zone and took several days to readapt.

Another interesting feature of this record is that the temperature minimum (when physiological sleep drive is highest), sometimes occurs in flight, for example on the flight from NRT to HKG. At these times, the crewmember is at greatest risk of falling asleep unintentionally on the flight deck. Alternatively, if he has the opportunity for a rest break (which was not the case in this operation), this would represent a very good time to try to get some in-flight sleep.

[26] Gander, P.H., Gregory, K.B., Miller, D.L., Rosekind, M.R., Connell, L.J., and Graeber, R.C. (1998) Flight crew fatigue V: long-haul air transport operations. *Aviation, Space, and Environmental Medicine* 69:B37-B48

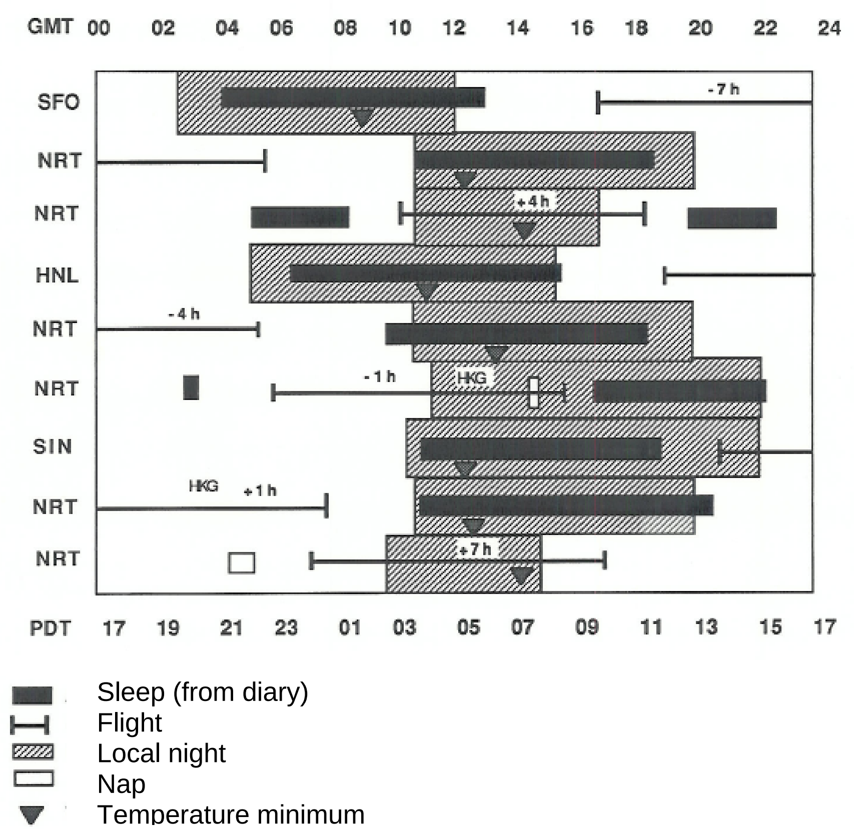

Figure B14: Sleep times (diary data) and times of the circadian temperature minimum of a crewmember during a long haul trip pattern.

Clearly, Figure B14 provides valuable information that can be related to the crewmember's sleep, fatigue, mood, and performance capacity. However, it has been several decades since this type of monitoring has been undertaken primarily because of the logistics and cost of tracking circadian rhythms during flight operations.

There is ongoing research aimed at developing more robust and less intrusive methods for continuously monitoring circadian rhythms outside the laboratory, including a new generation of temperature 'pills', that are swallowed and transmit temperature measurements as they transit through the digestive system. However, body temperature is also affected by the level of physical activity, and it is complex to separate out this 'masking effect' from the actual circadian clock-driven component of the temperature rhythm (this was done mathematically in Figure B14).

The second rhythm that is commonly monitored in the laboratory to track the cycle of the circadian body clock is the level of the hormone melatonin. Melatonin can be measured in blood or saliva samples taken at regular intervals, and its metabolites can be measured in urine samples. There are obvious difficulties associated with collection and frozen storage of body fluid samples during flight operations. Another complicating factor is that synthesis of melatonin is switched off by bright light. Thus, if a crewmember is exposed to daylight during his/her "biological night" (for example, a few hours either side of the of the temperature minimum in Figure B14), melatonin secretion will stop. This makes it impossible to track its normal circadian cycle cross a trip such as that in Figure B14. Analyzing for hormone levels in body fluids is a highly skilled task that needs to undertaken by a reputable laboratory.

Strengths and Weaknesses of Monitoring the Circadian Body Clock Cycle

There is remarkably little information available on how the circadian body clock is affected by any kind of flight operations. Where data have been collected, there is evidence of considerable variability between individuals on the same trip patterns. Better information in this area would improve the predictive power of bio-mathematical models for fatigue hazard identification, and might provide insights on how to tailor personal mitigation strategies for crewmembers who are morning-types versus evening-types. A number of groups are actively working on new technologies for monitoring the circadian body clock cycle, but as yet none of these has been validated or demonstrated to be robust enough and practical for use during flight operations.

B3 EVALUATING THE CONTRIBUTION OF FATIGUE TO SAFETY EVENTS

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 in-depth 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. [27]

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?

[27] Transportation Safety Board of Canada, 1997. A Guide for Investigating for Fatigue. Transportation Safety Board of Canada, Gatineau, Quebec.

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).

Checklist 1 is designed to establish whether the person or crew were in a fatigued state, based on a series of questions or probes that address key aspects of fatigue. The answer to each question is compared to the best case response, in order to build an overall picture of the fatigue hazard. Any departure from the best case response indicates increased risk of fatigue.

Checklist 2 is designed to establish whether the unsafe action(s) or decision(s) were consistent with the type of behaviour expected of a fatigued person or crew.

Checklist 1: Establishing the Fatigued State

Questions	Best Case Responses	Investigator's Notes
	Quantity of Sleep establish whether or not there was a sleep debt	
How long was last consolidated sleep period?	7.5 to 8.5 hours	
Start time?	Normal circadian rhythm, late evening	
Awake Time?	Normal circadian rhythm, early morning	
Was your sleep interrupted (for how long)?	No	
Any naps since your last consolidated sleep?	yes	
Duration of naps?	Had opportunity for restorative (1.5-2 hrs) or strategic (20 min) nap prior to start of late shift	
Describe your sleep patterns in the last 72 hours. (Apply sleep credit system)	2 credits for each hour of sleep; loss of one credit for each hour awake - should be a positive value	
	Quality of Sleep establish whether or not sleep was restorative	
How did the sleep period relate to the individual normal sleep cycle i.e., start/finish time?	Normal circadian rhythm, late evening/early morning	
Sleep disruptions?	No awakenings	
Sleep environment?	Proper environmental conditions (quiet, comfortable temperature, fresh air, own bed, dark room)	
Sleep pathologies (disorders)	None	
	Work History establish whether hours worked and type of duty or activities involved had an impact on sleep quantity and quality	
Hours on duty and/or on call prior to the occurrence?	Situation dependent - hours on duty and/or on call and type of duty that ensure appropriate level of alertness for the task	
Work history in preceding week?	Number of hours on duty and/or on call and type of duty that do not lead to a cumulative fatigue	

Checklist 1: Establishing the Fatigued State (continued)

Questions	Best Case Responses	Investigator's Notes
Irregular Schedules establish whether the scheduling was problematic with regards to its impact on quantity and quality of sleep		
Was crewmember a shift worker (working through usual sleep times)?	No (The circadian body clocks and sleep of shift workers do not adapt fully)	
If yes, was it a permanent shift?	Yes -days	
If no, was it rotating (vs irregular) shift work?	Yes - Rotating clockwise, rotation slow (1 day for each hour delayed), night shift shorter, and at the end of cycle	
How are overtime or double shifts scheduled?	Scheduled when crewmembers are in the most alert parts of the circadian body clock cycle (late morning, mid evening)	
Scheduling of critical safety tasks?	S Scheduled when crewmembers are in the most alert parts of the circadian body clock cycle (late morning, mid evening)	
Has crewmember had training on personal fatigue mitigation strategies?	Yes	
Jet Lag establish the existence and impact of jet lag on quantity and quality of sleep		
Number of time zones crossed?	one	
If more than one, at what rate were they crossed?	the slower the better	
In which direction was the flight?	westward	

Checklist 2: Establishing the Link between Fatigue and the Unsafe Act(s)/Decision(s)

Performance Indicators	Investigator's Notes
Attention	
Overlooked sequential task element	
Incorrectly ordered sequential task element	
Preoccupied with single tasks or elements	
Exhibited lack of awareness of poor performance	
Reverted to old habits	
Focused on a minor problem despite risk of major one	
Did not appreciate gravity of situation	
Did not anticipate danger	
Displayed decreased vigilance	
Did not observe warning signs	
Memory	
Forgot a task or elements of a task	
Forgot the sequence of task or task elements	
Inaccurately recalled operational events	
Alertness	
Succumbed to uncontrollable sleep in form of microsleep, nap, or long sleep episode	
Displayed automatic behavior syndrome	
Reaction Time	
Responded slowly to normal, abnormal or emergency stimuli	
Failed to respond altogether to normal, abnormal or emergency stimuli	
Problem-Solving Ability	
Displayed flawed logic	
Displayed problems with arithmetic, geometric or other cognitive processing tasks	
Applied inappropriate corrective action	
Did not accurately interpret situation	
Displayed poor judgment of distance, speed, and/or time	

Checklist 2: Establishing the Link between Fatigue and the Unsafe Act(s)/Decision(s) (continued)

Performance Indicators	Investigator's Notes
Mood	
Was less conversant than normal	
Did not perform low-demand tasks	
Was irritable	
Distracted by discomfort	
Attitude	
Displayed a willingness to take risks	
Ignored normal checks or procedures	
Displayed a 'don't care' attitude	
Physiological Effects	
Exhibited speech effects	
Exhibited reduced manual dexterity - key-punch entry errors, switch selection	

APPENDIX C: PROCEDURES FOR CONTROLLED REST ON THE FLIGHT DECK

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 Operations Manual.

Recommended Procedures for Controlled Rest on the Flight Deck

The following recommended procedures are based on a survey of major air carriers. They represent considerable experience in many regions of the globe and include options reflecting variations between different types of operations.

Note: this is not intended to be an all inclusive list, nor are all of these procedures necessarily required. Each operator should work with their regulator to define appropriate procedures.

- Only one pilot may take controlled rest at a time in his/her seat. The harness should be used and the seat positioned to minimize unintentional interference with the controls.
- The autopilot and auto-thrust systems (if available) should be operational.
- Any routine system or operational intervention which would normally require a cross check, should be planned to occur outside controlled rest periods.
- Controlled rest on the flight deck may be used at the discretion of the captain to manage both unexpected fatigue and to reduce the risk of fatigue during higher workload periods later in the flight.
- It should be clearly established who will take rest, and when it will be taken. If the pilot in command requires, the rest may be terminated at any time.
- The pilot in command should define criteria for when his/her rest should be interrupted.
- Hand-over of duties and wake-up arrangements should be reviewed.
- Flight crews should only use controlled rest if they are familiar with the published procedures.
- Some operators involve a third crewmember (not necessarily a pilot) to monitor controlled flight deck rest. This may include a planned wake-up call, a visit to be scheduled just after the planned rest period ends, or a third crewmember on the flight deck throughout controlled rest.
- The controlled rest period should be no longer than 40 minutes, to minimize the risk of sleep inertia on awakening.

- Controlled rest should only be utilized during the cruise period from the top of climb to 20 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 pilot must perform the duties of the pilot flying and the pilot monitoring, be able to exercise control of the aircraft at all times and maintain situational awareness. The non-resting pilot 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 pilot.