

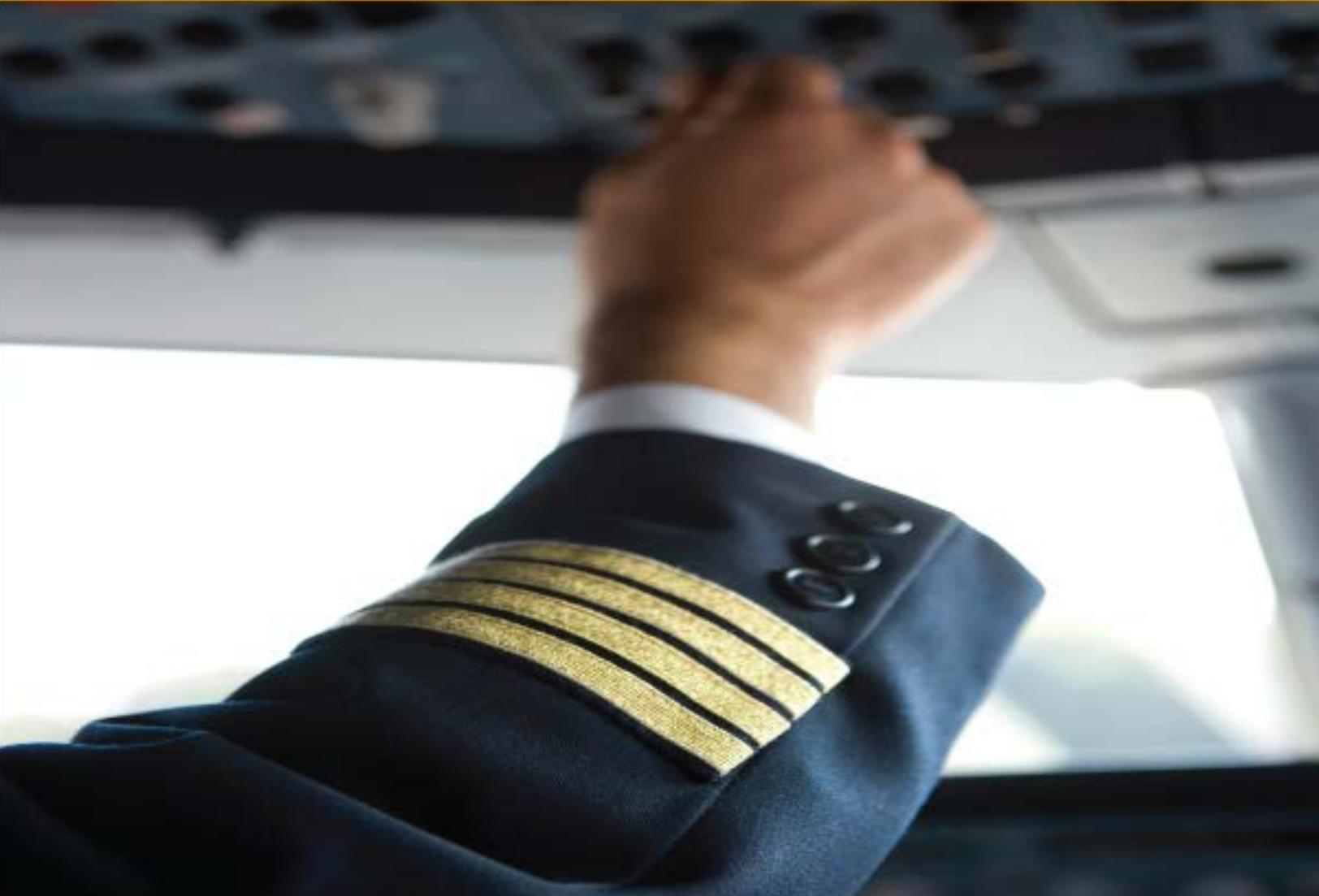


ICAO



Fatigue Management Guide for Airline Operators

Second Edition, 2015



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EXECUTIVE LETTER

Dear Colleagues,

In July 2011, IATA, ICAO and IFALPA developed and co-branded the first edition of the *Fatigue Risk Management Systems (FRMS) Implementation Guide for Operators*. This guide has been adopted around the world as a successful path to implement FRMS.

The FRMS approach to fatigue management relies heavily on continuous improvement and is the principle which guided the development of this, the second edition of the *FRMS Implementation Guide for Operators*. Renamed the *Fatigue Management Guide for Airline Operators*, Edition 2015 provides operators with a complete document on prescriptive and performance-based fatigue management approaches.

The *Fatigue Management Guide for Airline Operators*, Edition 2015 builds upon the successful collaboration between IATA, ICAO and IFALPA to describe science-based and operationally oriented fatigue management processes. The input of these three organizations has ensured that this document continues to present approaches that are widely acceptable to the operators and crew members who will be using them.

We are extremely proud to mutually introduce this document, which will contribute to the improved management of fatigue risk and help us achieve our common goal of improving aviation safety worldwide.



Kevin Hiatt
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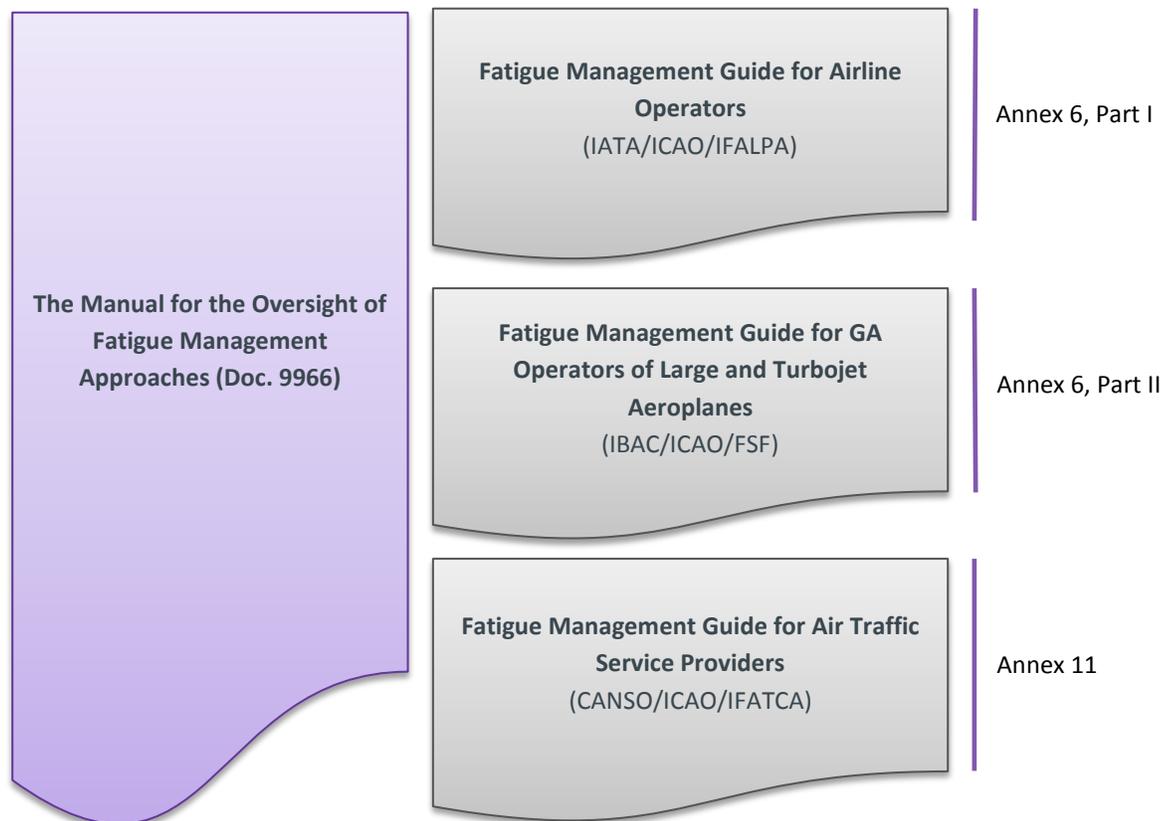
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President
International Federation of Air
Line Pilots' Associations

USE OF THIS MANUAL

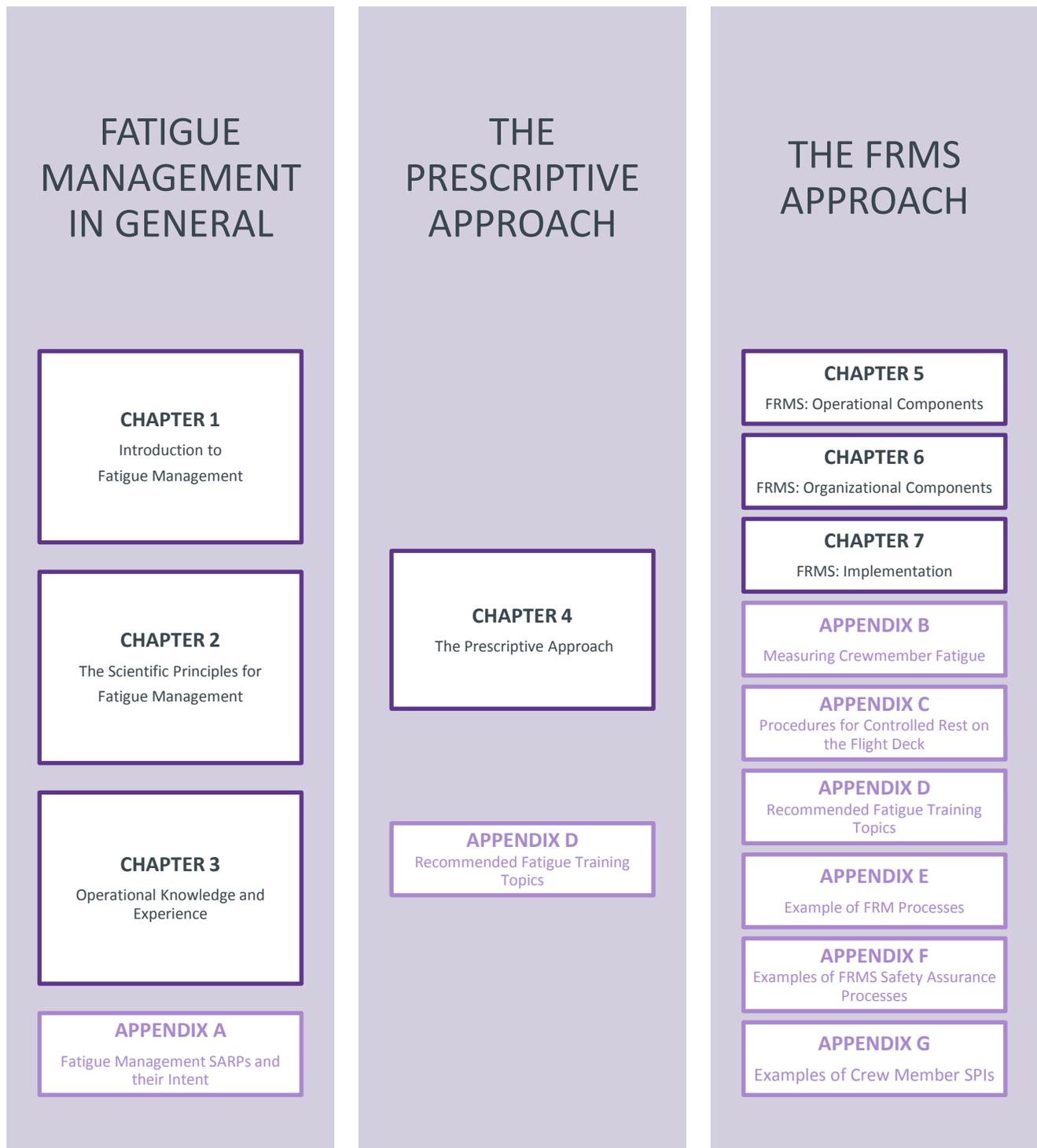
The Fatigue Management Guide for Airline Operators is one in a suite of manuals related to fatigue management. Developed specifically for airline operators, this manual presents information on managing fatigue risks using both a prescriptive approach to fatigue management and FRMS.

This document is designed to be read in association with the ICAO Manual for the Oversight of Fatigue Management Approaches (Doc. 9966). All of the manuals in the suite of manuals are based on the work of the ICAO FRMS Task Force.

The suite of Fatigue Management Manuals, and the Annexes to which they pertain, is as follows:



The following diagram provides an overview of the Fatigue Management Guide for Airline Operators and is presented to assist readers in navigating its contents¹. The diagram separates the contents of this document into three general areas:



¹ A corresponding diagram is provided in The Manual for the Oversight of Fatigue Management Approaches (Doc. 9966), to assist readers in using these manuals in parallel.

The ICAO SARPs apply to both flight and cabin crew. However to date, flight crew fatigue has received much more scientific, operational, and regulatory attention than cabin crew fatigue, so the examples in this manual focus on flight crew. The safety risks associated with fatigue-related impairment are different for flight and cabin crew members, and some mitigation strategies may be different. More specific advice on managing cabin crew fatigue will become possible as research and fatigue management experience with cabin crew increases.

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GLOSSARY

**denotes an ICAO definition.*

Actigraph. 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 or work pattern.

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 crew member can leave his or her assigned post to obtain in-flight rest and be replaced by another appropriately qualified crew member.

Bio-mathematical Model. A computer programme designed to predict aspects of a schedule that might generate an increased fatigue risk for the average person, based on scientific understanding of the factors contributing to fatigue. Biomathematical models are an optional tool (not a requirement) for predictive fatigue hazard identification within an FRMS. All biomathematical models have limitations that need to be understood for their appropriate use.

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.

Countermeasures. Personal mitigation strategies that individuals can use to reduce their own fatigue risk. Sometimes divided into strategic countermeasures (for use at home, for example good sleep habits, napping before night duty), and operational countermeasures, for example strategic use of caffeine.

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

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 flight or cabin 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 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, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to perform safety related operational duties.

Fatigue Safety Action Group (FSAG). A group comprised of representatives of all stakeholder groups (management, scheduling, operational personnel) together with any additional specialist experts (i.e. scientists, data analysts, and medical professionals), which is responsible for coordinating all fatigue management activities in the organisation.

***Fatigue Risk Management System (FRMS).** A data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles, knowledge and operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness.

***Flight duty period.** A period which commences when a flight or cabin 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 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.

***Hazard.** A condition or an object with the potential to cause or contribute to an aircraft incident or accident.

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. 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. Interventions designed to reduce a specific identified fatigue risk.

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.

On-call. A defined period of time, during which an individual is required by the service provider to be available to receive an assignment for a specific duty. Synonymous with **standby**.

Pairing. A scheduling expression describing the time from when a flight crew member initially reports for duty until he/she returns home from the sequence of flights and is released from duty. (See **Trip**)

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).

***Rest period.** A continuous and defined period of time, subsequent to and/or prior to duty, during which personnel are free of all duties.

Roster. (noun) a list of planned shifts or work periods within a defined period of time;

(verb) assignment of individuals to a schedule or pattern of work. Synonymous with **Schedule**.

***Safety.** The state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level.

***Safety management system (SMS).** A systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies and procedures.

***Safety oversight.** A function performed by a State to fulfil its responsibility for the effective implementation of safety-related Standards and Recommended Practices (SARPs), guidance material and associated procedures, as well as national regulations, including SMS where required.

***Safety performance.** A State or a service provider's safety achievement as defined by its safety performance targets and safety performance indicators.

***Safety performance indicator.** A data-based parameter used for monitoring and assessing safety performance.

***Safety performance target.** The planned or intended objective for safety performance indicator(s) over a given period.

***Safety risk.** The predicted probability and severity of the consequences or outcomes of a hazard.

Schedule. (noun) a list of planned shifts or work periods within a defined period of time;

(verb) assignment of individuals to a roster or pattern of work. Synonymous with **Roster**.

Shift Work. Any work pattern that requires an individual to be awake at a time in the circadian body clock cycle that they would normally be asleep.

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.

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. Examples include obstructive sleep apnoea, 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 after waking. The length and intensity of sleep inertia is greatest when the individual has not had enough sleep, is woken from **slow-wave sleep** (non-REM stages 3 and 4) or woken during the WOCL.

Sleep Need. The amount of sleep that is required on a regular basis to maintain optimal levels of waking alertness and performance. Sleep need is 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. 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.

Standby. A defined period of time, during which an individual is required by the service provider to be available to receive an assignment for a specific duty. Synonymous with *on call*.

***State safety programme (SSP).** An integrated set of regulations and activities aimed at improving safety.

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 flight crew member 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 (see *Pairing*).

Unforeseen operational circumstance. Unexpected conditions that could not reasonably have been predicted and accommodated, such as bad weather or equipment malfunction, which may result in necessary on-the-day operational adjustments.

Unrestricted sleep. Sleep which is not restricted by any demands. Sleep can begin when an individual feels sleepy, and does not have to be delayed for any reason. In addition, the individual can wake up spontaneously and does not have to set the alarm.

Window of Circadian Low (WOCL) Time in the circadian body clock cycle when 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 0200-0600 when a person is fully adapted to the local time zone. However, there is individual variability in the exact timing of the WOCL.

CHAPTER 1. INTRODUCTION TO FATIGUE MANAGEMENT

The aviation industry provides one of the safest modes of transportation in the world. Nevertheless, a safety critical industry must actively manage hazards with the potential to impact safety. Crew member fatigue is now acknowledged as a hazard that predictably degrades various types of human performance and can contribute to aviation accidents and incidents. Fatigue is inevitable in 24/7 operations because the human brain and body function optimally with unrestricted sleep at night. Therefore, as fatigue cannot be eliminated, it must be managed.

1.1. APPROACHES TO FATIGUE MANAGEMENT IN AVIATION

Fatigue management refers to the methods by which Service Providers and operational personnel address the safety implications of fatigue. In general, the ICAO SARPs support two distinct approaches for fatigue management:

1. the operator complies with prescriptive flight and duty time limits defined by the regulator, and manages fatigue hazards using the SMS processes that are in place for managing other types of hazards; or
2. the operator develops and implements a Fatigue Risk Management System (FRMS)² that is approved by the regulator³.

These approaches share two important basic features. First, they are based on scientific principles and knowledge as well as operational experience. Both should take into account:

- the need for adequate sleep (not just resting while awake) to restore and maintain all aspects of waking function (including alertness, physical and mental performance, and mood); 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 circadian clock in the brain; and
- the contribution of workload to fatigue and physical and mental performance degradation; and
- the operational context and the safety risk that a fatigue-impaired crew member represents in that context.

Second, because fatigue is affected by all waking activities (not only work demands), fatigue management has to be a shared responsibility between regulators, operators and crew members.

- The regulator is responsible for providing a regulatory framework and ensuring that operators manage their fatigue-related risks to achieve an acceptable level of safety.
- Operators are responsible for providing fatigue management education, creating pairings and rosters that enable crew members to perform their duties safely, and implementing processes for monitoring and managing fatigue hazards.
- Crew members are responsible for arriving fit for duty, including making appropriate use of rest breaks to obtain sleep, and for reporting fatigue hazards.

² Annex 6 Part II is an exception to this, where regulations for prescriptive limits are not mandated for flight crew of large and turbojet aeroplane operations.

³ Only where FRMS regulations have been established by the regulator.

1.1.1. COMPARING PRESCRIPTIVE AND FRMS APPROACHES

In the prescriptive fatigue management approach, operations must remain within prescribed limits established by the regulator for flight time, flight duty periods, duty periods and rest periods. In addition, an operator should manage fatigue hazards using the SMS processes that are in place for managing other types of hazards. Chapter Four provides detailed information on how to implement a prescriptive fatigue management approach.

The FRMS approach represents an opportunity for operators to use advances in scientific knowledge to improve safety and increase operational flexibility. An FRMS is a system that uses a service provider's SMS processes and procedures to specifically identify and manage crew member fatigue as a hazard. It addresses actual fatigue risk in the operations to which it applies, rather than predicted risk which is the basis of prescriptive limits. FRMS has additional requirements to ensure a level of safety that is at least equivalent to that achieved by operating within the prescriptive flight and duty time limits and using generic SMS processes to manage fatigue hazards. Where an airline operator already has sufficiently mature SMS processes in place, it should not be necessary for it to develop entirely new processes to implement FRMS. Rather, the operator can build upon the organization's existing SMS processes to address the added requirements of an FRMS. Chapters Five and Six provide detailed information on what is required in each of these components and on how to implement an FRMS approach.

Having an FRMS still requires having maximum limits, but these are proposed by the operator and must be approved by the regulator. To get approval, the operator must demonstrate to the regulator that it has appropriate processes and mitigations to achieve an acceptable level of safety. The cost and complexity of an FRMS may not be justified for operations where fatigue risk can be managed to an acceptable level within the prescriptive flight and duty time limits. Operators can choose to manage none, some, or all of their operations under an FRMS.

Table 1-1 below compares key characteristics of the two fatigue management approaches.

Table 1-1. Comparison of key characteristics of prescriptive and FRMS fatigue management approaches

	PRESCRIPTIVE APPROACH	FRMS APPROACH
AIM	<p>Regulator</p> <ul style="list-style-type: none"> Regulator ensures that the Service Provider is managing their fatigue risks to a level acceptable to the State. 	<ul style="list-style-type: none"> Regulator ensures that the Service Provider is managing their fatigue risks to a level equivalent to, or better than, a prescriptive approach.
	<p>Service Provider</p> <ul style="list-style-type: none"> Service Provider manages fatigue risks within constraints of prescribed limits using existing SMS processes. 	<ul style="list-style-type: none"> Service Provider identifies their limits, manages their fatigue risks within agreed safety objectives and targets, and monitors them through their FRMS processes. These are continually assessed and may be altered as a result of FRMS experience.
POLICY & DOCUMENTATION	<p>Regulator</p> <ul style="list-style-type: none"> Regulator sets the regulations for prescriptive limits and Service Provider obligations. The prescriptive limits are intended to be outer limits, not targets. 	<ul style="list-style-type: none"> Regulator establishes FRMS regulations and develops processes for approval and oversight of FRMS.
	<p>Service Provider</p> <ul style="list-style-type: none"> Service Provider’s SMS policy includes fatigue as a hazard to be managed. Service Provider documents duty time limits and non-duty time minimums in their operations manual. Service Provider maintains records of planned and actual working times. 	<ul style="list-style-type: none"> Service Provider has specific FRMS policy signed by the accountable executive. Service Provider’s policy defines maximum work periods and minimum non-work periods for each operation covered by the FRMS. These limits may be altered by agreement with the Regulator as a result of FRMS experience. Service Provider develops full FRMS documentation including description of processes, outputs and training records. Service Provider develops specific fatigue report procedures and documentation. Service Provider documents decisions and actions made in response to fatigue hazards detected by the FRMS. Service Provider maintains records of planned and actual working times.
FATIGUE RISK MANAGEMENT PROCESSES	<p>Regulator</p> <ul style="list-style-type: none"> Regulator identifies generic fatigue hazards within an operational context. Regulator makes risk assessment based on generic information (scientific principles, literature reviews, best practices). Regulator identifies prescriptive limits. 	<ul style="list-style-type: none"> Regulator reviews and approves the Service Provider’s maximum work periods and minimum non-work periods for each part of their operations covered by the FRMS. Regulator reviews and approves the Service Provider’s processes for fatigue hazard identification, risk assessment and mitigation.
	<p>Service Provider</p> <ul style="list-style-type: none"> Service Provider identifies fatigue hazards mainly through reactive processes, including data collected through existing safety reporting mechanisms. Service Provider considers scientific principles when developing work schedules (rosters) that are compliant with prescriptive limitation regulations. Service Provider assesses and mitigates their fatigue-related risks using existing SMS processes. 	<ul style="list-style-type: none"> Service Provider identifies maximum work periods and minimum non-work periods for each part of their operations covered by the FRMS. Service Provider develops and implements reactive, proactive and predictive processes for identifying fatigue. Service provider develops and implements fatigue risk assessment methodologies and adds specific fatigue mitigation strategies.

PRESCRIPTIVE APPROACH

FRMS APPROACH

	PRESCRIPTIVE APPROACH	FRMS APPROACH
SAFETY ASSURANCE	Regulator <ul style="list-style-type: none"> Regulator reviews compliance with prescriptive limits. Regulator reviews Service Provider's scheduling practices to evaluate whether they are based on scientific principles. SMS Safety Performance Indicators are agreed by regulator and Service Provider. 	<ul style="list-style-type: none"> Regulator reviews and agrees to Service Provider-identified Safety Performance Indicators. Regulator may require adjustment of Service Provider-identified maximum limits and non-duty minimums.
	Service Provider <ul style="list-style-type: none"> SMS Safety Performance Indicators are agreed by regulator and Service Provider. Service Provider considers changes to its operating environment and any impacts these changes may have on fatigue risks. 	<ul style="list-style-type: none"> Service Provider identifies FRMS Safety Performance Indicators. Service Provider considers changes to its operating environment and any impacts these changes may have on fatigue risks.
TRAINING AND COMMUNICATION	Regulator <ul style="list-style-type: none"> Regulator provides guidance for safety education and promotional material that includes fatigue. 	<ul style="list-style-type: none"> Regulator provides guidance for FRMS training and promotional material. Regulator assesses the Service Provider's fatigue training programme. Regulator develops an FRMS approval and oversight training programme for inspectors. Regulator assesses the effectiveness of their FRMS training programme.
	Service Provider <ul style="list-style-type: none"> Service Provider assesses fatigue management training needs using SMS processes. Service Provider safety training includes fatigue management specific to the operational context. Service Provider keeps safety training records. Service Provider considers fatigue when reporting on safety performance. Service Provider includes general fatigue information in internal safety communications. 	<ul style="list-style-type: none"> Service Provider training includes fatigue management specific to how the FRMS works and roles of the various stakeholders. Service Provider assesses the effectiveness of their FRMS training programme. Service Provider keeps safety training records. Service Provider identifies a feedback process to communicate fatigue issues identified through data collection. Service Provider includes fatigue topics in internal safety communications.

1.2. FATIGUE MANAGEMENT IN AIRLINE OPERATIONS

According to ICAO Standards and Recommended Practices (SARPs), where FRMS regulations have been established by a regulator for airline operations, the operator has three options for implementing the two different approaches to fatigue management:

1. The operator may comply with prescriptive limitation regulations throughout all their operations; OR
2. The operator may implement an FRMS that has been approved for use throughout their operations; OR
3. The operator may employ a combination of the two approaches, implementing an FRMS in part of their operations and comply with the prescriptive flight and duty time limitations in other operations.

Where no FRMS regulations are established, the operator is limited to managing their fatigue risks, using their existing SMS processes, within the constraints of the prescribed limits.

ICAO Fatigue Management Standards and Recommended Practices (SARPs) for Annex 6 Part I (International Air Transport Operations - Aeroplanes), along with clarifications of their intent, are presented in Appendix A. Operators will need to familiarize themselves with the related fatigue management regulations of their national authority.

CHAPTER 2. SCIENTIFIC PRINCIPLES FOR FATIGUE MANAGEMENT

The operational demands on crew members continue to change in response to changes in technology and commercial pressures, but human physiology remains unchanged. Both prescriptive fatigue management regulations and FRMS represent an opportunity to use advances in scientific understanding of human physiology to reduce fatigue and increase operational safety and flexibility.

Fatigue results in a reduced ability to carry out operational duties and can be considered 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 manage fatigue requires strategies to manage the exertion of waking activities and/or to improve 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 sleep loss; and
2. Circadian rhythms — daily cycles in physiology and behaviour that are driven by the circadian body clock (a pacemaker in the brain). Circadian rhythms include:
 - rhythms in subjective feelings of fatigue and sleepiness;
 - rhythms in the ability to perform mental and physical work; and
 - rhythms in the ability to fall asleep and stay asleep (sleep propensity).

This chapter summarizes the science under four key principles:

1. Periods of wake need to be limited. Getting enough sleep (both quantity and quality) on a regular basis is essential for restoring the brain and body.
2. Reducing the amount or the quality of sleep, even for a single night, decreases the ability to function and increases sleepiness the next day.
3. The circadian body clock affects the timing and quality of sleep and produces daily highs and lows in performance capacity on various tasks.
4. Workload can contribute to crew member fatigue. Low workload may unmask physiological sleepiness while high workload may exceed the capacity of a fatigued individual.

Fatigue. A physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person's alertness and ability to adequately perform safety-related operational duties.

ICAO definition

2.1. SCIENTIFIC PRINCIPLE 1: THE NEED FOR SLEEP

Have you ever wondered what happens from the time you fall asleep at night to when you wake up in the morning? If you have slept well, you will wake up feeling physically and mentally refreshed. Your experiences of the previous day will have been sorted, stored, and linked to your existing memories so that you wake up with a seamless sense of who you are. If you have not slept well, you know that the coming day will not be easy.

We are meant to spend about a third of our lives asleep. The optimal amount of sleep per night varies between individuals, but most adults require between 7 and 9 hours. 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 cannot be sacrificed without consequences. Sleep has multiple functions – the list keeps growing - but it is clear that it has vital roles in memory and learning, in maintaining alertness, performance, and mood, and in overall health and well-being.

SCIENTIFIC PRINCIPLE 1

PERIODS OF WAKE NEED TO BE LIMITED. GETTING ENOUGH SLEEP (BOTH QUANTITY AND QUALITY) ON A REGULAR BASIS IS ESSENTIAL FOR RESTORING THE BRAIN AND BODY.

2.1.1. TYPES OF SLEEP

A complex series of processes is taking place in the brain during sleep. Various methods have been used to look at these processes, from reflecting on dreams to using advanced medical imaging techniques. Sleep scientists have traditionally looked at sleep by monitoring electrical patterns in brain wave activity, eye movements, and muscle tone.

These measures indicate that there are two very different types of sleep:

- Non-rapid eye movement (Non-REM) sleep; and
- Rapid eye movement (REM) sleep.

NON-RAPID EYE MOVEMENT SLEEP (NON-REM SLEEP)

During non-rapid eye movement sleep (non-REM sleep), brainwave activity gradually slows compared to waking brainwave activity. Among other things, the body is being restored through muscle growth and repair of tissue damage. Non-REM sleep is sometimes described as “a quiet brain and quiet body.” Across a normal night of sleep, most adults normally spend about three quarters of their sleep time in non-REM sleep.

Non-REM sleep is divided into three 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.

Sleep is a complex series of processes that has multiple functions.

Stage 3 non-REM sleep is also known as slow-wave sleep (SWS) or deep sleep. Basically, in SWS the brain largely stops processing information from the outside world and huge numbers of brain cells (neurons) start firing in synchrony,

generating big, slow electrical waves. More stimulation is needed to wake someone up than from non-REM Stages 1 and 2. During SWS, consolidation of certain types of memory is occurring, so SWS is necessary for learning.

The longer you are awake and the more physically active you are, the more slow-wave activity your brain will show in your next sleep period. Thus SWS fits the traditional idea that sleep somehow restores you from the demands of waking activities. This is sometimes described as the ‘sleep homeostatic process’.

RAPID EYE MOVEMENT SLEEP (REM SLEEP)

During non-rapid eye movement sleep (non-REM sleep) brainwave activity looks similar to waking brainwave activity. 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. Most adults normally spend about a quarter of their sleep time in REM sleep.

There are two different types of sleep: non-REM and REM (rapid eye movement) sleep.

During REM sleep, the brain is restoring itself and information from the previous day is being sorted and related to stored memories. People awakened from REM can typically recall vivid dreaming. During REM sleep, 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, if reversal of this “REM block” is slightly delayed. Because of these features, REM sleep is sometimes described as a “busy brain and paralyzed body.”

Figure 2-1 summarizes the proportion of night time sleep that a young adult typically spends in each of the types of sleep.

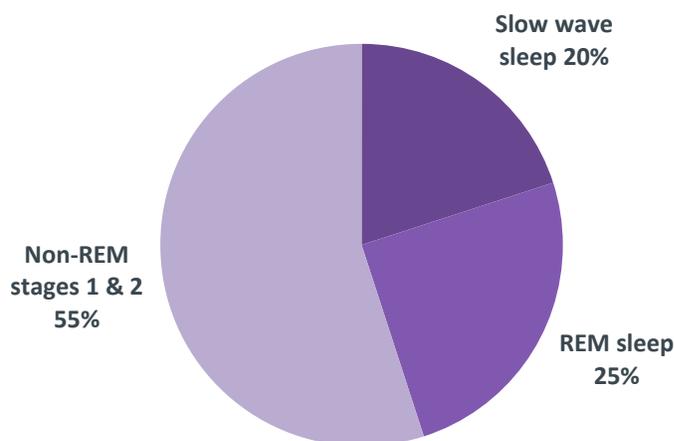


Figure 2-1. Proportion of the night spent in each types of sleep, for a young adult

2.1.2. THE NON-REM/REM CYCLE

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 2-2 is a diagram summarizing the non-REM/REM cycle across the night in a healthy young adult who goes to bed at 11:00 pm and wakes around 07:30am. 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 the horizontal axis.

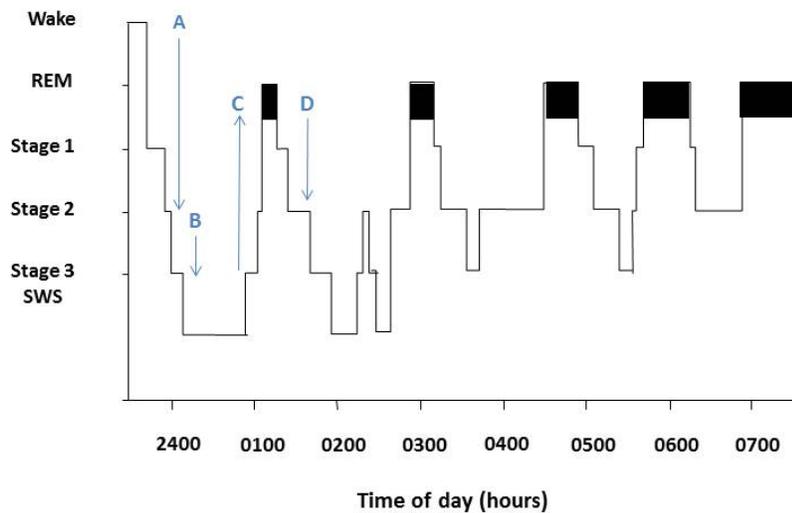


Figure2-2. The non-REM/REM cycle across the night, for a healthy young adult

Sleep is entered through Stage 1 non-REM and then progresses through Stage 2 non-REM (see 'A' in Figure2-2) and eventually into slow-wave sleep (see 'B' in Figure2-2). About 80-90 minutes into sleep, there is a shift out of slow-wave sleep (see 'C' in Figure2-2). This shift 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 Figure2-2). After a fairly short period of REM, the sleeper progresses back down again through lighter non-REM sleep (see 'D' in Figure2-2) and into slow-wave sleep, and so the cycle repeats. In the morning, the sleeper in Figure 2-2 wakes up out of REM sleep and is likely to be able to remember dreaming.

In non-REM/REM cycles across a normal night of sleep:

- the amount of slow-wave sleep decreases (there may be none at all in later cycles);
- in contrast, the amount of REM sleep increases.

Waking up from sleep is a process, not an on/off switch and various parts of the brain have to reactivate in sequence. People sometimes experience the transient grogginess and disorientation known as 'sleep inertia', when they are conscious but not fully awake. Sleep inertia can occur during waking from any stage of sleep and may be worse after longer periods of sleep. More information on sleep inertia is provided later in this chapter in the section on napping.

OPERATIONAL IMPLICATION 1. MITIGATION STRATEGIES FOR SLEEP INERTIA

The possible occurrence of sleep inertia is sometimes used as an argument against napping in the work setting. It would not be desirable to have an individual who is woken up in an emergency, and is impaired by sleep inertia.

The risk of sleep inertia can be reduced by having a protocol for returning to active duty that limits the duration of sleep or allows time for sleep inertia to wear off (see *Operational Implication 5: Napping as a Fatigue Mitigation*). It is suggested that at least 10-15 minutes should be allowed before recommencing safety-related duties.

2.1.3. FACTORS THAT AFFECT 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.

For sleep to be fully restorative, it must contain unbroken cycles of non-REM and REM sleep.

OPERATIONAL IMPLICATION 2. PROCEDURES FOR MINIMISING SLEEP INTERRUPTIONS

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

Rest periods (in flight or on layovers) should include protected blocks of time (sleep opportunities) during which crewmembers are not contacted except in emergencies. These protected sleep opportunities need to be known to crewmembers 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 should 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).

SLEEP QUALITY AND AGING

Across adulthood, the proportion of sleep time spent in slow-wave sleep declines, particularly among men. In addition sleep generally becomes more fragmented after about age 50-60 years. These age-related trends are seen in the sleep of flight crew members, both on the ground and in the air.⁴ A study of in-flight sleep on delivery flights of B-777 aircraft (from Seattle to Singapore or Kuala Lumpur) found that older pilots took longer to fall asleep, obtained less sleep overall, and had more fragmented sleep than their younger colleagues.

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. From both practical and scientific perspectives, age is not considered to be a specific factor to be addressed in order to manage fatigue.

Sleep quality declines as a normal part of aging.

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 crew members because, in addition, they often have restricted time available for sleep. Fatigue management training should include basic information on sleep disorders and their treatment, where to seek help if needed, and any requirements relating to fitness to fly.

Sleep disorders can reduce the amount and quality of sleep a person can obtain, even when they spend enough time trying to sleep.

CAFFEINE, NICOTINE, AND ALCOHOL

Caffeine (in coffee, tea, energy drinks, colas and chocolate) stimulates the brain, making it harder to fall asleep and disrupting the quality of sleep. Some people are more sensitive to effects of caffeine than others, but even heavy coffee drinkers will have lighter and more disturbed sleep if they drink coffee close to bedtime (although they may not even notice this). Nicotine in cigarettes is also a stimulant and affects sleep in a similar way. Alcohol on the other hand makes us feel sleepy but it also disturbs sleep. While the body is processing alcohol (at the rate of about one standard drink per hour), the brain cannot obtain REM sleep. Pressure for REM sleep builds up, and sleep later in the night often contains more intense REM periods and is more disturbed as a consequence.

Caffeine, nicotine, and alcohol can disrupt sleep quality.

⁴ Signal TL, Gander PH, van den Berg M. Sleep in flight during long rest opportunities. Internal Medicine Journal 34(3): A38, 2004.

OPERATIONAL IMPLICATION 3. USE OF CAFFEINE

Caffeine can be useful to temporarily reduce sleepiness on duty because it blocks a chemical in the brain (adenosine) that increases sleepiness. It can also be used in advance of a period that is likely to be associated with higher fatigue (e.g., the early hours of the morning). Caffeine takes approximately 30 minutes to have an effect and can last for up to 5 hours, (but people differ widely in how sensitive they are to caffeine and how long the effects last). It is important to remember that caffeine does not remove the need for sleep and it should only be used as a short term strategy. For maximum benefit, caffeine should be avoided when alertness is high, such as at the beginning of a duty period, and instead used at times when sleepiness is expected to be high, e.g., towards the end of a long duty period or at the times in the circadian body clock cycle when sleepiness is greater.

ENVIRONMENTAL FACTORS

Environmental factors can also disturb sleep. Bright light increases alertness; it is much easier to sleep in a dark room. Heavy curtains or a mask can be used to block out light. Sudden sounds also disturb sleep. Masking them using white noise can help, for example tuning the radio in the hotel room between stations. Falling asleep requires being able to lower core body temperature (by losing heat through the extremities), so it is easier to fall asleep if the room is cooler rather than hotter. For most people (18-20 °C/ 64-68 °F) is an ideal room temperature for sleep. A comfortable sleep surface is also important.

The sleep environment can affect sleep quality.

QUALITY OF IN-FLIGHT SLEEP

Studies using polysomnography show that crew members' sleep in on-board crew rest facilities is lighter and more fragmented than their sleep on the ground⁵. Sleep during flight deck naps is also lighter and more fragmented than would be predicted from laboratory studies⁶. Nevertheless, there is good evidence that in-flight sleep improves subsequent alertness and reaction speed and is a valuable mitigation strategy in fatigue management. Interestingly, the fragmented quality of in-flight sleep is not seen in studies in hypobaric chambers at cabin pressures (6,000-8,000 feet), so it cannot be due to altitude⁷. The factors most commonly identified by crew members as disturbing their in-flight sleep are random noise, thoughts, not feeling tired, turbulence, ambient aircraft noise, inadequate bedding, low humidity, and going to the toilet.

Sleep obtained at work is often not as good quality as sleep under normal conditions at home.

⁵ Signal TL, Gale J, Gander PH. Sleep Measurement in Flight Crew: Comparing actigraphic and subjective estimates of sleep with polysomnography. *Aviation Space and Environmental Medicine* 76(11):1058-1063, 2005.

⁶ Rosekind MR, Graeber RC, Dinges DF, et al. 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, 1994.

⁷ Mumm JM, Signal TL, Rock PB, Jones SP, O'Keefe KM, Weaver MR, Zhu S, Gander PH, Belenky G. Sleep at simulated 2438 m: effects on oxygenation, sleep quality, and post-sleep performance. *Aviation, Space, and Environmental Medicine* 80 (8):691-697, 2009.

QUALITY OF SLEEP WHEN ON STANDBY

Sleep may also be disturbed if there is an expectation of being woken and called back to work. A laboratory study compared the sleep of people who were told on one night that they may be woken and required to respond to a noise, to their sleep on another night when they received no instructions⁸. The findings showed that it took people longer to fall asleep and they spent longer awake during the night when they expected to be woken. In this study the noise never occurred so sleep was not disturbed by external factors.

Sleep obtained when on call may be poorer quality.

A limited number of field studies have looked at the effects on sleep quality of being on-call. For example, an older polysomnographic study of the sleep of ships engineers found that sleep during on-call nights (with an average of two alarms) was shorter and contained more light non-REM sleep, less slow-wave sleep, and less REM sleep, and higher heart rate than sleep on nights when engineers were not on call.⁹ Many of these effects were observable before any alarms had occurred on on-call nights. In addition, engineers rated their sleep quality as lower on on-call nights and their sleepiness as higher on the day following an on-call night. These findings and subsequent studies with junior doctors support the idea that the anticipation of being called for duty somehow interferes with sleep quality.

2.1.4. THE IMPACT OF CONTINUOUS TIME AWAKE

Scientific evidence shows that the longer crew members remain awake, the worse their alertness and performance become. This is due to an increasing homeostatic pressure for sleep associated with the longer period of wakefulness. Sleep is the only way to reverse this.

The US National Transportation Safety Board has examined the relationship between time since awakening (TSA) and errors in 37 aircraft accidents (1978-1990) in which flight crew actions or inactions were causal or contributing factors¹⁰. The median TSA at the time of the accident was 12 hours for captains and 11 hours for first officers. Six crews were classified as low TSA (both the captain and the first officer were below the median) and six crews were classified as high TSA (both the captain and the first officer were above the median). For low TSA crews, the median time awake was 5.3 hours for captains and 5.2 hours for first officers. For high TSA crews the median time awake was 13.8 hours for captains and 13.4 hours for first officers. Overall, high TSA crews made about 40% more errors than low TSA crews (12.2 versus 8.7 errors), primarily due to making more errors of omission (5.5 versus 2.0 errors). In terms of error types, high TSA crews made significantly more procedural errors and tactical decision errors than low TSA crews.

Research supports the benefits of napping as a mitigation in flight operations. For two-pilot crews on long range flights, planned 40-minute nap opportunities on the flight deck seat have been shown to provide an average of 23 minutes of sleep and to improve alertness and performance at top of descent, with no apparent effect on

A short nap can improve alertness and performance and is a valuable mitigation strategy in fatigue management.

⁸ Wuyts, J., De Valck, E., Vandekerchove, M., Pattyn, N., Exadaktylos, V. Haex, B., Verbraecken, J. and Cluydts, R. (2012) Effects of pre-sleep simulated on-call instructions on subsequent sleep. *Biological Psychology*, 91:383-388.

⁹ Torsvall L, Akerstedt T. Disturbed sleep while being on-call: an EEG study of ships' engineers. *Sleep*, 11: 35-38, 1998

¹⁰ National Transportation Safety Board Safety Study 94/01.

subsequent layover sleep¹¹. Note that not all regulators permit flight deck napping.

OPERATIONAL IMPLICATION 4. PROTOCOLS FOR STANDBY, RESERVE AND ON-CALL DUTIES

Although standby, reserve and on-call duties lack the certainty associated with scheduled shifts, the same scientific principles still apply. It is important to establish protocols for assigning unscheduled duties that aim to:

- *Minimize interruptions during circadian times when sleep is more likely.* (Circadian influences are further discussed in *Section 2.3: Circadian Effects on Sleep and Performance*)

During periods of being on standby, reserve or on-call, there will be times when an individual is more likely to be able to sleep. Therefore, interruptions (such as non-urgent phone calls from work) during those times should be minimised as much as possible.

- *Minimize continuous hours of wakefulness before and during duty periods that are unscheduled.*

When being called-in is highly likely, establishing minimal notification periods before the individual can be asked to report for duty allows the opportunity for some sleep. If minimal notification periods are not operationally feasible, an extended duty is required or a call-back occurs late in the day or during the night, naps will reduce increasing sleep pressure over extended waking hours. Consideration should be given to appropriate napping facilities and the establishment of napping protocols (See *Operational Implication 5: Napping as a Fatigue Mitigation*).

- *Build in some level of schedule predictability.*

Individuals can maintain a better level of alertness if they have a general idea of what will be expected of them. Therefore, the time of day for potential duty should be predictable and consistent and the number of consecutive days that an individual may be subject to being assigned unscheduled duties should be limited. This provides some level of consistency in the timing of duty periods and allows for individuals to plan and manage their sleep periods.

Further information on assigning unscheduled duties is provided in *Section 4.1.3 Designing and Managing Pairings and Rosters – Assigning Unscheduled Duties*.

¹¹ Rosekind MR, Graeber RC, Dinges DF, et al. Crew factors in flight operations IX: Effects of planned cockpit rest on crew performance and alertness in long-haul operations. NASA Technical Memorandum 108839, 1994.

OPERATIONAL IMPLICATION 5. NAPPING AS A FATIGUE MITIGATION

If a crew member has been awake for a long period of time or if he/she has not had enough sleep over one or more days, some sleep is always better than none. Napping is a mitigation that can help maintain performance and alertness in the short term, until a full sleep opportunity is available and utilised. Napping should not be used as a means of extending a duty period, which requires the opportunity for longer sleep periods with the provision of appropriate facilities.

Napping before duty: When a duty period starts later in the day (e.g. in the evening or at night) a nap prior to commencing work will reduce the period of wakefulness and help maintain performance and alertness during the work period. It has been shown that napping prior to work does not reduce the amount of sleep obtained during a rest break at work.

Napping during a duty period: A nap during a duty period can help maintain performance during extended work periods or during duty periods at night. How such naps are managed will depend on the context in which they occur and where they can be taken (e.g. for airline pilots: on-board in designated crew rest facilities or on the flight deck (controlled rest)). The length of the nap will depend largely on the available time away from duties but it should allow enough time for individuals to fall asleep (it may take people longer than usual to fall asleep in these circumstances) and enough time after waking before recommencing duties to ensure that any sleep inertia has dissipated (see Operational Implication 1: Mitigation Strategies for Sleep Inertia). It is also critical that individuals are educated to not reduce their sleep time in anticipation of a nap during a flight or duty period. If they sleep less before work because they assume they will get a nap at work, the overall benefit of allowing napping may be negated.

Controlled rest on the flight deck: These types of naps are taken by pilots in response to unexpected fatigue experienced during operations. If these are allowed, they need to be supported by specific guidance material and policies to ensure operational integrity and continued safe operations when this fatigue mitigation measure is necessary (see Appendix D for details on controlled rest on the flight deck).

2.2. SCIENTIFIC PRINCIPLE 2: SLEEP LOSS AND RECOVERY

Even for people who have good quality sleep, the amount of sleep they obtain is very important for restoring their waking function.

2.2.1. SLEEP RESTRICTION IN THE LABORATORY

Numerous laboratory studies have looked at the effects of ‘trimming’ sleep at night by an hour or two (known as **sleep restriction**). Losing as little as two hours of sleep on one night will reduce alertness the next day and degrade performance on many types of tasks. Studies that have restricted sleep on multiple nights in a row have key findings that are important for fatigue management.

SCIENTIFIC PRINCIPLE 2

REDUCING THE AMOUNT OR THE QUALITY OF SLEEP, EVEN FOR A SINGLE NIGHT, DECREASES THE ABILITY TO FUNCTION AND INCREASES SLEEPINESS THE NEXT DAY.

EFFECTS OF SLEEP RESTRICTION ACCUMULATE AND ARE DOSE-DEPENDENT

The effects of restricting sleep night after night accumulate, so that people become progressively less alert and less functional each subsequent day. This is sometimes described as *accumulating a sleep debt*. This is a common occurrence for crew members.

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 time¹². 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. Figure 2-3 summarizes the results of this study.

The effects of restricting sleep night after night accumulate. Less sleep per night = more rapid performance degradation.

¹² Balkin TJ, Thorne D, Sing H, Thomas M, Redmond D, Wesensten N, Williams J, Hall S, Belenky G. Effects of Sleep Schedules on Commercial Motor Vehicle Driver Performance. U.S. Department of Transportation Federal Motor Carrier Safety Administration Report No. DOT-MC-00-133, May 2000.

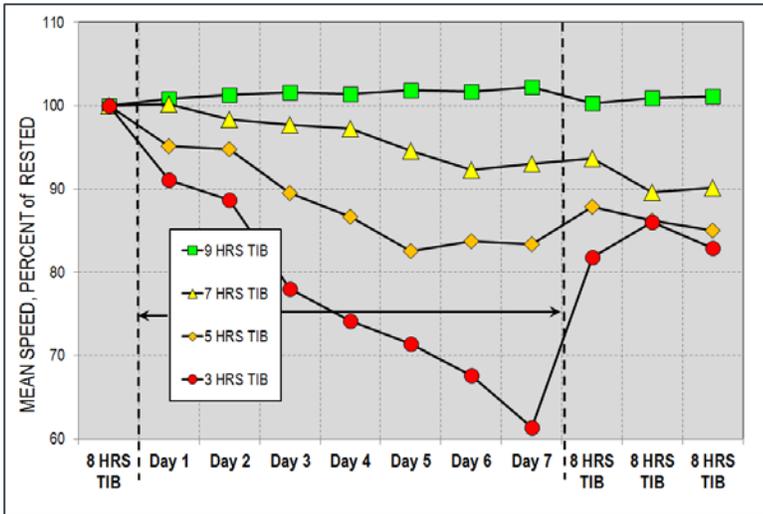


Figure 2-3. Impact of different nightly times in bed (TIB) on daytime performance¹³

SOME TYPES OF TASKS ARE MORE AFFECTED THAN OTHERS

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 (for example anticipating events, planning and determining relevant courses of action -particularly under novel situations) are the most affected by sleep loss and have the greatest need for sleep to recover their normal function.

HOW YOU FUNCTION VERSUS HOW YOU FEEL

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 though their alertness and performance continues to decline. In other words, as sleep restriction continues, people become increasingly unreliable at assessing their own functional status. Both objective and subjective tests are useful in fatigue management. Objective ratings of fatigue and sleepiness are often considered more reliable for measuring fatigue-related impairment (see Appendix B of this guidance).

People are not very accurate at judging their alertness and performance after sleep has been restricted for several days.

¹³ Figure provided by Dr N. Wesensen, adapted from Figure 2-24, U.S. Department of Transportation Federal Motor Carrier Safety Administration Report No. DOT-MC-00-133, May 2000.

SLEEPINESS CAN BECOME UNCONTROLLABLE

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.

Sleepiness eventually becomes overwhelming and results in uncontrollable micro-sleeps.

SOME PEOPLE ARE MORE AFFECTED THAN OTHERS

Individuals vary widely in their ability to tolerate sleep loss.

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 fatigue management (for example, by recommending different personal mitigation strategies for people who are more or less affected by sleep restriction).

LIMITATIONS OF LABORATORY SLEEP RESTRICTION STUDIES

Laboratory studies are currently the main source of information on the effects of sleep restriction, but they have some obvious limitations. Laboratory studies usually look at the effects of restricting sleep at night and participants sleep in a dark, quiet bedroom. More research is needed on the effects of restricting sleep during the day, and on the combination of restricted sleep and poor quality sleep. This limitation may mean that current understanding of the effects of sleep restriction is based on a 'best case scenario'.

When examining performance effects, laboratory studies have also focused on the performance of individuals, not people working together as a crew. More research is needed to improve understanding of how the fatigue levels of individual crew members affect the flight deck performance of two-pilot crews. For example, one simulation study with 67 experienced B747-400 crews found that sleep loss in the last 24 hours increased the total number of errors made by the crew (the captain was always the pilot flying)¹⁴. Paradoxically, greater sleep loss among first officers improved the rate of error detection, but greater sleep loss among captains 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 for some crews, a tendency to choose lower risk options, which would help mitigate fatigue risk.

¹⁴ Thomas MJW, Petrilli RM, Lamond NA, et al. Australian long haul fatigue study. In: Enhancing Safety Worldwide: Proceedings of the 59th Annual International Air Safety Seminar. Alexandria, USA, Flight Safety Foundation, 2006..

2.2.2. SLEEP RESTRICTION IN FLIGHT OPERATIONS

Table 2.1 summarizes data on sleep restriction across different flight operations that were monitored by the NASA Fatigue Programme in the 1980s¹⁵. In these studies, crew members completed sleep and duty diaries before, during, and after a scheduled commercial trip. For each crew member, 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, crew members often had split sleep (slept more than once in 24 hours).

Scheduling has undoubtedly changed since these studies, so in many cases the data in Table 2.1 are likely to be unrepresentative of the current situation. 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
crew members averaging at least 1 hour of sleep restriction per trip day	67%	54%	43%
crew members 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 crew members 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.

¹⁵ Gander PH, Rosekind MR, Gregory KB. Flight crew fatigue VI: an integrated overview. *Aviation, Space, and Environmental Medicine* 69: B49-B60, 1998.

2.2.3. RECOVERY FROM THE EFFECTS OF SLEEP RESTRICTION

Prolonged sleep restriction may have effects on the brain that can continue to affect alertness and performance days to weeks later¹⁶. Available laboratory studies do not yet give a clear answer to the question of how long it takes to fully recover from these effects. However, the following findings are reliable.

- Lost sleep is not recovered hour-for-hour, although recovery sleep may be slightly longer than normal sleep at night.
- At least two consecutive nights of unrestricted sleep are required for the non-REM/REM sleep cycle to return to normal.
 - Typically, on the first night of recovery, more SWS will occur, but this can limit the time available for REM sleep.
 - On the second night of recovery, the brain catches up on REM sleep.
 - Recovery of a normal non-REM/REM cycle may take longer if recovery sleep is not at night, or if a crew member is not adapted to the local time zone.
- If sleep restriction continues over multiple nights, then the recovery of waking alertness and performance will normally require more than two consecutive nights of unrestricted sleep.
 - One 10-hour sleep opportunity at night is not enough to recover from the cumulative effects of 5 nights of sleep restricted to 4 hours per night¹⁷.
 - Three 8-hour sleep opportunities at night are not enough to recover from 7 nights of sleep restricted to 7 hours per night¹⁸.

Recovery of a normal sleep pattern after an accumulated sleep debt takes at least two nights of unrestricted sleep.

Recovery of waking alertness and performance after accumulating a sleep debt may take longer than two nights of unrestricted sleep.

During prolonged low-level sleep restriction, it may be that the brain somehow reconfigures the way it manages tasks, so that we adapt by settling at a stable but sub-optimal level of alertness and performance. However, the prolonged recovery times seen in laboratory sleep restriction studies suggest that return to optimal performance may be a slow process. Longer periods of time off, such as blocks of annual leave, may be important for full recovery.

¹⁶ Rupp TL, Wesensten NJ, Bliese PD, et al. Banking sleep: realization of benefits during subsequent sleep restriction and recovery. *Sleep* 32:311-321, 2009

¹⁷ Banks S, Van Dongen HPA, Maislin G, et al. Neurobehavioral dynamics following chronic sleep restriction: dose-response effects of one night for recovery. *Sleep* 33:1013-26, 2010.

¹⁸ Belenky G, Wesensten NJ, Thorne DR, et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *Journal of Sleep Research* 12: 1-12, 2003.

OPERATIONAL IMPLICATION 6. ALLOWING FOR SLEEP RECOVERY

Because the effects of sleep restriction are cumulative, schedules must be designed to allow periodic extended 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 a minimum of two consecutive nights of unrestricted sleep. This is not necessarily 48 hours off duty. A 48-hour break starting at midnight will not allow most people two consecutive nights of unrestricted sleep (most people go to sleep before midnight). Conversely, a 40-hour break starting at 20:00 will allow most people two consecutive nights of unrestricted sleep.

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.

THE RECOVERY VALUE OF SPLIT SLEEP

The laboratory studies addressing recovery sleep typically allow participants a single sleep opportunity at night. However, split sleep is common during different types of flight operations. For example, in-flight sleep on long flights results in split sleep (either by the use of controlled rest or where augmented crews enable scheduled in-flight rest breaks). Layovers after transmeridian flights also commonly include split sleep, as do daytime layovers between night duty periods without transmeridian flights.

Laboratory studies suggest that having a restricted sleep period at night plus a daytime nap has equivalent recovery value to an identical total amount of sleep taken in one consolidated block at night.¹⁹ However, these are short-term studies that take place in dark, quiet laboratory environments with no distractions, and participants are fully adapted to the local time zone. These conditions do not always apply in 24/7 flight operations, so careful consideration is needed before applying the findings to crew members.

An important advantage of split sleep is that it reduces the length of time that a crew member is continuously awake (see *Section 2.1.4, page 13*).

¹⁹ Mollicone DJ, Van Dongen H, Rogers NL, et al. Response surface mapping of neurobehavioral performance: Testing the feasibility of split sleep schedules for space operations. *Acta Astronautica* 63: 833-40, 2008.

2.2.4. LONG-TERM SLEEP RESTRICTION AND HEALTH

Evidence from 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 people who report averaging less than 7 hours of sleep per night 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 crew members 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 cannot be sacrificed without consequences.

2.3. SCIENTIFIC PRINCIPLE 3: CIRCADIAN EFFECTS ON SLEEP AND PERFORMANCE

Sleeping at night is not just a social convention. It is programmed by the circadian clock - an ancient adaptation to life on our 24-hour rotating planet.

Like other mammals, we have a circadian master clock located in a small cluster of cells (neurons) deep in the brain. The cells that make up the master 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 master clock is slightly longer than 24 hours.

This master clock, also known as the *circadian body clock*, receives information about light intensity through a direct connection to

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).

special cells in

the retina of the eye (this special light input pathway is not involved in vision). Being light sensitive enables the circadian body clock to stay in step with the day/night cycle. However, it also creates problems for crew members 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. The effects of light on the circadian body clock are considered in more detail later in this chapter.

Other parts of the brain and some other organs including the liver, kidneys, and gut, contain peripheral oscillators that generate their own local circadian rhythms. (Indeed, every cell in the body contains the ‘clock genes’ that are the basic molecular machinery for generating circadian rhythms.) The circadian body clock in the suprachiasmatic nucleus (SCN) is at the top of a hierarchy, keeping the rhythms in other parts of the brain and body in step with the day/night cycle and with each other.

The circadian body clock programmes humans for daytime wakefulness and night time sleepiness.

SCIENTIFIC PRINCIPLE 3

THE CIRCADIAN BODY CLOCK AFFECTS THE TIMING AND QUALITY OF SLEEP AND PRODUCES DAILY HIGHS AND LOWS IN PERFORMANCE ON VARIOUS TASKS.

2.3.1. EXAMPLES OF CIRCADIAN RHYTHMS

It is not possible to directly measure the electrical activity of the circadian body clock in the SCN of human beings. However, many circadian rhythms in physiology and behaviour can be measured as a way of indirectly tracking the cycle of the circadian body clock. Figure 2-3 shows an example of some circadian rhythms of a 46-year old short-haul pilot monitored before, during, and after a 3-day pattern of flying on the east coast of the USA (staying in the same time zone²⁰). The black horizontal bars indicate when he was on duty.

²⁰ Gander PH, Graeber RC, Foushee HC, Lauber JK, Connell LJ. Crew Factors in Flight Operations II: Psychophysiological Responses to Short-Haul Air Transport Operations. NASA Technical Memorandum #108856. Moffett Field: NASA Ames Research Center, 1994.

- He kept a daily diary of his activities, including when he slept (the shaded vertical bars in Figure 2-3).
- His core body temperature was monitored continuously (shown in the upper panel in Figure 2-3).
- In his logbook, he also rated his fatigue every 2 hours while he was awake, on a scale from 0 = most alert to 100 = most drowsy (shown in the lower panel in Figure 2-3).

His core temperature fluctuated by about 1 degree Celsius across the 24-hour day. Notice that his temperature started to rise each morning *before* he woke up. In effect, his body was preparing 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).

This crew member 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. (He was not asked to wake up every 2 hours across the night to rate his fatigue).

Core body temperature is often used 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 2-4.

The circadian body clock affects every aspect of human functioning resulting in cycles of high performance and low performance.

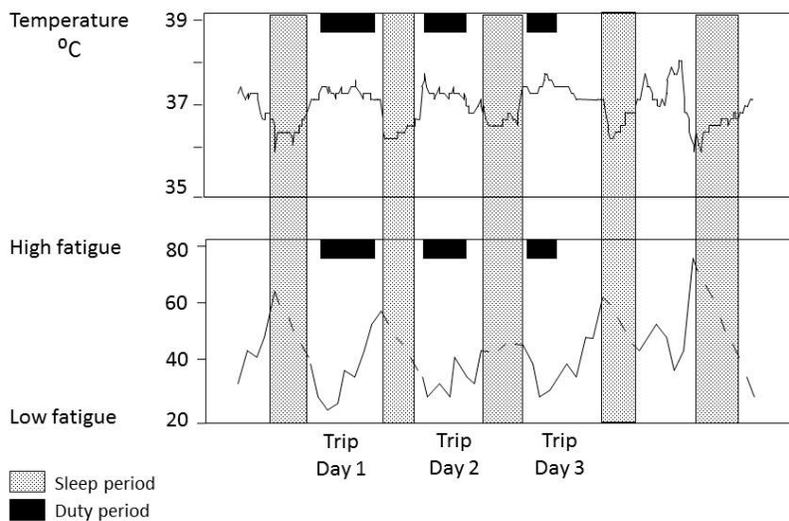


Figure 2-4 Circadian rhythms of a short-haul pilot

2.3.2. SLEEP REGULATION: THE CIRCADIAN BODY CLOCK AND THE SLEEP HOMEOSTATIC PROCESS

The circadian body clock is one of two key processes that regulate sleep timing and quality (the other is the sleep homeostatic process, which is described in more detail below). The circadian body clock has connections to sleep-promoting and wake-promoting centres in the brain, which it modulates to control the sleep/wake cycle. It also influences the timing and amount of REM sleep. Just after the minimum in core body temperature, the brain goes more quickly into

REM sleep and stays in REM for longer than at any other time in the circadian body clock cycle. This is sometimes described as a circadian rhythm in 'REM sleep propensity'. Thus, during a normal night of sleep, the longest bouts of REM sleep occur in the last non-REM cycles towards morning (see Figure 2-2).

Figure 2-5 is a diagram that summarizes the relationships between sleep and the circadian body clock cycle (tracked here by the circadian rhythm in core body temperature). The figure is based on data collected from 18 night cargo pilots on their days off, i.e., when they were sleeping at night²¹. Their core body temperature was monitored continuously and they recorded their sleep and duty times in a daily diary. Their average core body temperature rhythm has been simplified (the continuous curve). The dot represents the average time of the temperature minimum, which is used as a reference point for describing the other rhythms.

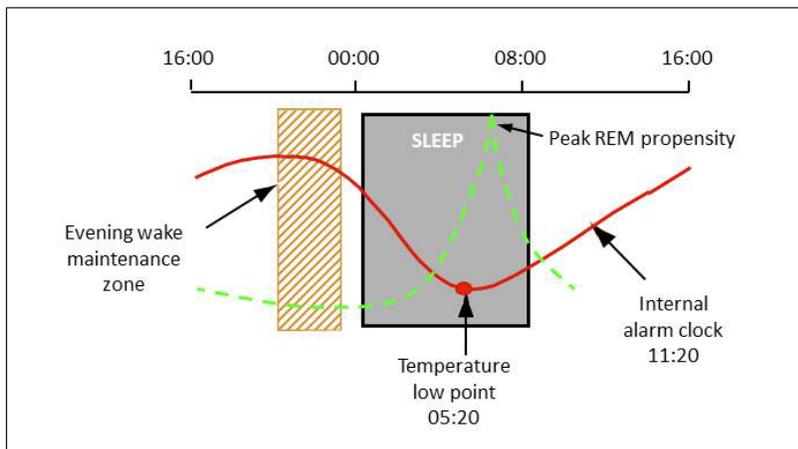


Figure 2-5. Relationships between normal sleep at night and the circadian body clock cycle²²

Figure 2-5 highlights the following relationships:

- 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 propensity (the dashed curve) peaks just after the minimum in core body temperature.
- As core body temperature begins to rise, the circadian body clock sends an increasingly strong signal to the brain centres that promote wakefulness, sometimes called the 'circadian alerting signal'. About 3 hours after waking up, homeostatic pressure for sleep is low (see below) and the circadian alerting signal is strong enough to make it very hard to fall asleep or stay asleep. This is sometimes referred to as the *internal alarm clock*.

The circadian clock exerts strong influence over sleep, creating windows when sleep is promoted and windows when sleep is opposed.

²¹ Gander PH, Rosekind MR, Gregory KB. Flight crew fatigue VI: an integrated overview. *Aviation, Space, and Environmental Medicine* 69: B49-B60, 1998.

²² Figure provided by Prof. P. H. Gander, adapted from Gander PH et al (1998) Gregory, K.B., Connell, L.J., Graeber, R.C., Miller, D.L., and Rosekind, M.A. Flight crew fatigue IV: overnight cargo operations. *Aviation, Space, and Environmental Medicine* 69:B26-B36.

- The circadian alerting signal is strongest just before usual bedtime. This makes it very difficult to fall asleep a few hours earlier than usual, and this part of the circadian body clock cycle is known as the *evening wake maintenance zone*.

The time around the daily minimum in core body temperature is the part of 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)*.

The second key process regulating sleep timing and quality is the sleep homeostatic process (see Principle 1). This can be summarized as: your brain's need for sleep builds up while you are awake and the only way to discharge this pressure is to sleep. The homeostatic process can be tracked by the amount of slow-wave sleep.

- Across time awake, the pressure for slow-wave sleep builds up. The longer you are awake, the more slow-wave sleep you will have in the first few non-REM/REM cycles when you next sleep.
- Across sleep, the amount of slow-wave decreases in each subsequent non-REM/REM cycle. In other words, the pressure for slow-wave sleep is discharged across the sleep period.

Discharging the homeostatic pressure for sleep seems to take priority - slow-wave sleep is always greatest in the first non-REM/REM cycles, regardless of when that sleep occurs in the circadian body clock cycle.

The circadian body clock and the sleep homeostatic process interact to produce two times of peak sleepiness in 24 hours.

1. Sleepiness is greatest when people are awake during the *WOCL*, which occurs around 3-5 am for most people on a normal routine with sleep at night.
2. Sleepiness increases again in the early afternoon - sometimes called the afternoon nap window (around 3-5 pm for most people). Restricted or disturbed sleep at night 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 crew members across the age range 20-60 years.

The combined effects of the sleep homeostatic pressure and the circadian body 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).

2.3.3. HOW LIGHT SYNCHRONIZES THE CIRCADIAN BODY CLOCK

The cells (neurons) in the circadian body clock spontaneously generate electrical signals faster during the day than at night (usually described as 'firing' faster during the day than at night). Light exposure effectively increases the firing rate of the clock cells. Depending on when in the body clock cycle light is received, there are three possible outcomes:

1. Light in the morning shortens the body clock cycle in that cycle (known as a phase advance);

2. Light in the middle of the day does not change the body clock cycle length (no phase change); or
3. Light in the evening lengthens the body clock cycle in that cycle (known as a phase delay).

Figure 2-6 shows graphically how these different responses are possible. The solid line in each panel represents the circadian rhythm in firing rate of the circadian body clock cells.

- In the left hand panel, light speeds up the rising part of the body clock cycle, leading to a phase advance.
- In the middle panel, light causes no phase change.
- In the right hand panel, light slows down the falling part of the body clock cycle, leading to a phase delay.

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

In summary, for a crew member fully adapted to the local time zone and sleeping regularly at night:

- light exposure after the circadian temperature low point in the morning will result in a phase advance of the body clock cycle;
- light exposure in the middle of the day will have minimal effect on the body clock cycle;
- light exposure in the evening before the circadian temperature low point will result in phase delay of the body clock cycle.

Light in the morning shortens the circadian body clock cycle and light in the evening lengthens the body clock cycle.

In theory, this means that just the right amount of light exposure at the same time every morning would speed up a slightly slow circadian body clock cycle just enough to synchronize it to exactly 24 hours (most of us have an innate body clock cycle slightly longer than 24 hours). In practice, staying in step with the day/night cycle is more complex than this. In modern industrialized 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, for example it 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 can create challenges for crew members involved in 24/7 operations because it causes the 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 crew member to be awake during the time in the circadian body clock cycle when they would normally be asleep if they were free to choose their own schedule (see Figure 2-4).

The further sleep is displaced from the optimum part of the circadian body clock cycle, the more difficult it becomes for crew members to get adequate sleep (i.e., the more likely they are to experience sleep restriction). For example, crew members 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 crew members are flying at night.

Figure 2-7 is a diagram that summarizes what happened to the circadian biological clock and sleep when the night cargo crew members in Figure 2-5 were flying at night and trying to sleep in the morning. Again, their average core body temperature rhythm has been simplified (the continuous curve).

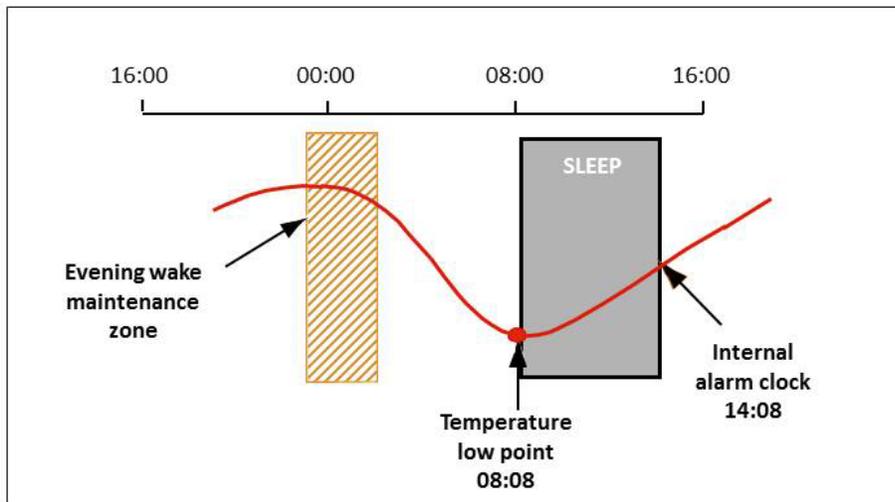


Figure 2-6. Relationships between sleep after night duty and the circadian body clock cycle²³

On off duty days, when these crew members were sleeping at night, the average time of the temperature minimum was 05:20 (Figure 2-4). When they were flying at night (Figure 2-7) this moved to 08:08, i.e., the average temperature minimum delayed by 2 hours 48 minutes. The circadian body clock did not adapt fully to night duty, which would have required a shift of about 12 hours. As a result, crew members had to sleep in a different part of the circadian body clock cycle after night duty.

- After night duty (Figure 2-7), they fell asleep close to the circadian temperature minimum. In contrast when they slept at night (Figure 2-5), they fell asleep about 5 hours before the temperature minimum.
- After night duty (Figure 2-7), crew members woke up about 6 hours after the circadian temperature minimum, within 5 minutes of the predicted time of the internal alarm clock. In contrast when they slept at night (Figure 2-5), they woke up about 3 hours after the temperature minimum.
- Crew members were not asked what woke them up from sleep episodes after night duty, 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 crew members 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 crew members to respond to non-routine situations.

²³ Figure courtesy of Prof. P. H. Gander, adapted from Gander PH et al (1998) Gregory, K.B., Connell, L.J., Graeber, R.C., Miller, D.L., and Rosekind, M.A. Flight crew fatigue IV: overnight cargo operations. *Aviation, Space, and Environmental Medicine* 69:B26-B36.

OPERATIONAL IMPLICATION 7. SCHEDULING

The perfect schedule for the human body is daytime duties with unrestricted sleep at night. Anything else is a compromise. There are, however, general scheduling principles based on fatigue science that should be taken into account when designing a duty schedule:

- The circadian body clock does not adapt fully to altered schedules such as rotating shifts or night work. Some adaptation may occur on slow rotating schedules. There is no clear difference between forwards versus backwards rotating shift schedules.
- Whenever a duty period overlaps an individual'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 a duty period overlaps an individual's usual sleep time, the less sleep the individual is likely to obtain. Working right through the usual night-time sleep period is the worst-case scenario.
- Night duty also 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. Napping before and during a night duty period is a useful strategy (discussed above in *Operational Implication 5: Napping as a Fatigue Mitigation*).
- Night duty also forces an individual to sleep later than normal in their circadian body clock cycle, so they have a limited time to sleep before the circadian alerting signal wakes them up. This can cause restricted sleep following a night shift. To provide the longest sleep opportunity possible, night shifts should be scheduled to end as early as possible and individuals need to get to sleep as soon as possible after coming off duty.
- The evening wake maintenance zone occurs in the few hours before usual bedtime. This makes it very difficult to fall asleep earlier than usual, ahead of an early duty report time. Early report times have been identified as a cause of restricted sleep in aviation operations.
- Across consecutive duty periods that result in restricted sleep, individuals will accumulate a sleep debt and fatigue-related impairment will increase.
- To recover from a sleep debt, individuals need a minimum of two full nights of sleep in a row. The frequency of rest periods should be related to the rate of accumulation of sleep debt.

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. During the period of adaptation, 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.

Studies with participants flown as passengers have identified the following factors that affect the rate of adaptation to a new time zone:

- Adaptation generally takes longer when more time zones are crossed.
- Adaptation is usually faster after westward travel (phase delay) than after eastward travel (phase advance) across the same number of time zones. The fact that the innate cycle of the circadian body clock is slightly longer than 24 hours (for most people) probably contributes to this. It is easier to lengthen the cycle to adapt to a westward shift.
- 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.
- Rhythms in different functions can adapt at different rates, depending on how strongly they are influenced by the circadian body clock. Thus, during adaptation, rhythms in different body functions can be out of step with each other, as well as out of step with the day/night cycle.
- Adaptation is faster when the circadian body clock is more exposed to local time cues, including outdoor light, and exercising and eating on local time.
- Beginning a trip with a sleep debt seems to increase the duration and severity of jet lag symptoms.

The circadian body clock is not able to adapt immediately to changes in time zones.

Crew members who operate transmeridian flights rarely have enough time in a destination to adapt fully to local time, with 1-2 day layovers being typical. However, different patterns of transmeridian flights can have different effects. For example, there appears to be very little circadian adaptation across flights leaving and returning to a crew member's domicile time zone, with a 1-2 day layover in the destination city. On the other hand, longer sequences of back-to-back transmeridian flights can lead to the circadian body clock adopting a non-24-hour period that may be close to its innate period²⁴. This presumably happens when repeated time zone crossings are combined with a non-24-hour sleep/wake pattern, so that there are no longer any 24-hour day/night cues to synchronize the circadian body clock.

Figure 2-8 depicts data from an early NASA study with B747 200/300 flight crews (3-person crews consisting of a captain, first officer, and flight engineer). Similar trip patterns are still being flown by some operators but with an aircraft designed to be operated by two pilots and augmented 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 indicate the average time of the temperature minimum (for 6 crew members per day).

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 (and the WOCL) sometimes occurred in flight, for example on the last flight from NRT to SFO. At these times, crew members 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 (crew members did not have in-flight sleep opportunities on this trip).

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

²⁴ Gander PH, Gregory KB, Miller DL, Rosekind MR, Connell LJ, Graeber RC. Flight crew fatigue V: long-haul air transport operations. *Aviation, Space, and Environmental Medicine* 69:B37-B48, 1998.

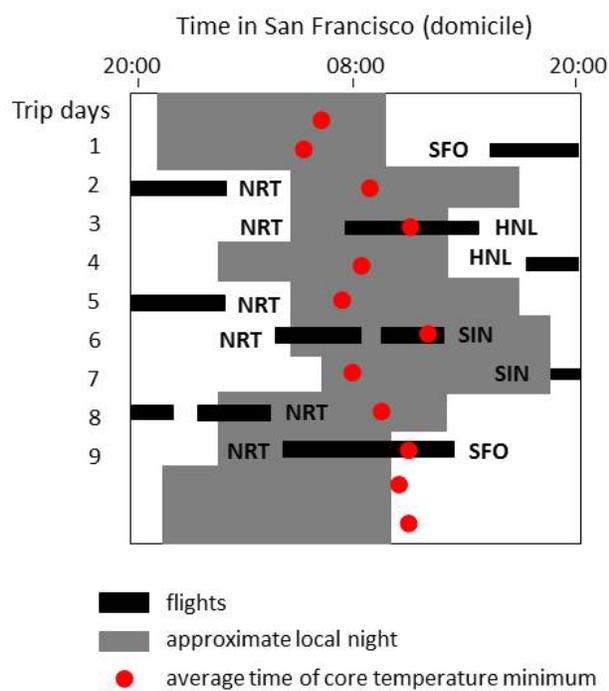


Figure 2-7. Study tracking the circadian body clock across multiple trans-Pacific flights

The fact that long-haul and ULR crew members seldom stay long enough in any destination time zone to become adapted to local time has effects on their layover sleep. Often, crew members 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 unaugmented 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, one study that monitored crew members on unaugmented long-haul trips found that the average duty day involved staying awake for 20.6 hours (the average duty period lasted 9.8 hours).¹³

There is some evidence that when crew members 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 zone²⁵. This may improve layover sleep. On the other hand, when they arrive back in their home time zone, they may need additional days to readapt to local time.

²⁵ Gander P, van den Berg M, Mulrine H, et al. Circadian adaptation of airline pilots during extended duration operations between the USA and Asia. *Chronobiology International* 30: 963-972, 2013.

2.4. SCIENTIFIC PRINCIPLE 4: INFLUENCE OF WORKLOAD ON FATIGUE

The ICAO definition of fatigue describes workload as ‘mental and/or physical activity’ and includes it as a potential cause of fatigue. Three dimensions of workload are commonly identified:

1. The nature and amount of work to be done (including time on task, task difficulty and complexity, and work intensity).
2. Time constraints (including whether timing is driven by task demands, external factors, or by the crew member).
3. Factors relating to the performance capacity of the crew member (for example experience and skill level, sleep history, and circadian phase).

At present, there is no clear operational definition of workload or agreed ways of measuring it for flight or cabin crew

members, and it seems likely that its causes and consequences will vary in different operational contexts. There is fairly

wide acceptance of the idea that intermediate levels of workload may contribute least to performance impairment. Low workload situations may lack stimulation, leading to monotony and boredom which could expose underlying physiological sleepiness and thus degrade performance. At the other end of the spectrum, high workload situations may exceed the capacity of a fatigued crew member, again resulting in poorer performance.

High and low workload can contribute to fatigue

High workload may also have consequences for sleep, due to the time required to “wind down” after demanding work.

Compared to the research available on other causes of fatigue, there is only limited research addressing the effects of differing levels of workload on crew member fatigue. One older European study used a ‘hassle factor’ as a measure of workload²⁶. The amount of hassle increased significantly on flights into and out of Schiphol airport. It was also associated with duty periods that were unusually long, given the number of flights, possibly as a result of flight delays. A more recent European study examined the independent factors that predict the fatigue of short-haul pilots at the end of FDPs, using the 7-point Samn-Perelli fatigue scale²⁷. The main predictors were time awake and duty duration, with a minor contribution from workload (measured with the NASA Task Load Index).

It is widely accepted that workload increases with the number of sectors in a flight duty period. This is reflected, for example, in the US Federal Aviation Administration’s duty time limits for flight crew, which are shorter for duty days with

SCIENTIFIC PRINCIPLE 4

WORKLOAD CAN CONTRIBUTE TO AN INDIVIDUAL’S LEVEL OF FATIGUE. LOW WORKLOAD MAY UNMASK PHYSIOLOGICAL SLEEPINESS WHILE HIGH WORKLOAD MAY EXCEED THE CAPACITY OF A FATIGUED INDIVIDUAL.

High workload may disturb sleep due to the time required to “wind down” after demanding work.

²⁶ Air crew fatigue: a review of research undertaken on behalf of the UK Civil Aviation Authority. CAA Paper 2005/4. https://www.caa.co.uk/docs/33/CAAPaper2005_04.pdf

²⁷ Vervodja M, Elmenhorst E-M, Pennig S, et al. Significance of time awake for predicting pilots’ fatigue on short-haul flights: implications for flight and duty time regulations. Journal of Sleep Research 23(5):564-7. 2014.

more flight segments. A number of studies have confirmed that fatigue is higher at the end of short-haul FDPs with more flight segments²⁸.

Few studies have attempted to investigate the potential interactive effects between workload and other causes of fatigue. A field study of fatigue ratings made by air traffic controllers found some evidence for self-rated workload and time-on-task having interactive effects on fatigue.²⁹ When self-rated workload was low, fatigue ratings remained relatively stable

The relationship between workload and fatigue has not been well researched

for continuous work periods up to 4 hours. However when workload was high, there was a rapid increase in fatigue after 2 hours of continuous work. These effects of workload became more evident after controllers had been awake for at least 12 hours. The time-of-day variation in fatigue ratings was also influenced by workload, being more marked at low and high levels of workload than at intermediate levels.

OPERATIONAL IMPLICATION 8. PROVIDING BREAKS DURING A DUTY PERIOD

Operationally, breaks during a duty period are an important way of reducing the decline in performance with increasing time on task due to the effects of high workload. Such breaks differ from rest periods between duty periods which are designed to allow for sleep recovery.

The length of time working before a break occurs, and the duration of the break are dependent on the type of task being performed. For example, performance on tasks requiring sustained attention, such as monitoring for an infrequent event, has been shown to improve with frequent short breaks.

²⁸ Powell D, Spencer MB, Holland D, et al. Pilot fatigue in short haul operations: effects of number of sectors, duty length, and time of day. *Aviation, Space, and Environmental Medicine* 78:698-701, 2007.

Powell D, Spencer MB, Holland D, et al. Fatigue in two-pilot operations: implications for flight and duty time regulations. *Aviation, Space, and Environmental Medicine* 79:1047-1050, 2008.

Air crew fatigue: a review of research undertaken on behalf of the UK Civil Aviation Authority. CAA Paper 2005/4.

²⁹ Spencer MB, Rogers AS, Stone BM. A review of the current scheme for the regulation of air traffic controllers hours (SCRATCOH). Farnborough, England: Defense Evaluation and Research Agency, 1997.

CHAPTER 3. OPERATIONAL KNOWLEDGE AND EXPERIENCE

Effective fatigue management not only requires consideration of scientific principles, but also needs to be based on operational knowledge and experience, which is acquired through conducting specific operations over time and managing fatigue-related risks in those operations. These two sources of expertise are complementary.

Science generally aims to develop principles that can be broadly applied. Many of the scientific studies that underpin the principles in Chapter 2 do not have flight operations as their primary focus, but the findings are applied in flight operations. This means that knowledge of the operational and organizational context, as well as understanding of the constraints and motivations of the workforce must be considered alongside the science to develop an appropriate fatigue management approach in specific flight operations.

Note that prior operational experience alone is not sufficient for fatigue management in either prescriptive or FRMS approaches. A safety case requires more than just the argument that ‘we have always done it this way’. There needs to be evidence of consideration of scientific principles, risk assessment, and risk mitigation.

In the following two sections, contextual factors are categorised as relating either to the flight operations context or to the broader organizational context. However it can be argued that some factors belong in both categories and clearly the two contexts interact in their effects on fatigue management.

3.1. FLIGHT OPERATIONS CONTEXT

Operational context covers factors that a crew member experiences on duty, such as local environmental factors, working conditions, and the influence of crew member qualifications and experience (both their own and that of the other crew members they are working with). Examples include the weather at the departure and arrival airports, traffic delays, airspace complexity, irregular operations, interactions with other aviation professionals (for example air traffic control), short-haul versus long-haul operations, and managing operational demands.

Table 3-1 identifies some of the factors in the flight operations context that can influence crew member fatigue. Some or all of these factors may be relevant, depending on the specific tasks to be completed by the crew member on the day.

Table 3-1. Examples of factors in the flight operations context that can influence fatigue

Factor in operational context	
Specific fleet attributes	<ul style="list-style-type: none"> • The quality of on-board rest facilities and policies for their use • Patterns and types of flying (e.g., long-haul versus short-haul)
Routes and destinations	<ul style="list-style-type: none"> • Airport traffic density • ATC behaviours • Time spent in ground transportation • Standard of layover accommodation • Availability of food and water • Social opportunities • Cultural differences
Experience in managing operational demands	<ul style="list-style-type: none"> • Experience level in aircraft type (of crew members and of the operator) • Experience on type of operation • Experience level as pilot in command • Experience level at specific airline
Staffing Levels	<ul style="list-style-type: none"> • Sufficient to be able to offer adequate sleep opportunities during and between pairings to avoid cumulative fatigue • Sufficient staff to cover sickness and other absences • For cabin crew, a sufficient number of crew members to cover the service needs on a given flight
Irregular operations	<ul style="list-style-type: none"> • Frequency of the need to use Captain’s discretion/duty period extensions • Frequency of disruption to schedules and the assignment of unscheduled duties • Pressures to complete schedule

3.2. ORGANIZATIONAL CONTEXT

Knowledge of the context in which the organization operates can provide an understanding of the pressures it faces and the factors that affect how it is able to address fatigue issues. Organizational context also relates to how the organization does things internally. Table 3.2 identifies some of the ways in which the organizational context can influence fatigue.

Table 3-2. Examples of factors in the organizational context that can influence fatigue

Factor in organizational context	
Career stability	<ul style="list-style-type: none"> • Commercial pressures • Changing employment arrangements (e.g., labour agreements, use of contract employees) • Bankruptcy/receivership/merging airlines
Level of autonomy of crew during a duty period	<ul style="list-style-type: none"> • Pressures (commercial and personal) to complete the “mission” • Geographic separation from the crew support team , i.e., immediate support and supervision is not always readily available • Crew members are the final link in the safety chain for every flight
Fatigue management structure	<ul style="list-style-type: none"> • Fatigue management is integrated into day-to-day risk management activities versus being the responsibility of an independent group or individual
Effective reporting practises	<ul style="list-style-type: none"> • Safety reporting system • Ease of reporting fatigue hazards • Implications for a crew member of submitting a report • Actions by operator in response to fatigue reports

3.2.1. WORKFORCE CHARACTERISTICS

Within an organization, knowledge of the composition, behaviour and customs of the workforce provide context to the fatigue issues that may affect individual crew members and flight deck or cabin crews, as well as how best to manage them.

Table 3-3 identifies some of the areas where the workforce context may influence fatigue.

Table 3-3. Examples of areas where the workforce context may influence fatigue

Workforce factor	
Crew cultures	<ul style="list-style-type: none"> • Nationality, fleet or rank, home base, generation and gender • Communication • Crew co-ordination • Attitudes towards safety and fatigue
Procedural differences	<ul style="list-style-type: none"> • Division of in-flight roles, allotment of on-board rest, etc.
Experience of crew members	<ul style="list-style-type: none"> • Varying degrees of operational experience in both type of aircraft and crew position

Fatigue risk assessment and mitigation are covered in more detail in Section 5.2.3 below.

3.3. STAKEHOLDER RESPONSIBILITIES

Responsibility for fatigue management must be shared between the operator and the individual crew member. Operational knowledge provides information about how well that shared responsibility is understood and implemented.

The operator is responsible for providing:

- adequate resourcing for fatigue management;
- a working environment that has appropriate emphasis on mitigations for fatigue-related risk;
- robust fatigue reporting mechanisms;
- evidence of appropriate responses to fatigue reports;
- schedules that enable fatigue on duty to be maintained at an acceptable level, as well as providing adequate opportunities for rest and sleep; and
- education and awareness training for all stakeholders on how the operator's fatigue management approach works and how individuals can better manage their own fatigue.

Individual crew members are responsible for:

- making optimum use of off-duty periods to get adequate sleep;
- coming to work fit for duty;
- managing their own fatigue levels;
- reporting fatigue issues; and
- responsible use of individual authority (e.g., captain's discretion)

All stakeholders should play an active role in the development and dissemination of best practice and lessons learned, to ensure that these are embedded across the organization.

3.3.1. FATIGUE REPORTING

Fatigue management, whether by prescriptive approach or by an FRMS, relies on identification of fatigue hazards and effective safety reporting. It must be acceptable for all stakeholders to raise legitimate issues about fatigue without fear of retribution or punishment either from within or outside the organization. The issues associated with fatigue are difficult to detect if people are unwilling or unable to report them.

To encourage an ongoing commitment by staff to reporting fatigue hazards, the operator should:

- Have clear processes for reporting fatigue hazards.
- Be clear that the organisation expects crew members to report fatigue hazards.
- Establish a process for what to do when a crew member considers that they are too fatigued to perform safety-critical tasks to an acceptable standard.
- Identify the implications for individuals of submitting a fatigue hazard report.
- Identify how the organisation will respond to reports of fatigue hazards, including acknowledging receipt of reports and providing feedback to individuals who report.
- Take appropriate actions in response to fatigue reports consistent with stated policy.
- Maintain the integrity of the safety reporting system and reporter confidentiality.
- Provide feedback on changes made in response to identified fatigue hazards.

CHAPTER 4. THE PRESCRIPTIVE APPROACH

To manage crew member fatigue, ICAO requires States to develop regulatory limits on flight times, flight duty periods, and duty periods (see Annex 6 Part 1 SARPs presented in Appendix A). These limits should be identified over specific periods (for example daily, monthly, yearly) to give crew members an adequate opportunity to recover from fatigue and to limit the build-up of transient fatigue across each duty period and the accumulation of fatigue across multiple duty periods (see the ICAO Manual for Oversight of Fatigue Management Approaches, Doc 9966).. The objective of these prescriptive limits is to ensure that flight and cabin crew members remain sufficiently alert to be able operate to a satisfactory level of performance and safety under all circumstances.

Fatigue science suggests that staying within the prescriptive limits may not be enough on its own to manage fatigue. For example, daily prescriptive flight duty period limits are the same for day 1 and day 5 of a trip. They typically address each duty period in isolation and do not take into account cumulative effects. For example, they do not take into account the fact that on day 5, crew members may be starting duty with cumulative sleep loss and higher fatigue than on day 1 (see Chapter 2).

Operators are also required by ICAO to manage their safety risks using a safety management system (SMS – ICAO Annex 19). For operations that comply with the prescriptive flight and duty time limits, an operator’s SMS should include fatigue as one of the hazards it manages. An operator’s SMS must be appropriate to the size and complexity of their operations. Applying this principle to fatigue management, an operator’s fatigue management approach needs to be able to deal with the level of fatigue-related risk in the operation(s) to which it applies.

The first part of this Chapter describes how to manage fatigue by operating within the prescriptive limits in combination with recommended additional SMS elements, namely; appropriate fatigue management training and education to ensure that all personnel are competent to carry out their safety-related duties, and reactive processes for fatigue hazard identification, risk assessment, and mitigation (ICAO Annex 19, Appendix 2). The Chapter also provides principles that should be considered in the design of pairings and rosters.

The ICAO SARPs allow States to approve applications by operators for variations to the prescriptive limits (Annex 6 Part 1, Section 4.10.3). However, the SARPs specify that variations can only be approved for exceptional circumstances and approval must be based on a risk assessment provided by the operator. The operator has to show how they will provide a level of safety equivalent to, or better than that achieved by operating within the prescriptive limits. The second part of this Chapter provides advice on the use of variations and on how to develop a safety case to apply for a variation.

4.1. MANAGING FATIGUE WITHIN THE PRESCRIBED LIMITS AND ASSOCIATED REQUIREMENTS

An operation that is managed within the prescriptive flight and duty time limits should meet the following requirements:

1. The Operations Manual must record the rules relating to flight time, flight duty period, duty period limitations, and rest requirements for crew members (ICAO Annex 6 Part 1, Appendix 2, Section 2.1.2). Within the applicable regulatory limits, an operator may use more stringent limits, such as those negotiated in industrial agreements or established to manage an identified fatigue-related risk.
2. Regulators must base their prescriptive flight and duty time limits on scientific principles (ICAO Annex 6 Part 1, Section 4.10.1). Operators should use these scientific principles in designing pairings and rosters.
3. The operator's SMS should include crew member fatigue as one of the hazards it manages. An appropriate level of information on fatigue management should be included in general safety training.

The following sections describe additional SMS components that are recommended for operations that comply with prescriptive flight and duty time limits.

4.1.1. FATIGUE MANAGEMENT TRAINING

As part of their SMS, operators must have a safety training programme to ensure that staff are competent to perform their safety duties (ICAO Annex 19). Operators managing fatigue using a prescriptive approach are expected to provide basic fatigue management training as part of their SMS safety training. In addition to the SMS training requirements, some States specifically mandate fatigue management training under their prescriptive requirements (for example, US FAA, UK CAA, CASA (Australia)). Training records need to be kept and recurrent training is also recommended. The interval between training sessions and the level of training provided needs to be related to the expected level of fatigue risk in the operations.

Everyone whose role in the organization can influence crew member fatigue needs to have an appropriate level of fatigue management training. This includes crew members, people who design and manage pairings and rosters, operational decision-makers, and people involved in operational risk management. The content of training programmes should be adapted to make sure that each group has the knowledge and skills they need for their role in fatigue management.

The fatigue management-related content in training programmes for all of these individuals should comprise the basic scientific principles related to fatigue management and content specific to the operator's unique operational characteristics and fatigue management requirements. Suggestions for fatigue management training topics can be found in Appendix D.

Table 4.1 provides some examples of personal fatigue mitigation strategies that might be covered in training for crew members. These have been classified as strategic countermeasures (designed to be used at home or on layovers) and operational countermeasures that can be used in flight.

Table 4-1. Examples of Fatigue Hazards and Personal Mitigation Strategies (Not an Exhaustive List)

Fatigue Hazard	Strategic Countermeasure	Operational Countermeasure
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 on-board 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 hazard report identifying fatigue as a contributing factor.	Use eye mask, ear plugs, arrange a suitable wakeup call. Avoid caffeine for 3-4 hours before trying to sleep.
Repeated experience of fatigue on a tag flight at the end of a long-haul trip	Submit a hazard report identifying fatigue as a contributing factor.	Use sleep hygiene measures to maximize layover sleep. Controlled flight deck napping (if permitted), strategic use of caffeine in flight.
Non-restorative sleep	See a sleep disorders specialist.	Comply fully with recommended treatment.
Unpredictable call-outs that make it difficult to ensure adequate sleep prior to duty period	Ensure that sleep environment is dark and quiet, and use sleep hygiene measures to maximize sleep quality. Maximize recovery sleep on off-duty days. When feeling sleepy while waiting for call-out, attempt sleep (prioritize 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 hazard report identifying fatigue as a contributing factor.	Controlled flight deck napping, maximize sleep during in-flight rest periods (if available), strategic use of caffeine in flight.

A special feature of fatigue management 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 fatigue management but also to their lives outside of work, for example in safe motor vehicle driving and in staying healthy. Thus fatigue management training covers issues that everyone can identify with personally, and this can help promote the concept of shared responsibility for fatigue management. Suggestions for fatigue management training topics can be found in Appendix D.

4.1.2. IDENTIFYING FATIGUE HAZARDS

For operations that remain within the prescriptive flight and duty time limits, there are a number of sources of data already available to an operator that can be used to identify where fatigue might constitute a hazard. These all involve what ICAO calls ‘reactive hazard identification’, which means that fatigue is identified after it has occurred.³⁰ The following are some recommended examples.

PLANNED VERSUS ACTUAL DUTIES

To provide evidence of compliance with prescriptive limits, operators are required to keep records of crew members’ flight times, flight duty periods, duty periods, and rest periods for a period of time specified by their regulator (ICAO Annex 6 Part 1, Section 4.10.8).

As part of the prescribed limits, a regulator may include flexibility for last-minute duty extensions to allow the airline operator to manage on-the-day operational disruptions. Similarly, limits for reducing the minimum rest may also be prescribed. The ability to use these duty extensions and/or rest reductions should depend on the crew member’s assessment that they are fit to continue. Where such “flexibility” limits are prescribed, the airline operator should manage the frequency of their use as part of their normal SMS processes. Alternatively, the State may require the use of variations to allow the airline operator flexibility to manage operational disruptions on the day. Addressing unexpected operational circumstances and risks is discussed further in Section 4.2.1.

Comparing data on planned versus actual work periods can be used to identify times when fatigue might have been higher than expected. For example, an operator might track how often each month:

- flight duty periods end at least 30 minutes later than scheduled;
- the maximum scheduled duty day is exceeded (e.g., duty days longer than 13 hours);
- flight duty periods start or end within the window of circadian low (WOCL); or
- reserve crew are called out on particular flights, at a particular crew base, etc.

These kinds of metrics point to possible mitigations if needed, for example changes to scheduled flight times or increasing the number of crew members at a given base. As part of routine SMS processes, the data need to be monitored regularly to evaluate whether the hazards identified warrant additional action.

FATIGUE REPORTING

Hazard reporting has an essential role in SMS. To encourage open and honest reporting of hazards, 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 SMS; and
- deliberate violations of rules and established procedures. An operator should have processes independent of the SMS to deal with intentional non-compliance.

³⁰ The other types of hazard identification are proactive (monitoring fatigue during operations) and predictive (predicting likely fatigue levels in operations before they occur).

To encourage ongoing commitment of personnel to reporting hazards, operators should take appropriate and timely action in response to hazard reports. In a mature safety reporting culture, the majority of safety reports from operational personnel relate to identified or perceived hazards, instead of errors or adverse events.

Reports about high fatigue levels or fatigue-related performance issues provide vital information about fatigue hazards in the day-to-day running of an operation. Reports can come from crew members or other operational staff. As for any other safety hazard, a series of hazard reports citing fatigue on a particular route may indicate that further action is needed to assess and mitigate that hazard.

Crew members should be encouraged to report fatigue hazards such as the following.

- Fatigue contributes to a duty period not being started or completed. The operator needs to have a process for reporting 'not fit for duty' due to fatigue, and a clear procedure around the consequences.
- A crew member completes a duty period in which they believe their own fatigue or that of others reduced the safety margin to an unacceptable level or required some unplanned mitigation.
- A crew member identifies something in their operating environment that could significantly increase their fatigue, or that of others.

An effective fatigue reporting system should include information on recent sleep 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 his/her view of why it happened. An example of a fatigue report form can be found in Appendix B of this guidance. This information should be included in an operator's general hazard reporting form as well as in mandatory incident/accident reporting forms. Information on how to report should be covered in SMS training.

Figure 4-1 summarizes the use of reactive data for identifying fatigue hazards as part of an operator's SMS, for operations that comply with the prescriptive flight and duty time limits. Responsibility for risk assessment of fatigue hazards and mitigation resides with the SMS team. Section 5.3 (below) describes risk assessment processes in more detail.

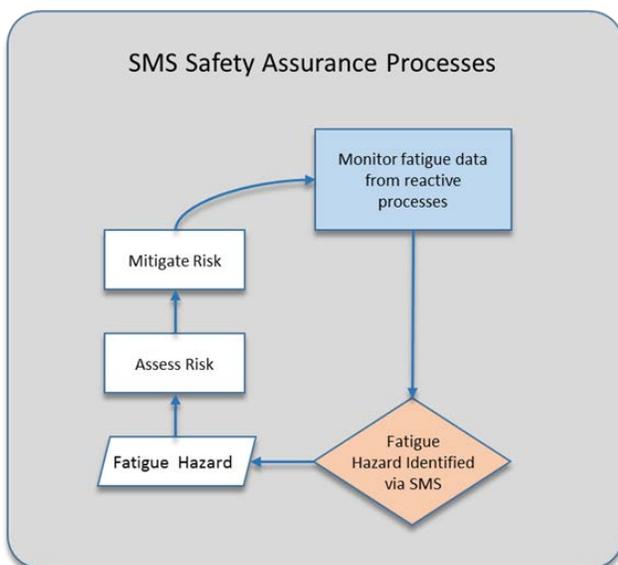


Figure 4-1. Diagram showing the use of reactive processes for identifying fatigue hazards as part of an operator's SMS, for operations that comply with the prescriptive flight and duty time limits

4.1.3. DESIGNING AND MANAGING PAIRINGS AND ROSTERS

Principles from fatigue science (Chapter 2) can be applied to identify possible fatigue hazards when developing pairings and rosters, to improve their design. 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 pairings (multiple, successive duty periods without extended time off), and successive pairings across rosters or monthly bid-lines.

The following are 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 crew member'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 crew member's usual sleep time, the less sleep the crew member is likely to obtain. Working right through the usual night time sleep period is the worst case scenario.
- Night duty also 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.
- The longer a crew member is awake, the worse their alertness and performance become.
- Across consecutive duties with restricted sleep, crew members will accumulate a sleep debt and fatigue-related impairment will increase.
- To recover from sleep debt, crew members 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 recovery breaks should be related to the rate of accumulation of sleep debt.
- Keep short notice changes to a minimum, especially where they infringe or overlap the WOCL.

These sorts of principles can be used by an expert reviewer, for example by a scheduler trained in fatigue hazard identification, to develop evidence-based scheduling rules. Rosters need to be published sufficiently in advance to allow crew members to plan for work and rest periods.

ASSIGNING UNSCHEDULED DUTIES

Within the prescribed limits, assignment of unscheduled duties to meet unpredictable operational needs is commonly managed through different approaches, e.g. on-call periods, standby, reserve and last-minute roster changes. For convenience, these are all covered by the term 'standby' in the following paragraphs.

The specific challenges associated with unscheduled duties are their inherent unpredictability and how likely it is that a crew member will undertake duty while on standby. The following considerations are important for managing fatigue in all types of unscheduled duties.

- The need for protected sleep opportunities before and after unscheduled duties. As for any other duty period, the crew member needs an opportunity to plan their sleep (as much as is possible) to enable them to perform to a satisfactory level. He/she also needs to be able to recover from the fatigue accrued across the duty period.
- Adjusting the length of the standby period in relation to the length of the notification period (for example airport standby versus long-call reserve). Short notification periods require the crew member to be fully rested and

immediately ready to undertake the duty. Longer notification periods can offer the opportunity to sleep in preparation for the duty, which allows the crew member to remain available longer to be assigned an unscheduled duty. Therefore the length of the period on-call should be directly related to the length of the notification period.

- Duty length may need to be adjusted in relation to the time spent on call or standby, depending on the length of the notification period.
- The extent to which an on-call period is counted as a work period is related to the level of fatigue it is likely to produce.

4.2. MANAGING FATIGUE UNDER VARIATIONS TO PRESCRIPTIVE LIMITS

The ICAO SARPS make provision for an operator who is managing fatigue within the prescriptive flight and duty time limits to apply to the regulator for a variation to those limits (Annex 6 Part 1, Section 4.10.3). However this is limited to addressing operational needs and wider operational risks in exceptional circumstances.

The intent of the ICAO provision is to minimize, not to encourage ‘regulation through variations’. It is not intended to offer a quick and easy alternative to an FRMS, when a more comprehensive fatigue risk management approach is required. Variations should be for the duration of the exceptional circumstances and managed using identified mitigation strategies. They tend to be route specific and relate to very minor extensions beyond prescriptive limits. The fundamental principal is that the fatigue management approach has to be sufficient to manage the expected level of risk. When multiple variations are in place it can become increasingly difficult to assess the combined risk.

The Airline Operator’s fatigue management obligations under variations are discussed below according to whether the circumstances are:

- unexpected and beyond the Airline Operator’s control; or
- expected but minor, with the aim of meeting an exceptional operational need.

4.2.1. VARIATIONS TO MEET UNEXPECTED OPERATIONAL CIRCUMSTANCES AND RISKS

Unexpected operational circumstances refer to those that do not occur on a regular basis or cannot be reasonably predicted to occur, based on past experience. If they are able to be reasonably predicted (e.g. known seasonal conditions or peak hour airport traffic that increase flight times), the airline operator should be expected to schedule accordingly. The airline operator should use mitigations, e.g. schedule “buffer periods” (scheduling additional time to allow for operational variability) or provide additional resources within the prescribed limits, and not rely on the use of variations.

However, it is recognized that unexpected operational circumstances can occur to which an airline operator must respond immediately and that may necessitate extending beyond prescribed limits. To enable such on-the-day extensions, the State may establish regulations which:

- prescribe outer limits and the circumstances in which they can be used³¹; or
- permit an airline operator the flexibility to manage on-the-day disruptions by requiring them to develop their own on-the-day response protocol.

In unexpected, sudden and extreme operational circumstances (such as a volcano eruption or an unexpected, immediate airspace closure), the regulator should have a special process for requesting a variation. The operator needs to assure the regulator that they will maintain an acceptable level of safety. In any unexpected operational circumstance requiring a variation to the prescribed limits, the following will need to be identified by the State or proposed by an airline operator:

- the circumstances in which the variation may be used;
- the operations to which the variation may be applied;
- the necessary mitigations to address the increased fatigue risks; and
- the variation limits.

The variation limits are dependent upon the operational circumstances and the crew member making an assessment of their fitness for duty.

4.2.2. VARIATIONS TO MEET EXPECTED OPERATIONAL CIRCUMSTANCES AND RISKS

Minor variations to the prescriptive limits may also be requested to meet expected operational needs and risks, without the need for operator to develop a full FRMS. Such variations may be related to a specific event (for example the Olympic Games) or a specific operational need (for example leaving the aircraft on the ground in an operationally undesirable location).

When applying for a variation to meet expected operational circumstances, the operator has to provide a safety case that is appropriate to the expected level of risk associated with the variation. The operator needs to be able to satisfy the regulator that they can manage the variation to provide a level of safety equivalent to, or better than that achieved through complying with the prescriptive fatigue management regulations. The operator should indicate how the fatigue risk associated with the variation will be managed under their SMS (see Figure 4-1). Some or all of the following areas may need to be addressed:

- The nature and scope of the variation, including which of the prescriptive rules it affects, the operations to which it applies, and why it is needed.
- The operating environment in which the variation will apply (this may include people, procedures, equipment, stakeholders, the physical environment, the organizational culture, the legal and regulatory environment, natural hazards, and external threats).
- Potential impact of the variation on other services, for example ATC or airport services.
- A well-substantiated estimate of the impact of the variation on crew member fatigue, for example using published data from scientific studies or appropriate bio-mathematical models.
- Explanation of how the potential effects of the variation on fatigue will be monitored and documented.
- Description of the processes for risk assessment, if new fatigue hazards are identified as a result of the variation.
- Description of additional mitigations that can be put in place, if needed.

³¹ While discussed under the heading of “variations” in this manual, these prescribed outer limits and conditions may be considered part of the prescribed limits and not variations *per se* (i.e. captain’s discretion for extending flight duty periods).

Operating within the prescriptive flight and duty time limits is one approach for managing crew member fatigue. As fatigue-related risk increases, additional strategies need to be added. The point at which an FRMS is required will be determined by the regulator after discussions with the operator. Alternatively, an operator may decide that an FRMS approach better suits operational needs in some or all of their operations, if this option is offered by their regulator.

CHAPTER 5. FRMS: OPERATIONAL COMPONENTS

An FRMS is a specialized system that uses SMS principles and processes to manage the hazard of crew member fatigue. Consistent with SMS, FRMS seeks to achieve a realistic balance between safety, productivity, and costs. However, there are some important features of an FRMS approach that distinguish it from managing fatigue risks using an SMS within prescriptive limits only.

With a prescriptive approach, fatigue is one of the possible hazards that the SMS should consider. The service provider reacts when a fatigue hazard is identified. With FRMS, the service provider must additionally identify and assess potential fatigue risks prior to conducting operations under the FRMS as well as identifying and assessing actual fatigue risks proactively during operations.

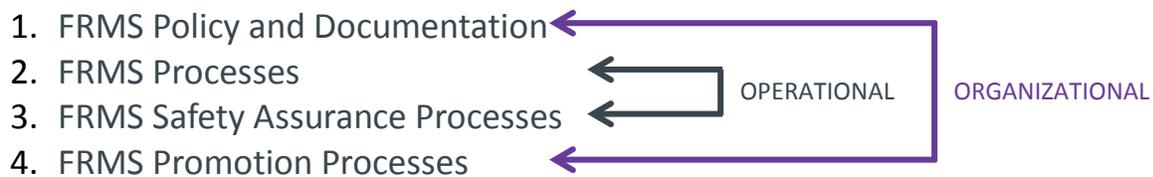
An FRMS approach will require additional resources to be allocated to fatigue management, enhanced processes specifically established to address fatigue risks, and more comprehensive fatigue management training than that required for using prescriptive limitations only.

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.

ICAO definition

5.1. NECESSARY COMPONENTS OF AN FRMS

An FRMS has four components, two of which are operationally focused and two which are organizationally focused:



The FRM processes and the FRMS safety assurance processes make up the operational FRMS activities. These operational activities are governed by the FRMS policy and supported by FRMS promotion processes (organizational activities).

The ICAO SARPs have detailed minimum requirements for each of these four FRMS components. This Chapter focuses on the operational FRMS components while Chapter 6 focuses on the organizational FRMS components.

5.1.1. OPERATIONAL ACTIVITIES IN AN FRMS

The operational activities in an FRMS are summarized in Figure 5-1. The FRM processes form a closed loop with: 1) ongoing monitoring of fatigue levels; 2) identification of situations where fatigue may constitute a hazard; 3) risk assessment; and 4) introduction of additional risk mitigations when needed. The effectiveness of all current mitigations is

captured in the ongoing monitoring of fatigue data, so the FRM processes form a closed loop. Figure 5-1 includes two FRM process loops to highlight that small hazards and large hazards may be managed somewhat differently within an organization. For example, small hazards may be dealt with entirely within the day-to-day FRM processes, whereas large hazards may require involvement of the wider SMS team in risk assessment and mitigation. Mitigating small hazards usually does not require major financial resources or procedural changes. However successful mitigation of small hazards can have major safety benefits.

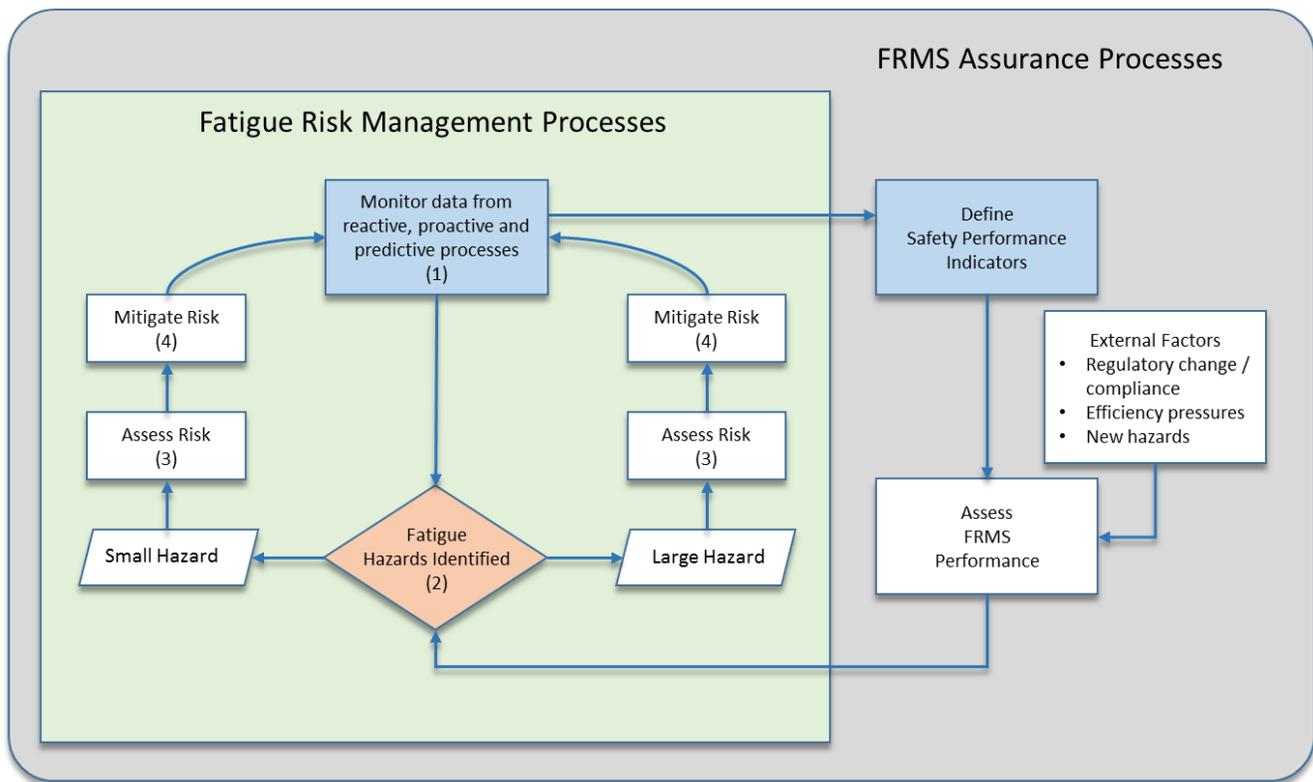


Figure 5-1 Operational activities of an FRMS

A range of data monitored in the FRM process loop is used to generate fatigue safety performance indicators (SPIs). These are used, along with data from sources outside the FRMS, in the FRMS Safety Assurance loop to check whether the FRMS is delivering an acceptable level of fatigue risk and safety. This must meet internal and external standards set by the operator’s FRMS policy and/or by the regulator. The FRMS Safety Assurance loop also monitors external changes that could affect fatigue risk in the operations covered by the FRMS. It identifies emerging hazards and can make recommendations for mitigations and changes to the FRM processes, providing feedback that drives continuous improvement of the FRMS.

The fatigue monitoring data required for operational FRMS activities are more comprehensive than what is required for managing fatigue in operations that operate within the prescriptive limits and are managed under an operator’s SMS (see 4.1.2, page 42). In addition to using reactive data (gathered after an event or incident) to identify fatigue hazard(s), an FRMS must also use proactive data (monitored during operations) and predictive data (predicting likely fatigue levels in operations before they occur).

5.1.2. THE FATIGUE SAFETY ACTION GROUP

Although not required by the SARPs, it is recommended that operators establish a Fatigue Safety Action Group (FSAG) with responsibility for coordinating FRMS activities. Since fatigue management must be based on shared responsibility and requires an effective safety reporting culture, it is strongly recommended that the FSAG includes representatives of all stakeholder groups (management, scheduling staff, and crew member representatives) with input from other individuals as needed to ensure that it has appropriate access to scientific, statistical, and medical expertise. Inclusion of all stakeholders is an important strategy for promoting engagement in the FRMS.

The size and composition of the FSAG will vary for different operators, but should be appropriate 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. Larger airlines will have specialized departments that interact with the FSAG. The regulator needs to be confident that the operator has considered its operational and organizational profile in deciding the composition of the FSAG.

The principle functions of the FSAG are to:

- oversee the development of the FRMS;
- assist in FRMS implementation;
- oversee the ongoing operation of the FRM processes;
- contribute as appropriate to the FRMS safety assurance processes;
- maintain the FRMS documentation; and
- be responsible for ongoing FRMS training and promotion.

The FSAG should operate under Terms of Reference that are included in the FRMS documentation and which specify its activities, interactions with other parts of the organization, and the lines of accountability between the FSAG and the operator's SMS. An example of Terms of Reference for an FSAG can be found in Chapter 6 (Section 6.2.2).

5.2. FRM PROCESSES

5.2.1. SOURCES OF DATA FOR FATIGUE MONITORING

FRM processes are data driven. A range of types of data can be useful, and the key is choosing the right combination of measures for each operation covered by the FRMS, both for routine monitoring and when additional information is required about a potential hazard that has been identified, for example by a series of fatigue reports or a change in marketing strategy.

To be able to identify fatigue hazards, the FSAG needs to have a good understanding of the operational factors that are likely to cause crew member fatigue, which vary across different types of operations. For example, Figure 5-2 compares

flight and duty times in daytime short-haul, domestic night cargo, and long-haul operations studied by the NASA Fatigue Programme³².

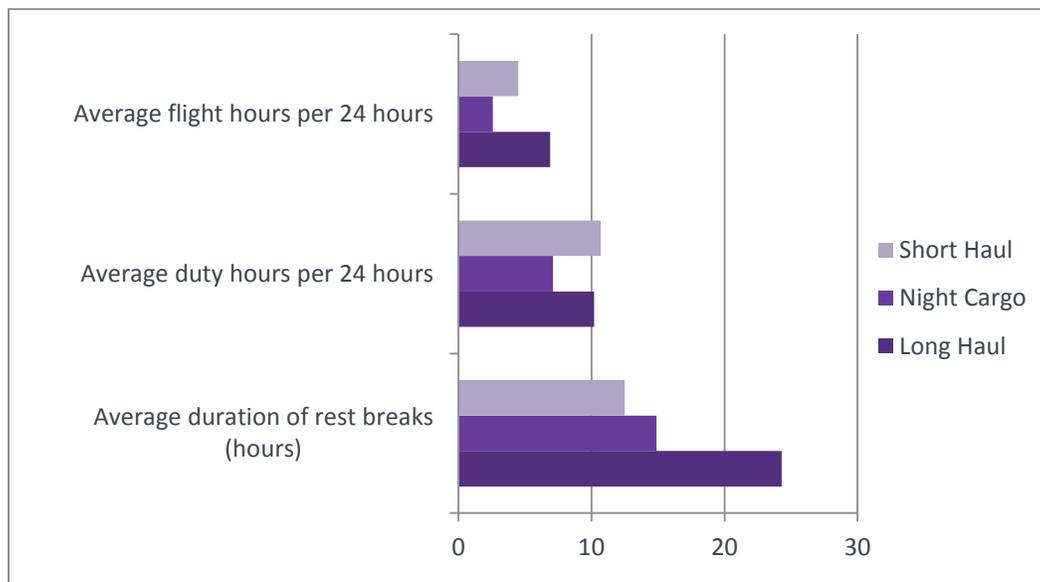


Figure 5-2 Average flight, duty, and rest periods in a sample of daytime short-haul, domestic night cargo and long-haul operations

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

- restricted sleep caused by short rest breaks 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 engineer) had the shortest duty periods, averaged 3 flights per duty period, and had longer rest breaks than the short-haul operations. They also crossed a maximum of 1 time zone per 24 hours. However, the night cargo crew members' rest breaks 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 engineer) had long duty periods, but averaged only 1 flight per duty period and had the longest rest breaks. However, every layover was in a different time zone, with a maximum of 8 time zones crossed per 24 hours. The crew members' circadian body clocks (tracked by their core body temperature rhythms) did not adapt to

³² Gander PH, Rosekind MR, Gregory KB. Flight crew fatigue IV: a synthesis. *Aviation, Space and Environmental Medicine* 69 (9): B49-B60, 1998.

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 hours) associated with duty days (these were unaugmented crews with 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 crew members' domicile time zone so additional time for circadian re-adaptation may have been needed for full recovery after the trip.

Table 5-1 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 on-board 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 5-1. Summary of Identified Causes of Flight Crew Fatigue (from NASA field studies)³³

Cause of Fatigue Hazard	Type of Operations		
	Short-haul	Night Cargo	Long-haul
Restricted sleep due to short rest breaks	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 trips			X

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

³³ Gander PH, Graeber RC, Foushee HC, Lauber JK, Connell LJ. Crew Factors in Flight Operations II: Psychophysiological Responses to Short-Haul Air Transport Operations. NASA Technical Memorandum #108856. Moffett Field: NASA Ames Research Center, 1994.

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.

5.2.2. HAZARD IDENTIFICATION

The ICAO SARPs (Annex 6 Part 1, Appendix 7) require three types of hazard identification:

1. Predictive

- fatigue hazards identified by examining planned work schedules (rosters), taking into account factors known to affect sleep and fatigue.

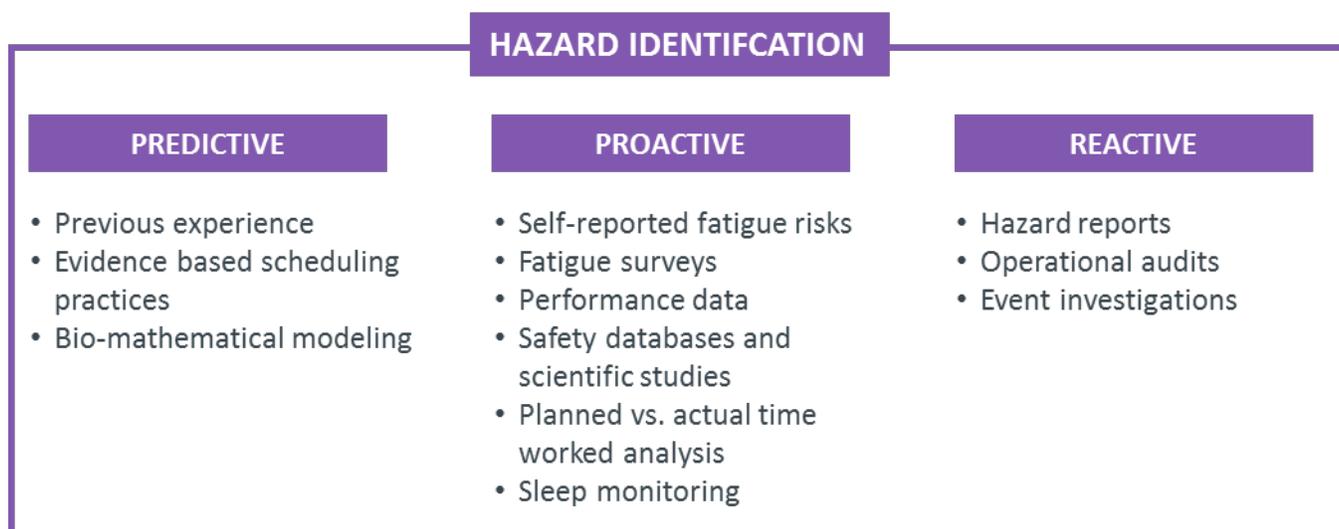
2. Proactive (monitored during operations)

- fatigue hazards identified by measuring fatigue levels in current operations.

3. Reactive (gathered after an event or incident)

- fatigue hazards identified by assessing the contribution of fatigue to safety reports and events that have occurred.

ICAO SARPs also propose suitable types of data that can be monitored:



The following sections describe each of these types of data.

PREDICTIVE HAZARD IDENTIFICATION

Predictive processes are designed to identify fatigue hazards by examining crew scheduling before the pairings (rosters) are actually worked, taking into account factors known to affect sleep and fatigue. ICAO FRMS SARPs list 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 that none of these methods is required by the SARPs, and other methods may be used.

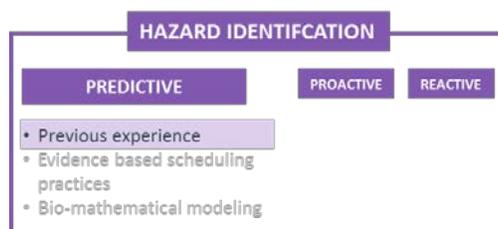
PREVIOUS EXPERIENCE

The collective experience of managers, schedulers, and crew members is an important source of information for identifying fatigue hazards relating to crew scheduling. For example, crew members may recognize a particular trip as generating a high level of fatigue because of regular delays caused by heavy traffic. The value of this collective experience can be enhanced by having staff educated about the dynamics of sleep loss and recovery, and about the circadian biological clock. These biological factors help explain why particular scheduling practices affect fatigue (for example, practices such as early starts, long duty days, short layovers, daytime sleep opportunities, and time zone crossings).

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 sickness absences.

When operational demands are changing, reliance on previous experience can have 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 in Section 5.2.4).



EVIDENCE-BASED SCHEDULING PRACTICES

As summarized in Section 4.1.3 fatigue hazards relating to scheduling can also be predicted when fatigue science is applied in the building of schedules. Evidence-based scheduling rules can be developed by an expert reviewer, for example by a scheduler trained in fatigue hazard identification, or by the FSAG. The scientific basis for the scheduling rules should be recorded in the FRMS documentation. The ongoing monitoring



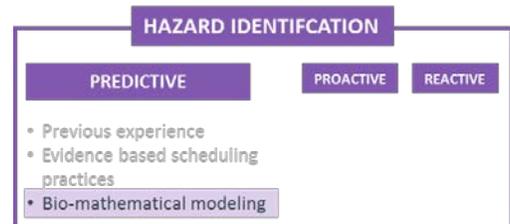
of fatigue levels in the FRM processes provides a mechanism for continuous improvement of evidence-based scheduling rules for an operation.

Potential fatigue hazards may be identified by gathering information on schedules that approach or exceed evidence-based scheduling rules. This could occur due to delays, crew sickness or due to soft rules being waived by individual crew members as part of schedule manipulation.

BIO-MATHEMATICAL MODELS

Bio-mathematical models aim to predict aspects of a schedule that might generate an increased fatigue risk. They do not constitute an FRMS on their own, but are only one tool of many that may be used within an FRMS.

Bio-mathematical models begin life as computer programmes 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 modelling process begins by trying to write a programme 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 modelling 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 crew members;
- do not take into account the impact of workload or personal and work-related stressors that may affect fatigue levels;
- do not take into account the effects of personal or operational mitigation strategies that may or may not be used by crew members (caffeine consumption, exercise, improved rest facilities, etc.);
- do not predict the safety risk that fatigued crew members represent in a particular operation, i.e., they are not a substitute for risk assessment (the next step 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 verified.

Bio-mathematical modelling can identify potential fatigue hazards through the analysis of a flight, pairing or roster, which can then be used as a trigger for further investigation. The most reliable use of currently available commercial models is

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.

The Australian Civil Aviation Safety Authority has published valuable guidance on the use of bio-mathematical models in FRMS³⁴.

PROACTIVE HAZARD IDENTIFICATION

Proactive processes are designed to identify fatigue hazards by measuring fatigue levels in current operations. Because fatigue-related impairment affects many skills and has multiple causes, there is no single measurement that gives a total picture of a crew member'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. More intensive fatigue monitoring should be targeted at operations where the risk is expected to be higher.

The success of proactive processes (and of the FRMS) depends on the willingness of crew members to continue participating in data collection. This makes it important to consider the demands placed on crew members by different types of fatigue measurement (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 crew members 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. Measuring fatigue levels may involve monitoring crew members 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 crew members, confidentiality and use of data, and whether crew members 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.

The ICAO SARPs (Annex 6 Part I, Appendix 7) list five possible methods of proactive fatigue hazard identification:

- self-reporting of fatigue risks;
- crew fatigue surveys;
- relevant crew member performance data;
- available safety databases and scientific studies; and
- 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.

³⁴ Bio-mathematical Fatigue Models: Guidance Document
http://www.casa.gov.au/wcmswr/_assets/main/aoc/fatigue/fatigue_modelling.pdf

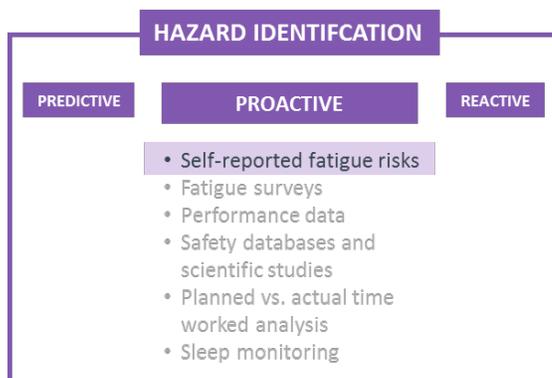
SELF-REPORTING OF FATIGUE RISKS

Reports about high fatigue levels or fatigue-related performance issues provide vital information about fatigue hazards in the day-to-day running of an operation, whether fatigue is managed by an FRMS or under the prescriptive flight and duty time limits (Section 4.1.2). Reports can come from crew members or other operational staff.

Depending on an operator's SMS hazard reporting system, a separate form for reporting fatigue may not be essential. However, adequate information needs to be gathered. This includes information on recent sleep history (minimum last 3 days), time of day of the event (if the report involves an event), and measures of different aspects of fatigue-related impairment (for example, validated alertness or sleepiness scales). Fatigue reports should also provide space for written commentary so that the person reporting can explain the context of the event and give his/her view of why it happened. An example of a fatigue report form can be found in Appendix B of this guidance. Information to identify fatigue as a contributing factor should also be included in mandatory incident/accident reporting forms.

FRMS education needs to cover the procedures for reporting fatigue. Different procedures may be involved depending on whether or not flight safety is an immediate concern, or for calling in too fatigued to undertake a duty.

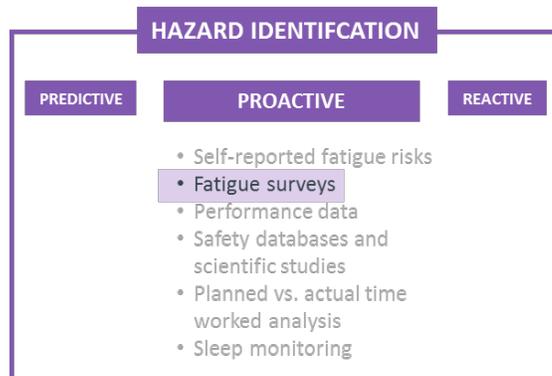
Fatigue reports should be analysed regularly by the FSAG and feedback provided as appropriate to individuals and groups about any actions taken, or why no action was considered necessary. A series of fatigue reports on a particular route can be a trigger for further investigation by the FSAG. Fatigue reports can also provide useful examples for recurrent fatigue management training.



CREW FATIGUE SURVEYS

Crew fatigue surveys are of two basic types:

1. **retrospective surveys** that ask crew members about their past experiences of sleep, fatigue and the factors causing it. 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 crew members to record their experiences of sleep and fatigue in real time. 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 of this guidance 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 FSAG 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 FSAG to undertake a survey of all crew members flying that trip (retrospective or prospective), to see how widespread the problem is. The FSAG might also undertake a survey (retrospective or prospective) to get crew member 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 5-3 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 of this guidance)³⁵. For short duty periods (2-4 hours) there is a clear time-of-day variation in how fatigued crew members 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.

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

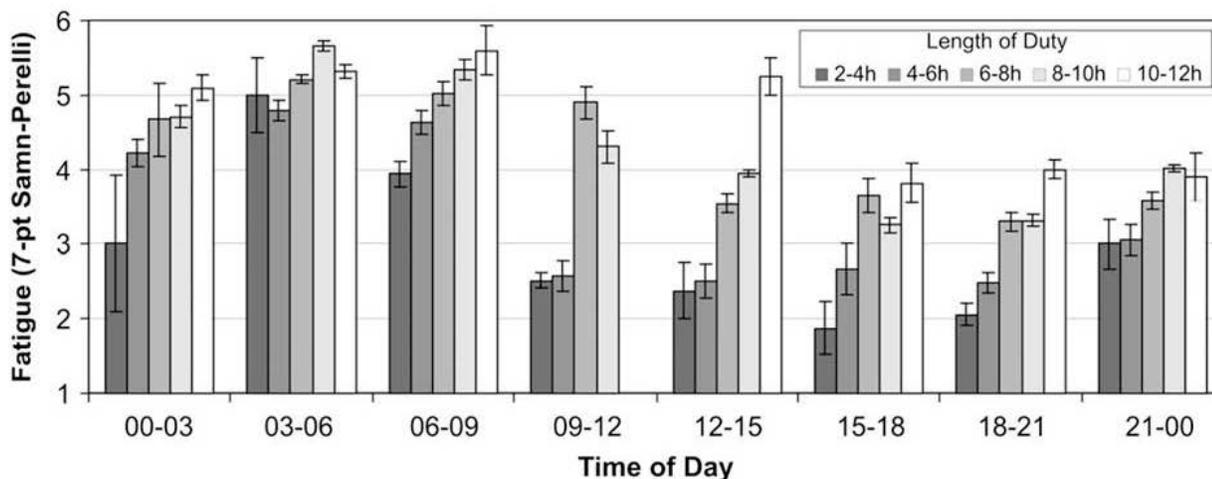


Figure 5-3 Effects of time of day and duty length on fatigue ratings at top of descent in 2-pilot short-haul operations (no time zone crossings) across a 3 month period.

³⁵ Powell D, Spencer MB, Holland D et al. Fatigue in two-pilot operations: implications for flight and duty time limitations. Aviation, Space and Environmental Medicine 79: 1047-1050, 2008..

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 crew member performance, each with strengths and weaknesses.

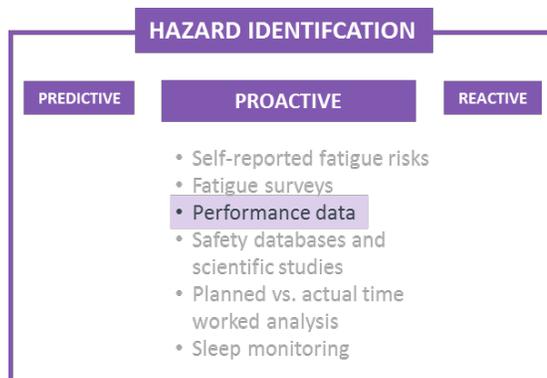
First, a range of simple tests developed and validated in the laboratory can be adapted for use in flight operations. These measure aspects of a crew member’s performance (for example, reaction time, vigilance, short-term memory, etc.). Things to consider when choosing a performance test for measuring crew member fatigue include the following.

- How long does the test last? Can it be completed at multiple time points (for example, in the operations room pre-flight, near top of climb, near top of descent, and post-flight before disembarking the aircraft), without compromising a crew member’s ability to meet duty requirements?
- 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?
- 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.)
- Has it been used in other aviation operations, and are the data available to compare fatigue levels between operations?

These ‘added performance measures’ have the disadvantage that they interrupt the normal flow of work. In addition, little is known about how an individual’s performance on simple laboratory tests relates to their performance on more complex tasks, or to their contribution to the performance of a 2-pilot flight deck crew. However, this is currently the most practical approach available. Appendix B of this guidance describes a performance test that is commonly used to measure crew member fatigue – the Psychomotor Vigilance Task or PVT³⁶.

Second, there is considerable interest in finding ways to link crew member fatigue levels to flight data analysis (FDA) parameters, particularly during approach and landing. FDA data has the advantages that it is routinely collected, does not interrupt the normal flow of work, 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 a measure of crew member fatigue would require demonstrating consistent changes in FDA data that are reliably linked to other measures of crew member fatigue (for example sleep loss in the last 24 hours, time in the circadian body clock cycle, etc.). Research in this area is ongoing.

The third approach involves having trained flight deck observers rating the performance of crew members on the flight deck (for example, Line-Oriented Safety Audit). However, this is very labour-intensive and expensive. Having the observer present may also have an alerting effect and place additional demands on crew members. These factors currently limit the usefulness of this approach for proactive fatigue hazard identification in an FRMS.

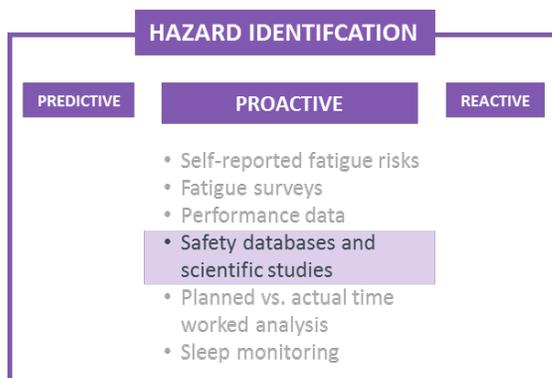


³⁶ Balkin TJ, Bliese PD, Belenky G, et al. Comparative utility of instruments for monitoring sleepiness-related performance decrements in the operational environment. *Journal of Sleep Research*, 13: 219-227, 2004..

AVAILABLE SAFETY DATABASES AND SCIENTIFIC STUDIES

More general information about fatigue hazards may be available from external safety databases maintained by safety authorities, or databases maintained by airline organizations or research institutions. Because safety events are relatively rare, databases that collect and analyse them are an important additional source of information that complements direct measurement of fatigue levels in the operation(s) covered by the FRMS.

Scientific research on crew member fatigue in flight operations is expanding, although much of it is still focused on long range operations. Many scientific papers can be located by searching on the internet or by contacting the author(s). 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.



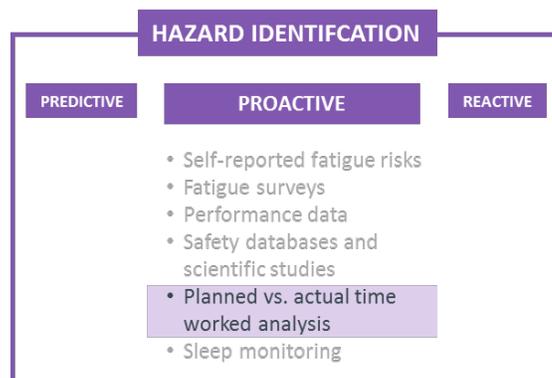
ANALYSIS OF PLANNED VERSUS ACTUAL TIME WORKED

Predictive identification of fatigue hazards is possible during the planning of schedules and pairings (see above). However, numerous unforeseen circumstances can cause changes to planned schedules, for example weather conditions, volcanic ash, unexpected mechanical problems, or crew member illness. Crew member fatigue relates to what is actually flown, not what is planned. Data on actual work periods can identify times when fatigue might have been higher than expected from the planned schedule.

For proactive hazard identification, planned and actual duties can be compared. For example, the FSAG might track how often each month:

- flight duty periods end at least 30 minutes later than scheduled;
- the maximum scheduled duty day specified in the FRMS policy is exceeded (e.g., duty days longer than 13 hours for 2-pilot operations);
- reserve crew are called out on particular flights, at a particular crew base, etc;
- trip swapping occurs.

Data on planned and actual schedules and pairings is readily available to operators, but the FSAG may need to establish additional processes for analyzing it to identify potential fatigue hazards in specific parts of the operations covered by the FRMS.



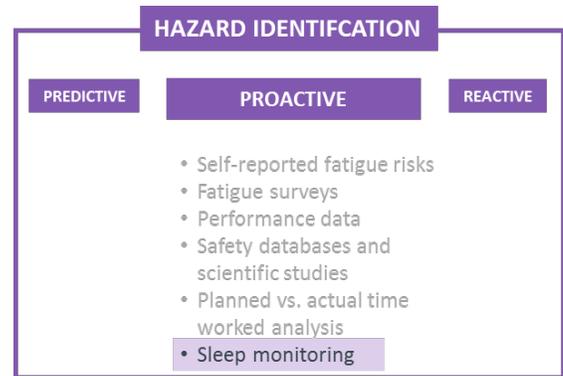
MONITORING CREW MEMBERS' SLEEP

Given the primary importance of sleep loss and recovery in the dynamics of crew member 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 of this guidance).

The simplest and cheapest method of monitoring sleep is to have crew members complete a daily sleep diary before, during, and after the trip 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 tablets, smart phones, etc.).

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 crew members 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 currently requires manual scoring and analysis by a trained technician.



SELECTING MEASURES OF CREW MEMBER FATIGUE

A lot of options have just been described for measuring crew member fatigue. The following general points are intended to help operators to decide which measures to use and when to use them.

- Fatigue-related impairment affects many skills and has multiple causes, so there is no single measurement that gives a total picture of a crew member’s current fatigue level.
- 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 FSAG prioritize where controls and mitigations are most needed.
- A core set of measures can be selected for routine monitoring. For example, crew fatigue reports and regular analyses of planned versus actual schedules and pairings could be used for ongoing monitoring of fatigue hazards.
- An additional range of measures can be available to be used if a potential hazard is identified and the FSAG decides that more information is needed. Again, the measures selected need to reflect the expected level of risk. For example:
 - A series of complaints about a particular layover hotel prompts a brief on-line survey of crew members using that hotel, to see how widespread the problem is and whether it merits action.

- 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 crew members flying that trip, using sleep diaries and subjective rating scales. Data collection continues for a month, followed by data analysis, so that within 3 months the FSAG 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).
- An operator with limited long-haul experience gets regulatory approval to undertake ULR operations on a specified city pair. As part of regulatory approval, the operator is required to undertake intensive monitoring of crew member 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.

Balance needs to be maintained between gathering enough data for the FSAG to be confident about its decisions and actions, and the additional demands that data collection can place on crew members (sometimes described in science as ‘participant fatigue’).

REACTIVE HAZARD IDENTIFICATION PROCESSES

Reactive processes are designed to identify the contribution of crew member fatigue to safety reports and events that have occurred. The aim is to identify how the effects of fatigue could have been mitigated, to reduce the likelihood of similar occurrences in the future. The ICAO SARPs (Annex 6 Part I, Appendix 7) list five examples of triggers for reactive processes:

- fatigue reports;
- confidential reports; } i.e., voluntary hazard reports
- audit reports;
- incidents; and
- Flight Data Analysis (FDA) events (also known as Flight Operations Quality Assurance or FOQA). The links between pilot fatigue and FOQA events cannot be made without comprehensive discussion with the involved crew to understand contextual elements.



Depending on the severity of the event, a fatigue analysis could be undertaken by the FSAG, the operator’s safety department, or an external fatigue expert or accident investigation agency. 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;

- the person or crew was probably 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 behavior expected of a fatigued person or crew.

A basic method for fatigue investigation is summarized in Appendix B of this guidance.

5.2.3. RISK ASSESSMENT AND MITIGATION

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. For service providers managing fatigue risk within prescribed limits through their SMS, existing SMS risk assessment methodologies may be sufficient. Using an FRMS requires more effort on fatigue-specific risk assessment.

Assessing the risks associated with the hazard of “fatigue” can be challenging because:

- fatigue can diminish an individual’s ability to perform almost all operational tasks; and
- there are many factors which can contribute to an individual’s level of impairment. Many of these factors may be unpredictable.

Further, not only does an individual’s ability to perform safety-related tasks decline with increasing fatigue but their capacity to respond to unexpected increases in task complexity also diminishes. Such increases in task complexity can be associated with managing threats, such as a flight crew member landing

in unfavourable weather conditions, a cabin crew member dealing with an unplanned evacuation, or an air traffic controller presented with an unexpected surge in air traffic. Conversely, low workload can unmask physiological sleepiness. Fatigue is rarely the sole cause of an event but it is regularly a likely contributor to varying degrees. The level of risk that fatigue presents is dependent on the task and the context in which the task is being performed.

Because of these factors, current methodologies for assessing risks, when applied to fatigue, are all limited to some degree. Further, the usefulness in application of all risk assessment methodologies is directly related to the knowledge and experience of the user. However, with growing maturity of SMS and more operational FRMS experience around the world, advances are continuing to be made in the way fatigue risks are assessed.

Where an airline operator operates under FRMS, more effort on fatigue-specific risk assessment is expected, with particular focus on assessing the time in a duty period or pattern of work where potential fatigue impairment poses the greatest risk.

Assessing fatigue risks using any methodology is limited because it is unclear how the complex interactions that exist between fatigue factors should be weighted. All methods need to be used with full recognition of their limitations.

USING RISK MATRICES TO ASSESS FATIGUE RISKS

Typically, safety risk is defined as the projected likelihood and severity of the consequence or outcome from an existing hazard or situation. A likelihood and severity matrix is commonly used by many service providers to assess all types of risk and assist them to decide whether it is necessary to invest resources in mitigation. The level of the risk associated with a hazard and whether that risk level is “tolerable” is determined by plotting its position on the matrix. The main disadvantage of using matrices to assess risks is that controls and mitigations are not systematically taken into account.

Table 5-2 presents an example of severity classification categories from ICAO’s Safety Management Manual (Doc. 9859, 2013, 3rd Edition). Table 5-3 presents an associated risk assessment matrix.

Table 5-2. Severity Classifications (from ICAO SMM, 3rd Edition)

Severity	Meaning	Value
Catastrophic	<ul style="list-style-type: none"> - Multiple deaths - Equipment destroyed 	A
Hazardous	<ul style="list-style-type: none"> - A large reduction in safety margins, physical distress or a workload such that crew members or controllers cannot be relied upon to perform their tasks accurately or completely - Serious injury - Major equipment damage 	B
Major	<ul style="list-style-type: none"> - A significant reduction in safety margins, a reduction in the ability of crew members or controllers to cope with adverse operating conditions as a result of increase in workload, or as a result of conditions impairing their efficiency - Serious incident - Injury to persons 	C
Minor	<ul style="list-style-type: none"> - Nuisance - Operating limitations - Use of emergency procedures - Minor incident 	D
Negligible	<ul style="list-style-type: none"> - Little consequences 	E

Table 5-3. Safety Risk Assessment Matrix (adapted from ICAO SMM, 3rd Edition)

Likelihood		Fatigue 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

Accident
Large safety reduction
Significant safety reduction

When using risk assessment matrices, airline operators are expected to customise the severity and likelihood categories. The value of using the severity classifications from Table 5-2 to assess fatigue risks is limited because the worst foreseeable consequence of fatigue-affected performance when performing a safety critical task is always catastrophic.

With regards to fatigue risks:

- to understand the severity of consequences, it is necessary to consider not just how fatigued an individual may be, but also the resulting impact on the individual’s performance and how that diminished performance will manifest in the workplace.
- it is the task being undertaken (when fatigued) that determines the severity of the consequences. For example, if an operational person falls asleep in the office while performing a routine administrative task, there are no immediate safety consequences. However, if the same operational person falls asleep on the flight deck or at their work station while performing a safety critical task, it can lead to an accident.

In other words, to assess different types of fatigue risks using a matrix, different severity classifications are needed to better reflect the variety of possible consequences of fatigue-affected performance. Likelihood classifications will depend on the type of fatigue severity classification used. Therefore, when using risk assessment matrices in an FRMS, it is necessary for fatigue subject matter experts to customise their matrices by carefully selecting how severity and likelihood are classified. The following provide simple examples of how severity and likelihood classifications can be adapted in order to assess different fatigue risks.

SEVERITY CLASSIFICATIONS:

As mentioned above, different severity classifications are needed to better reflect the variety of possible consequences of fatigue-affected performance. Examples of methods for classifying severity classifications include:

- Severity classification may reflect “perceived fatigue levels” on the basis that the more fatigued an individual feels, the more likely their performance will decline. In Table 5-4 the subjective Samn-Perelli Scale is used, although other subjective measures may also be used (see Appendix B of this manual and more detailed description in any of the associated Implementation Manuals).
- Bio-mathematical models aim to predict the average individual’s fatigue level at different points across a planned roster. Once the user is able to relate the model’s results to the operational context of their organisation, severity classifications may be based on defined bio-mathematical model thresholds.
- Severity classification may reflect the number of relevant fatigue factors associated with a specific duty or work pattern, as described in the next section (Assessing a Specific Duty or Work Pattern for Fatigue Risks).

Table 5-4. Example Fatigue Severity Classification: Perceived levels of fatigue.

Samn-Perelli Score	Meaning	Value
7	Completely exhausted, unable to function effectively	A
6	Moderately tired, very difficult to concentrate	B
5	Moderately tired, let down	C
4	A little tired	D
3	Okay, somewhat fresh	E
2	Very lively, responsive, not at peak	E
1	Fully alert, wide awake	E

LIKELIHOOD CLASSIFICATIONS

Generally, fatigue likelihood is based on subjective estimations of how often a particular consequence of fatigue-affected performance might occur. Because this is contextually dependent, there are infinite variables that influence the operational consequences.

Where a specific fatigue factor related to a type of shift or work schedule is being assessed (e.g. < 7h between duties; commencement of duties prior to 7am), the measurable frequency with which an individual may experience or be exposed to it may be preferred to determine likelihood classifications.

ASSESSING A SPECIFIC DUTY OR WORK PATTERN FOR FATIGUE RISKS

In an FRMS, an operator will need to consider the fatigue risks associated with a specific duty or work pattern in order to determine appropriate mitigation strategies. Many different tools and methods are available to assess risks and often they are used in combination.

One way of estimating the fatigue risk associated with a particular work pattern is through the use of a bio-mathematical model. Current models are generally designed to predict levels of average operator fatigue (performance and/or subjective ratings), not the safety consequences of that fatigue in specific operational environments. While informed use of models can make them very helpful for the purposes of risk assessment, operational decisions should not be based solely on bio-mathematical thresholds.

An alternative method to assess fatigue in relation to a particular duty or work pattern has been described³⁷ and is summarized below. It is based on the recognition that fatigue results from sleep loss, extended wakefulness, circadian influences and workload (see Scientific Principles presented in Chapter 2). In this methodology, “fatigue factors” (i.e., factors that have been found to be associated with increased fatigue) are identified through internal scientific studies, relevant scientific literature, internal surveys and fatigue management experience of the service provider.

This type of methodology may be used:

- to identify the causes of fatigue associated with a single duty / type of shift;
- to give a single duty or type of shift a specific and comparable “fatigue value”;
- to identify effective mitigations for a single duty / type of shift (part of the risk mitigation process);
- to be able to compare the same trip or tasks undertaken at different times;
- as starting point for a safety case.

Thorough research and informed operational input is essential to the identification of a meaningful list of fatigue factors and critical to the successful use of this methodology. By using customised lists generated for the specific circumstances of the service provider, this methodology can be adopted to any operations.

In the first step of this methodology, for a particular type of work duty or work pattern, all possible fatigue factors are determined to be either present or absent in the “worst case scenario” under existing conditions.

In the second step, each factor present is assessed to determine if it can be avoided through mitigation. The number of remaining fatigue factors is used to determine if the mitigated scenario is acceptable.

³⁷ Tritschler, T. (2015) Fatigue Risk Assessment Methodologies. Paper presented at the EASA FRMS Workshop, Cologne.

A third step can be added using risk assessment matrices that present an additional risk assessment of the fatigue factors to examine the cumulative fatigue-related risk over a period of time. This introduces a “frequency of exposure” dimension, allowing categorisation of fatigue risk according to the number of times a trip with a particular score is scheduled.

Figure 5-4 and the matrices below (Tables 5-5 to 5-7) present an example of the use of this methodology.

Type of Shift/Specific Duty: CGN-TFS-CGN: Check in 1600LT, Checkout 0300LT; FDT: 11:00h

	Fatigue Factor:	Worst Case:	Mitigated	Comments:
Sleep debt	Previous night sleep ** reduced < 4h (night: 22-08LT)	1**	1**	Not relevant if 1 st duty day
	Previous night sleep ** reduced > 4h	1**	0	Avoid previous day checkout after midnight
	Reduced night sleep > 4h before previous night ***	1***	0	Avoid any previous day checkout after midnight
	Previous “night duty”** (day sleep only)**	1**	0	Avoid any previous day checkout after midnight
Wakefulness	Time since awake > 2h prior C/I*	1	1	
	Time since awake > 6h prior C/I*	1	(1)	Recommend nap before duty
	Time on task > 10h (FDT)	1	1	FDT > 10h at night (!)
	Time on task > 12h < 14h (FDT)	--	--	
Circadian Factors	Circadian disruption > 4h **	1	0	Previous duties shall be late duties
	Flight after 2300LT or last landing during darkness	1	1	
	Flight time <2h during WOCL	1	1	
	Flight time > 2 h during WOCL	--	--	
Workload	3 or 4 consecutive flights/sectors	--	--	
	5 or 6 flights / or 3 flights during night	--	--	
	Known hassles	--	--	
	Training flights	1	0	Avoid training on this duty
Sum of fatigue factors		11	6	
Assessment of fatigue factors: 0-3 relevant factors: accept 4-6 relevant factors: check 7-9 relevant factors: mitigate >10 relevant factors: not acceptable		* Crew member’s responsibility ** Depending on preceding duty *** The night before, 2 consecutive nights are relevant		
Note. Factors are not fully weighted! Most important factors are sleep debt, wakefulness, circadian factors then workload, in this order.				

Figure 5-4. Example Fatigue Factor Assessment and Mitigation Table

Table 5-5. Example Categories for Assessment of Fatigue Factor Scores under Existing Conditions (Step 1)

Assessment of Fatigue Factors under Existing Conditions (Step 1):		
Relevant factors	Acceptability	Action
0-3	Accept	No mitigation required
4-6	Check	Identify mitigations to reduce relevant fatigue factors
7-9	Mitigate	Identify mitigations to reduce the remaining fatigue factors to the minimum
> 9	Not Acceptable	Identify mitigations to reduce the remaining fatigue factors to an acceptable minimum. If not possible this duty is not permissible

Table 5-6. Example Categories for Acceptability of Fatigue Factor Scores after Mitigating Actions (Step 2)

Acceptability of Fatigue Factors after Mitigating Actions (Step 2):		
Relevant factors	Fatigue Impairment	Acceptability
0-3	Low	Acceptable, no further mitigation required
4-6	Increased	Acceptable, but keep remaining fatigue factors as low as reasonably practicable. Monitor operation
7-9	Significant	Acceptable if remaining fatigue factors are kept at the minimum (all avoidable fatigue factors are avoided). The number of times this duty can be scheduled is limited per crew member per time-period. Monitoring of this work period required
> 9	High	Not acceptable

Table 5-7. Example Risk Assessment Matrix for Cumulative Fatigue

Frequency of Exposure per Crew Member per Working Period (week)				
Relevant fatigue factors	May be scheduled every day	May be scheduled twice per week	May be scheduled once per week	Unexpected circumstances
0-3	low	low	low	low
4-6	moderate	moderate	low	low
7-9	high	moderate	moderate	moderate
> 9	high	high	high	high

In this example, the methodology has been applied to short-haul flight operations on a specific flight duty from Cologne to Tenerife to Cologne. Each fatigue factor identified is relevant for this type of operation and linked to a scientific study.

Step 1:

- The form shown in Figure 5-4 presents a Fatigue Factor Assessment and Mitigation Table which lists the fatigue factors identified by the short-haul carrier. In the first step, these have been scored as present (1) or absent (--) in the "Worst Case" column.
- Table 5-5 categorises the assessment of different numbers of fatigue factors under existing conditions (i.e., no mitigations). In the example provided, a fatigue factor score of 11 means that under existing conditions and in the worst case scenario, this duty is not permissible if the number of factors cannot be reduced through mitigation.

Step 2:

- The form shown in Figure 5-4 is again used to score each of the fatigue factors present (n=11) as either avoidable (0) or not (1) in the "Mitigated" column. A description of how it can be avoided (the mitigation) is noted in the "Comment" column. In the example provided, there are 6 remaining fatigue factors.
- Table 5-6 categorises the acceptability of the mitigated fatigue factor score. The example score of 6 means that with the extra mitigations identified, fatigue impairment is expected to be increased, but acceptable.

Step 3:

- Table 5-7 presents an additional risk assessment of the fatigue factors in order to examine the cumulative fatigue-related risk over a period of time. Here, a "frequency of exposure" dimension has been added to a matrix, allowing categorisation of fatigue risk according to the number of times a trip with a particular score is scheduled. Again, the categories should be defined by each operator for their specific context.

MITIGATION

Depending on an operator's safety management structure, the decision about whether or not a fatigue hazard requires mitigation may rest with the FSAG. For example, if a mitigation does not require additional resource allocation or changes to procedures, it may be actioned directly by the FSAG. Otherwise the FSAG would pass a recommendation forward to the SMS team responsible for coordinating risk mitigation across all hazards in the operation.

Since the FSAG have relevant expertise and will normally be responsible for implementing and monitoring mitigations, it is recommended that they be consulted in all fatigue mitigation decisions.

Table 5-8. provides some examples of organizational-level controls and mitigations for managing fatigue hazards. Controls should focus on reducing the potential for fatigue to occur. In cases where controls alone cannot reduce fatigue to an acceptable level, appropriate mitigations should be implemented to reduce the likelihood and/or severity of the risks to the safety of the operation. These are examples only, not exhaustive lists.

Table 5-8. Examples of Fatigue Hazards and possible Operator Controls and Mitigations (not an exhaustive list)

Fatigue Hazard	Controls	Mitigations
Multiple consecutive night flights	Scheduling rules do not permit multiple consecutive night flights.	Software is programmed to prohibit scheduling of multiple consecutive night flights. Reserve crew available to cover exceptional circumstances.
Lack of ULR long range 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 crew members to departure city base. Ensure that sufficient reserve crew are available to support ULR flight schedules.
Reports of inadvertent crew napping on the flight deck	Scheduling rules, construction of pairings, crew augmentation 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.
Crew members not getting enough sleep in on-board rest facilities	Pay attention to design of crew rest facilities when ordering aircraft. Improve aircraft crew rest facilities. Flight ops manual contains rules for organizing in-flight rest. Route-specific guidance on use of in-flight rest.	Provide crew members 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, construction of pairings.	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, construction of pairings.	Protocols for in-flight rest and controlled flight deck napping.

If the controls and mitigations perform to an acceptable standard, they become part of normal operations. To decide what is acceptable, the relevant safety performance indicators must reach their pre-defined acceptable values or targets (see Section 5.4). Alternatively, the risk assessment for the fatigue hazard needs to be in the ‘acceptable’ or ‘tolerable’ regions of Table 5-3 (or equivalent).

If the controls and mitigations do not reduce the fatigue hazard to an acceptable level, it will be necessary to re-enter the FRM processes at the appropriate step (Figure 5-1). This could require: gathering of additional information and data, re-evaluation of the safety risks associated with the hazard, and/or implementing and evaluating new controls and mitigations.

An example of the FRM processes is provided in Appendix E.

5.3. FRMS SAFETY ASSURANCE PROCESSES

FRMS safety assurance processes form the second closed loop of the operational activities of the FRMS (Figure 5-1), and monitor how well the entire FRMS is functioning. Using SPIs monitored in the FRM processes along with information and expertise from other sources, the FRMS Safety Assurance processes have three main functions (Annex 6, Part I, Appendix 7).

1. To monitor that the FRMS is delivering an acceptable level of fatigue risk that meets the safety objectives defined in the FRMS policy and any other regulatory requirements.
2. To monitor changes in the operational environment and the organization that could affect fatigue risk in the operations covered by the FRMS, and to identify ways in which FRMS performance can be maintained or enhanced prior to the introduction of changes.
3. To provide ongoing feedback that drives continuous improvement of the FRM processes and other FRMS components.

Responsibility for FRMS safety assurance activities may be distributed differently, depending on the number and complexity of operations covered by the FRMS and the size of the operator. Typically, FRMS safety assurance processes would be the responsibility of the SMS team. Some of the FRMS safety assurance processes may be undertaken by the FSAG. However activities such as audits of the FRM processes should be undertaken by a different organizational unit.

The following subsections describe the functions of the FRMS safety assurance processes further.

5.3.1. MONITORING FRMS SAFETY PERFORMANCE

Performance of the FRMS should be examined through FRMS SPIs that are identified through a variety of different sources, including:

- trends in SPIs from the FRM processes (see Section 5.2) and the operator's SMS;
- hazard reporting and investigations;
- audits and surveys; and
- reviews and fatigue studies.

HAZARD REPORTING AND INVESTIGATIONS

The FSAG should record all fatigue hazards identified in the FRM processes, together with any actions taken to mitigate those hazards, in the FRMS documentation. The fatigue hazard register should be regularly evaluated as part of the FRMS safety assurance processes.

Trends in voluntary fatigue reports (by crew members or others) can also be monitored as indicators of the effectiveness of the FRMS. Safety events in which crew member 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 the role of fatigue (see Appendix B of this guidance).

AUDITS AND SURVEYS

Audits periodically assess the effectiveness of the FRMS, focusing on the integrity of the FRM processes. They should address questions such as:

- Are all departments addressing the recommendations of the FSAG?
- Are crew members using mitigation strategies as recommended by the FSAG?
- Is the FSAG maintaining the required documentation of its activities?
- Are all SPIs maintaining acceptable values or being actively managed?

Internal audits need to be conducted by a unit in the operator's organization that is external to the FSAG. 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 FSAG and the scientific validity of their decisions. A scientific review panel can also provide the FSAG with periodic updates on new scientific developments relevant to the FRMS.

Trends in SPIs can provide valuable information in an FRMS safety assurance audit. These may include SPIs used by the FSAG in the FRM processes, as well as indicators that capture more global aspects of the safety performance of the FRMS, for example safety performance metrics within the operator's SMS.

Surveys can provide information on the effectiveness of the FRMS. For example they can document how schedules and pairings are affecting crew members, 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 Appendix B of this guidance). Note 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').

REVIEWS AND FATIGUE STUDIES

A safety review would be carried out to evaluate whether the FRMS is likely to be adequate to deal with a change³⁸, for example the introduction of a new type of operation or a significant change to an existing operation covered by the FRMS.

³⁸ See ICAO Doc 9859 Safety Management Manual.

The review evaluates the likely effects of the change on fatigue risk and the appropriateness and effectiveness of the FRM processes to manage those effects.

In FRMS safety assurance processes, fatigue studies are mainly used as a source of broader information from external sources, about common issues in FRMS (whereas in the FRM processes they are carried out to evaluate specific fatigue hazards). Sources of information can include the experience of other operators, industry-wide or State-wide studies, or scientific studies. Such information can be particularly valuable in situations where the operator has limited experience and knowledge on which to build a safety case.

EVALUATING FRMS PERFORMANCE

The sources of data that an operator uses to monitor the safety performance of their FRMS need to be evaluated regularly to check whether:

- all SPIs are maintaining acceptable values or meeting targets, and/or are in the 'tolerable' or 'acceptable' region of risk assessments;
- the FRMS is meeting the safety objectives defined in the FRMS policy; and
- the FRMS is meeting all regulatory requirements.

Figure 5-5 tracks an SPI that measures the effectiveness of the Air New Zealand FRMS across time³⁹. 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.

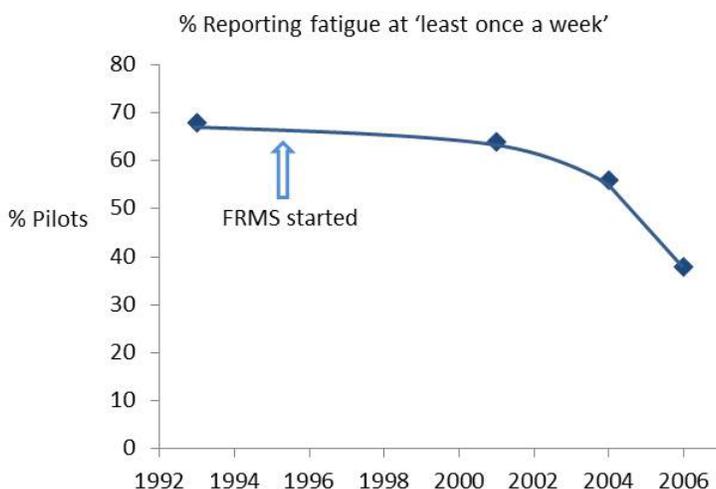


Figure 5-5. Declining reports of crew member fatigue across successive Air New Zealand surveys

³⁹ Figure 5.5 is used by kind permission of Dr David Powell.

The following are examples of SPIs that could be used in FRMS safety assurance processes.

- 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 crew members and other affected personnel to adjust to the new operation). The FSAG 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 sick call rate of flight crews by more than 25%.
- ULR operations covered by the FRMS do not attract any more fatigue reports than the long-haul operations managed under the prescriptive flight and duty time limits.
- In the last quarter, designated management has provided adequate resourcing for the FRMS, as specified in the FRMS policy.
- In the last quarter, the FSAG 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 designing schedules and pairings have met annual FRMS training requirements as specified in the FRMS promotion processes.
- Measures of the effectiveness of FRM training and education programmes (see Section 6.3.1 for examples).

When FRMS SPIs are not at an acceptable level, the controls and mitigations in use may need to be modified via the FRM processes. A review of relevant fatigue studies might provide new ideas. Reviews of compliance by crew members or other departments with the recommendations of the FSAG, or of the functioning of FSAG itself, may be needed to find out why the FRMS is not working as intended. It may also be appropriate to review the SPIs to ensure that they are still appropriate measures of the safety performance of the FRMS.

5.3.2. MAINTAINING FRMS PERFORMANCE IN THE FACE OF CHANGE

The commercial aviation environment is very dynamic and 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.

The ICAO SARPs (Annex 6, Part I, Appendix 7 Part 3) require an operator to have formal processes for the management of change which must address, but are not limited to:

- identification of changes in the operational environment that may affect FRMS;
- identification of changes within the organization that may affect FRMS; and
- consideration of available tools which could be used to maintain or improve FRMS performance prior to implementing changes.

When a planned change is identified, the FSAG can undertake the following steps.

1. Use the FRM and SMS processes to identify fatigue hazards, assess the associated risk, and propose controls and mitigations.

2. Obtain appropriate management and/or regulatory sign-off that the level of residual risk is acceptable.
3. Document the strategy for managing any fatigue risk associated with changes.

During the period of implementation of the change, FRMS safety assurance monitoring (described in Section 5.3.1) can 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 crew member fatigue is undertaken by the FSAG, together with more frequent assessment of SPIs as part of the FRMS safety assurance processes.

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 programmes, etc. The FSAG would normally propose such changes and obtain approval for them from appropriate management. FRMS safety assurance monitoring (described in Section 5.3.1) will track the effects of these changes on the overall effectiveness of the FRMS.

5.3.3. CONTINUED IMPROVEMENT OF THE FRMS

Feedback from the FRMS safety assurance processes to the FSAG and the FRM processes provides a mechanism for continuous improvement of the FRMS (Figure 5-1). The ICAO SARPs (Annex 6, Part I, Appendix 7 Section 3) require an operator to provide processes for the continuous improvement of the FRMS that must include, but are not limited to:

- the elimination and/or modification of risk controls that had unintended consequences or are no longer needed due to changes in the operational or organizational environment;
- routine evaluations of facilities, equipment, documentation and procedures; and
- the determination of the need to introduce new processes and procedures to mitigate emerging fatigue-related risks.

Identifying emerging fatigue hazards that are not the result of planned changes is also an important function of FRMS safety assurance processes, which take a broader system perspective than the FRM processes. Any newly identified fatigue hazard(s), or combination of existing hazards for which current controls are ineffective, should be referred back to the FSAG for evaluation and management using the FRM processes.

Changes made to the FRMS should be documented by the FSAG so that they are available for internal and regulatory audit.

5.3.4. RESPONSIBILITY FOR FRMS SAFETY ASSURANCE PROCESSES

To deliver effective oversight of the functioning of the FRMS, the FRMS safety assurance processes need to operate in close communication with the FSAG, but with a degree of independence from it. Figure 5-6 describes an example of how responsibility for the FRMS safety assurance processes might be assigned in a large organization.

In this example, the FSAG 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 5-6, these lines of accountability are indicated by heavy arrows. (In a large organization, there might eventually be separate FRMSs and FSAGs 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 FSAG;
- 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 5-6. 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.

Examples of FRMS safety assurance processes are provided in Appendix F.

5.4. SAFETY PERFORMANCE INDICATORS (SPIS)

Data monitored in the FRM process loop can be used to generate fatigue safety performance indicators (SPIS). SPIS are also used in the FRMS Safety Assurance loop to check whether the FRMS is delivering an acceptable level of fatigue risk. SPIS provide a metric to guide decision making. For example, changes in SPIS might signal a new fatigue hazard, and they can be used to track the effectiveness of new mitigations.

For SPIS to be useful in decision making, acceptable values or targets need to be set. These acceptable values or targets need to be appropriate to the level of risk in a given operation, and/or in the 'tolerable' or 'acceptable' regions of risk assessments. Having a variety of SPIS is expected to give a more reliable indication of fatigue levels and of the performance of the FRMS. SPIS may also need to be revised as operational circumstances change⁴⁰. Common types of fatigue SPIS include:

- operational SPIS that monitor the duty-related causes of fatigue;
- SPIS based on reactive fatigue data. Examples include the number of fatigue reports (e.g., on schedule or pairing), fatigue-related incidents), and measures of absenteeism;
- SPIS based on proactive monitoring of actual levels of crew member fatigue.

5.4.1. OPERATIONAL SAFETY PERFORMANCE INDICATORS

Operational SPIS can often be derived from data that are already routinely collected by operators. For example, operational SPIS and their acceptable values/ targets can be generated by comparing planned versus actual schedules and pairings. They need to reflect the specific causes of fatigue risk in different operations, such as early starts and multi-sector long duty days in domestic short-haul operations versus single-sector long duty days with flights crossing multiple time zones and the resulting circadian desynchrony in international long-haul operations. Table 5-9 contains some examples of operational SPIS.

⁴⁰ See IATA Introduction to Safety Management Systems (SMS), 2nd Edition.

Table 5-9. Examples of operational SPIs and acceptable values/targets

Safety Performance Indicator	Acceptable Value/Target
How often the maximum scheduled duty day (e.g., 13 hours) is exceeded	Maximum scheduled duty day will not be exceeded on more than 5% of days in any 28-d period
Number of flight duty periods ending 30 minutes later than scheduled	If report time is earlier than 05:00, flight duty period extensions of 30 minutes or more may not occur on more than 10% of days in any 28-d period
How often minimum 10-hour break is reduced	Not acceptable to operate next duty period. Acceptable on no more than 1% of flights in any 28-d period
How often duty periods end in the window of circadian low (WOCL)	For non-augmented crew, no duty period longer than 9 hours will be scheduled to end in the WOCL. Delays acceptable on no more than 1% of flights in any 28-d period
Number of pairings identified as high fatigue risk, e.g., no more than three consecutive night flights scheduled	Target - no exceptions
Number report times earlier than 06:30 on successive days	No more than 2 scheduled. Acceptable on no more than 1% of flights in any 28-d period
Number of reserve crew call-outs for fleet A at base B	Not to exceed 5% in any 28-day period

Figure 5-7 illustrates how operational data can be used to identify potential fatigue hazards. It shows the number of times per month a particular wide-body fleet in a very large operator had exceedances of the relevant flight and/or duty time limits, across a 16 month period. The data show a clear seasonal pattern, with most exceedances occurring during the winter months (in the northern hemisphere). Figure 5-7 also highlights that the great majority of exceedances are occurring on westward flights between city pair B-A. This enables the operator to focus on city pair B-A, decide what additional monitoring or mitigations may be necessary, and present a safety case to the regulator to show how fatigue risk on these flights will be handled in the FRMS.

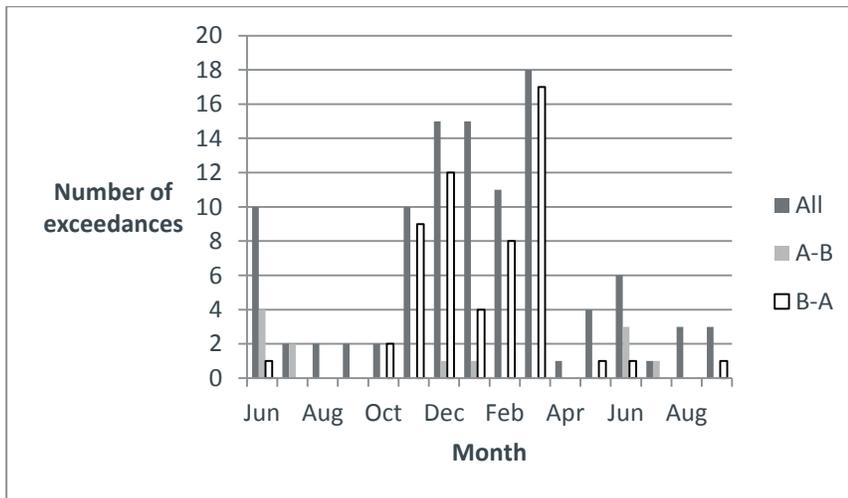


Figure 5-7. Exceedances of flight and/or duty time limits in a large fleet across a 16-month period

5.4.2. CREW FATIGUE SAFETY PERFORMANCE INDICATORS

Monitoring crew member fatigue as a source of data for SPIs is relatively resource-intensive and time-consuming compared to using routinely collected operational data. However, it may be justified in particular circumstances such as: in response to significant fatigue reports on a particular trip (to further identify the extent and severity of the hazard); in response to a safety incident; or as part of the operational validation of a new route, as in the example in Appendix E. As a general rule, the type of monitoring undertaken should be appropriate to the expected level of fatigue and safety risk.

The first edition of this guidance material proposed three key criteria for measures of crew fatigue that could be useful in an FRMS.

- 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 crew members' ability to perform their operational duties.
- They have been widely used in aviation, so data can be compared between different types of operations.

Since the first edition, a set of flight crew fatigue SPIs have been developed based on recommended measures that meet these criteria⁴¹. Table 5-9 summarizes the proposed measures and SPIs for long range and ultra-long range flights (one flight per duty period). Appendix B has more detail on these measures. Pre-flight SPIs (after reporting for duty) help

⁴¹ Gander PH, Mangie JM, van den Berg MJ, et al. Crew fatigue safety performance indicators for fatigue risk management systems. *Aviation, Space and Environmental Medicine*. 85: 139-147, 2014.

Gander PH, Mulrine HM, van den Berg MJ, Smith AAT, Signal TL, Wu LJ, Belenky G (2014) Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators. *Journal of Sleep Research* DOI: 10.1111/jsr.12197

Gander PH, Mulrine HM, van den Berg MJ, Smith AAT, Signal TL, Wu LJ, Belenky (2014) Pilot fatigue: relationships with departure and arrival times, flight duration and direction. *Aviation, Space, and Environmental Medicine* 85:833 – 40.

determine the fatigue status of flight crew members at the beginning of duty, while SPIs immediately prior to TOD help determine the fatigue status of flight crew members for landing.

Table 5-9. Proposed measures of crew fatigue and safety performance indicators (SPIs) based on them

Measure	SPIs for long range and ultra-long range operations (1 flight per duty period)
sleep/wake history monitored using actigraphy and sleep diaries	<ol style="list-style-type: none"> 1. sleep in the 24 hours prior to duty start time 2. time awake at duty start time 3. sleep in the 24 h prior to TOD (including in-flight sleep for augmented crews) 4. time awake at TOD
performance measured on the psychomotor vigilance task (PVT)	<ol style="list-style-type: none"> 1. pre-flight PVT performance speed 2. PVT performance speed in the hour prior to TOD
subjective fatigue rated on the 7-point Samn-Perelli crew checklist	<ol style="list-style-type: none"> 1. pre-flight fatigue rating 2. fatigue rating at TOD
subjective sleepiness rated on the 9-point Karolinska Sleepiness Scale	<ol style="list-style-type: none"> 1. pre-flight sleepiness rating 2. sleepiness rating at TOD

For short-haul duty periods that usually contain multiple flight segments, it may be appropriate to measure SPIs at the beginning and end of duty, since crew members may not have enough time to complete performance tests or rate their fatigue and sleepiness prior to TOD on short flights. It may also be appropriate to have SPIs relating to workload (for example number of flight segments) in short-haul operations.

It can be argued that sleep/wake history provides the most valuable information about crew member fatigue status, because sleep loss and extended time awake have a negative impact on many aspects of waking function, only some of which are captured by objective performance tests or subjective ratings. Appendix C provides an example comparing total sleep in the 24 hours prior to duty start time and total sleep time in the 24 hours prior to TOD across 10 different long range and ultra-long range flights.

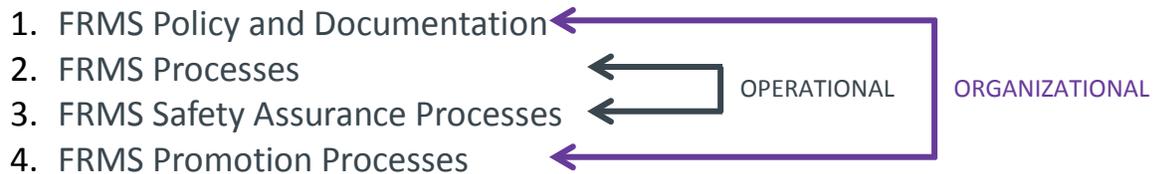
5.4.3. BIO-MATHEMATICAL MODEL THRESHOLDS AS SPIS

Threshold values on bio-mathematical model predictions are sometimes proposed as SPIs. Current models are generally designed to predict measures of average operator fatigue (performance and/or subjective ratings), not the safety consequences of that fatigue in specific operational environments. In other words, bio-mathematical models are not a stand-alone substitute for the FRM process loop (this is also true for other types of SPIs).

Given that fatigue affects diverse aspects of waking function, operational decisions should not be based on any single measure of functional status, including thresholds applied to bio-mathematical model predictions of functional status. It is also important to note that different SPIs may be appropriate in different types of operations. SPIs need to be identified in consultation with the regulator during the FRMS accreditation process (see Chapter 7) and they may change as experience with FRMS builds and as operations evolve.

CHAPTER 6. FRMS: ORGANIZATIONAL COMPONENTS

The operational activities of an FRMS discussed in Chapter 5 are governed by the FRMS policy and supported by FRMS promotion processes. Documentation must be kept of all FRMS activities. These form the organizational components of the FRMS. This Chapter describes the ICAO requirements for these organizational components.



6.1. FRMS POLICY

The FRMS policy may be a stand-alone document or be incorporated in an operator's SMS policy (check your Regulator's requirements). In either case, the ICAO SARPs (Annex 6, Part I, Appendix 7) require that the FRMS policy clearly defines all elements of the FRMS, is easily identifiable, and is able to be reviewed in its entirety.

6.1.1. SCOPE OF THE FRMS

An FRMS policy must clearly state which operations are covered by the FRMS. All operations not covered by the FRMS must operate under the applicable prescriptive flight and duty time limits. It is expected that the scope of the FRMS may expand as an operator's familiarity and experience with FRMS builds, and both operators and regulators need to give consideration to how this can be accommodated. As an example, the US Federal Aviation Administration (FAA) requires an operator to present a safety case for each new operation to be managed under the FRMS. This safety case is essentially similar to that which an operator would prepare when applying to operate under a variation from the prescriptive flight and duty time limits (see Chapter 4). The nature and complexity of the safety case needs to be sufficient to persuade the regulator that the operator can use their FRMS to manage fatigue risk to provide a level of safety equivalent to, or better than that achieved through complying with the prescriptive fatigue management regulations. The following are 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.

This statement of scope allows flexibility for additional operations to be brought under the FRMS without having to change the policy statement. For example, suppose that 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, without requiring a change to the FRMS policy statement. This change makes the FSAG responsible for establishing FRM processes and FRMS safety assurance processes applicable to the A-330 operations.

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

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

EXAMPLE 2: AIRLINE B - DOMESTIC CARRIER OPERATING BOTH SCHEDULED AND CHARTER OPERATIONS WITH 3 FLEET TYPES.

The FRMS for Airline B will apply to all operations as specifically identified in the flight Operations Manual. All other operations will be conducted under the prescriptive flight and duty time regulations

Airline B chooses to operate its charter operations under FRMS and to operate its scheduled operations under the prescriptive flight and duty time regulations.

6.1.2. OTHER REQUIREMENTS FOR AN FRMS POLICY

The ICAO SARPs (Annex 6, Part I, Appendix 7) require 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.

SHARED RESPONSIBILITY

Primary responsibility for fatigue management rests with managers who control the activities of personnel and the distribution of resources in the organization⁴². The FRMS is an organizational system that enables them to meet that responsibility. However, the FRMS can only be effective if all stakeholders are aware of their responsibilities and have the commitment, skills and resources to meet those responsibilities.

The particular nature of crew member fatigue as a safety hazard also makes shared responsibility essential. Fatigue is affected by all waking activities, not only work demands (Chapter 2). Crew members 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 while on duty. In addition, their cooperation is vital for voluntary reporting of fatigue hazards. Cooperation is also essential when crew member fatigue needs to be measured to provide data for FRM processes and FRMS safety assurance processes. Crew members' willingness to cooperate will depend on their confidence that the operator is committed to the principles of an effective safety reporting culture. Crew member representation on the FSAG can help promote the 'buy-in' of crew members that is essential for an effective FRMS.

SAFETY OBJECTIVES AND SAFETY PERFORMANCE INDICATORS

The safety objectives in the FRMS policy specify the standards that the operator and the regulator have agreed must be achieved by the FRMS. The FRMS policy also needs to identify safety performance indicators and targets that will be used to measure how well the FRMS is meeting its safety objectives. Examples of safety performance indicators can be found in Section 5.4

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 may be subject to periodic review by the regulator. The examples in Section 6.2.1 are intended to be used as guidance, not templates. Each operator needs to develop an FRMS policy appropriate their specific organizational context and operational needs.

⁴² ICAO Safety Management Manual (Doc 9859)

6.2. FRMS DOCUMENTATION

The documentation describes all the elements of the FRMS and provides a record of FRMS activities and any changes to the FRMS. It is essential for internal and external audit of 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 7) 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 programme, training requirements and attendance records;
- f. scheduled and actual flight times, duty periods and rest periods with deviations and reasons for deviations noted; and
- g. FRMS outputs including findings from collected data, recommendations, and actions taken.

It is recommended that the documentation includes the terms of reference for the FSAG and is maintained on an ongoing basis by the FSAG.

6.2.1. EXAMPLES OF FRMS POLICY STATEMENTS

EXAMPLE 1. FRMS POLICY STATEMENT FOR A MAJOR AIR CARRIER

[Insert Company Name] Fatigue Risk Management Policy

Safety is **[Insert Company Name's]** highest priority. To improve flight safety, operational reliability, and the quality of life for our flight crewmembers, we have decided to implement a Fatigue Risk Management System (FRMS).

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 programmes.

Management is responsible for:

- providing adequate resources for the FRMS;
- providing adequate crewing levels to support rosters that minimize 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 time off (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.

One of the primary aims is to enhance our understanding of fatigue and our FRMS through our training courses. These courses will ensure management, flight and cabin crew, and all other relevant personnel are aware of:

- the potential consequences of fatigue within our company;
- the importance of reporting fatigue-related hazards; and
- how to manage fatigue.

We have a safety target of 100% reporting by our staff of any fatigue hazards, fatigue-related issues, or incidents, with follow-up and feedback from management and supervisors within 30 days.

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 maximize the well-being of our staff.

Policy authorized by: (Signed) _____
Insert Title (e.g., CEO/Managing Director/or as appropriate)

[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 minimize 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 time off (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 crew members have doubts about their fatigue risk they are requested to use the company's 24-hour hotline.

One of the primary aims is to enhance our understanding of fatigue and our FRMS through our training courses. We have a safety target of 100% reporting by our staff of any fatigue hazards, incidents or fatigue-related issues with follow up and feedback from management and supervisors within 30 days.

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 (e.g. CEO/Managing Director/or as appropriate)

6.2.2. EXAMPLE OF TERMS OF REFERENCE FOR AN FSAG

The following 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 FSAG, 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 measures fatigue among flight crew members. 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 crew members, 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 crew member 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 crew members 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.

6.3. FRMS PROMOTION PROCESSES

Along with the FRMS policy and documentation, the FRMS promotion processes support the operational activities of the FRMS (FRM processes and FRMS safety assurance processes).

These must include:

- a. training programmes to ensure that all involved personal are trained and competent to undertake their responsibilities in the FRMS; and
- b. an effective FRMS communication plan that explains FRMS policies, procedures and responsibilities to all relevant stakeholders, and describes how information relating to the FRMS is gathered and disseminated.

6.3.1. FRMS TRAINING PROGRAMMES

Operators are required to maintain records of their FRMS training programme and monitor its effectiveness. ICAO also recommends that regulators have competency requirements for FRMS training instructors, who may be part of an operator's internal training department or external contractors.

Everyone whose role in the organization can influence the FRMS needs to have an appropriate level of fatigue management training. This includes crew members, people who design and manage pairings and rosters (crew schedulers, dispatchers), members of the FSAG and the FRMS safety assurance team, people responsible for overall operational risk assessment and resource allocation in the SMS. It also includes senior management, in particular the executive accountable for the FRMS and operational decision makers in any department managing operations within the FRMS.

The content of training programmes should be adapted to make sure that each group has the knowledge and skills they need for their role in fatigue management under FRMS. This will entail more in depth training than when using only a prescriptive approach.

Suggestions for FRMS training topics can be found in Appendix D.

6.3.2. FRMS COMMUNICATION PLAN

The ICAO SARPs require an operator to have an FRMS communication plan that:

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

The communication plan needs to address the frequency and type of communications necessary for the FRMS to be effective.

The FRMS training programmes 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 FSAG or other designated management) need to be clear, timely and credible, i.e., consistent with the facts, with previous statements, and with messages from other authorities including the regulator. 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 crew members are essential 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 crew members. There also needs to be clarity about the thresholds that separate non-culpable fatigue-related safety events from deliberate violations that will attract penalties.

One of the ways crew members can be encouraged to submit reports is by providing timely feedback when they do. This feedback should be specific to each report rather than generic to remain credible. Feedback does not require completion of a full investigation. Every crew member should receive a timely response to their report with some indication of the planned follow-up activity. For example, "To Capt. Jones; thank you for your fatigue report. This report will be forwarded to the Fatigue Safety Action Group (FSAG). The FSAG is composed of management, scheduling, and Air Traffic Controllers, with other specialists as required. The group meets quarterly to identify adverse trends in fatigue reports, evaluate potential mitigation strategies, and make recommendations to management at the local and national level".

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

CHAPTER 7. FRMS: IMPLEMENTATION

Regulatory requirements for FRMS differ slightly between States, and there is no ‘off-the-shelf’ version of FRMS that can suit all operations. Therefore, airline operators considering implementing an FRMS need to check their regulatory requirements carefully and start the dialogue with their regulator as soon as possible. Each operator needs to work with the regulator to develop an FRMS that is appropriate to the nature and level of the fatigue risk in the operations covered by their FRMS. The regulator and the operator need to collaborate to ensure that the FRMS will deliver an equivalent or enhanced level of safety to that achieved by operating within the prescriptive limits.

The implementation of an FRMS is done in phases, with the regulator reviewing and approving each phase before the next one can begin. Table 7-1 identifies 4 phases of implementation and summarizes the focus of the airline operator and the regulator during each phase.

Table 7-1. Aims of the airline operator and the regulator during the 4 phases of FRMS implementation

	Airline Operator	Regulator	
Approval process	Phase 1. Preparation	Developing FRMS capability	Assessment of feasibility
	Phase 2. Trial	Validating their FRMS capability	Assessment of FRMS capability
	Phase 3. Launch	Getting approval	Approval of FRMS
Continued oversight	Phase 4. Continuous Improvement	Embedding FRMS into normal operations	Embedding FRMS into normal regulatory oversight

Details of the implementation phases and uses of FRMS differ slightly between regulators. For example, the Australian Civil Aviation Safety Authority (CASA) has a four-phase implementation approach and FRMS can be used to manage fatigue: a) within the prescribed flight and duty time limits; or b) in specific operations that exceed the prescribed flight and duty time limits; or c) in operations for which the operator defines the flight and duty time limits⁴³. On the other hand, the US Federal Aviation Administration has a five-phase implementation approach and FRMS can be used to manage fatigue only in specified operations that exceed the prescriptive flight and duty time limits⁴⁴.

Although there are minor differences, all the regulatory approaches to FRMS implementation aim to accomplish the same steps that are summarized in the four phases in Figure 7-1.

⁴³ FRMS checklist, www.casa.gov.au/wcmswr/assets/main/lib100206/form817.xlsx
 FRMS Handbook, <http://www.casa.gov.au/wcmswr/assets/main/lib100206/frms.pdf>
 FRMS Process Manual, <http://www.casa.gov.au/wcmswr/assets/main/lib100206/frmsprocess.pdf>

⁴⁴ http://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_120-103A.pdf

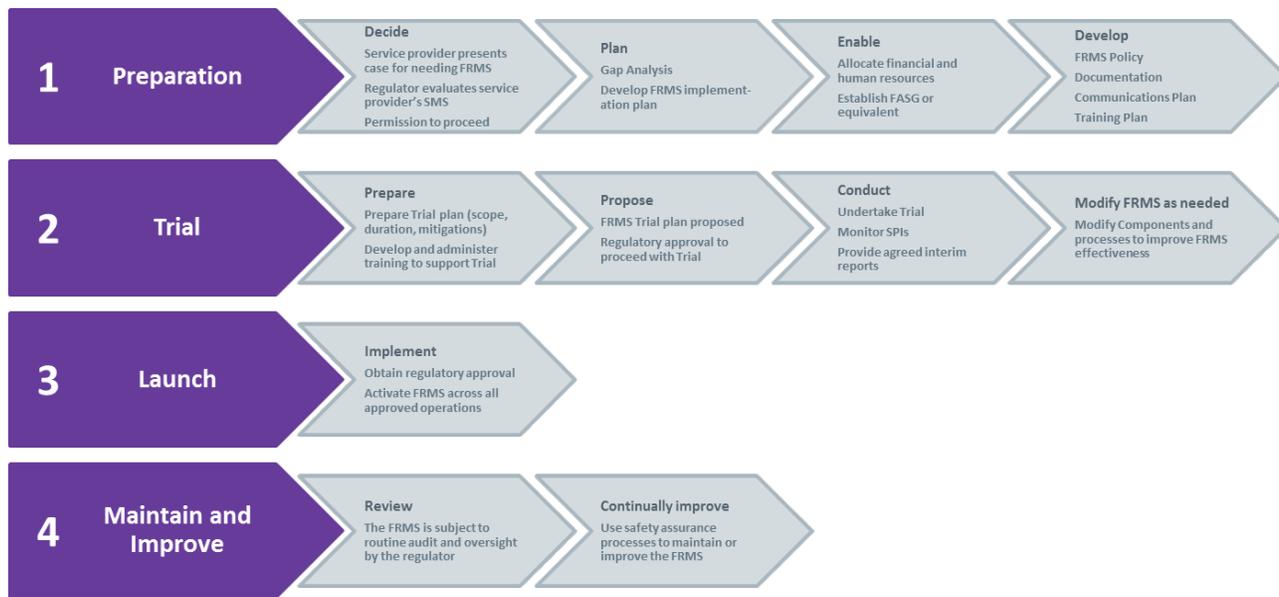


Figure 7-1. Four phases in FRMS implementation

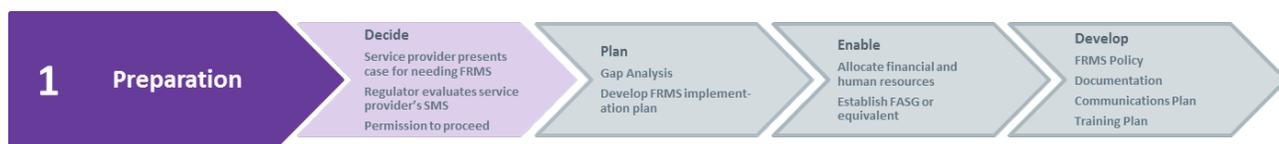
The time taken to progress through all four phases will depend on a range of factors including the complexity of the FRMS, the anticipated level of fatigue risk, and the capability and resources of both the operator and the regulator. However, the operational conditions that motivate operators to seek an FRMS usually require timely resolution and from a regulatory point of view, an operator cannot be allowed to operate outside of the prescriptive limits for an indefinite period using an “FRMS in progress”. A regulator should not allow an operator to continue using an “FRMS in progress” unless there are agreed activities being undertaken to bring the FRMS up to full approval requirements.

The services of outside consultants may be used to help develop the operator’s FRMS. However, an FRMS requires ownership and commitment by the people who will be using it, and the regulator needs to see evidence of this from the beginning of the implementation process. Outside experts can offer invaluable assistance, but they do not have the operator’s detailed organizational and operational knowledge and experience to develop and implement an FRMS. Consultants should not be the interface between the operator and the regulator.

7.1. PHASE 1: PREPARATION

The objective of Phase I is to establish an overall implementation plan that is acceptable to the regulator and addresses 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.

7.1.1. DECIDE



At the beginning of Phase I, the operator needs to explain to the regulator why they want to implement an FRMS. The operator should present a strong business case, operational and/or safety arguments, and a clear case for why the operation(s) cannot be managed within the prescriptive limits.

After receiving this proposal, the regulator will then assess the safety performance and risk management capability of the operator's SMS as an indicator of their readiness to implement an FRMS. The regulator will be looking for evidence that the operator has effectively managed fatigue-related risk within the prescriptive limits, using their SMS processes. A crucial element is the demonstration of an effective safety reporting system. Other areas likely to be considered are whether the operator: provides an appropriate level of fatigue management training; uses the SMS to identify fatigue hazards, assess risk, and implement appropriate mitigations; and has realistic scheduling (with no major ongoing differences between planned and actual schedules).

7.1.2. PLAN



Once the regulator has agreed that the operator can proceed with an application for an FRMS, the operator conducts a gap analysis. The purpose of the gap analysis is to identify: 1) elements of the FRMS that are already available in existing systems and processes; 2) existing systems and processes that could be modified to meet the needs of the FRMS (to minimize 're-inventing the wheel'); and 3) where new systems and processes are needed for the FRMS.

The findings of the gap analysis provide the basis for developing the FRMS implementation plan. Essentially this is a road map, with realistic timelines, that describes how the operator will progress through all four phases in Figure 7.1. It includes describing how the operator will proceed with implementing all the required FRMS components and processes

(Phase I), develop and conduct their FRMS trial (Phase II), refine the FRMS to the stage that it is approved by the regulator and ready to launch (Phase III) with embedded processes for continuous improvement (Phase IV).

7.1.3. ENABLE



To enable FRMS implementation to proceed, the accountable executive has to be identified, the necessary human and financial resources allocated, and the FSAG or equivalent identified. The stage at which the FSAG 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 II activities.

7.1.4. DEVELOP



By the end of Phase I (Preparation), all components and processes for the FRMS should be ready for the implementation trial. The following steps need to be completed.

- A completed gap analysis.
- An 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.
- Allocation of financial and human resources. The accountable executive for the FRMS needs to have the authority and control to ensure that this happens.
- An FRMS implementation plan.
- An FRMS documentation plan. This can be expected to evolve as the FRMS becomes operational.
- An FRMS communication plan. This can be expected to evolve as the FRMS becomes operational.
- Training programme ready for all personnel who will be involved in the FRMS trial in Phase II.
- An established Fatigue Safety Action Group (FSAG or equivalent) able to undertake Phase II.

Throughout Phase I, the onus is on the operator to consult with, and provide feedback to the regulator to ensure early identification and resolution of regulatory concerns.

7.2. PHASE 2: TRIAL

The objective of Phase II is for the operator to demonstrate their FRMS capability to the regulator. It tests the effectiveness of the FRMS components and processes that were established in Phase I. For Phase II, the operator prepares an FRMS Trial Plan and implements an initial version of the FRMS in the specific operation(s) for which the FRMS is being sought. As the Trial progresses, it is closely monitored by the regulator and modifications may be made to the FRMS components and processes to improve the overall effectiveness of the FRMS.

7.2.1. PREPARE



In preparation for the FRMS Trial, the regulator may ask the operator to demonstrate that the first version of the FRM processes (Section 5.2) has been implemented. For example, this could involve building on the SMS processes using reactive data (Chapter 4) such as confidential safety reports, accident and incident investigations, audits, and using historical rostering data to compare scheduled and actual flight and duty times and to track exceedances. The FRMS safety assurance processes should also be ready to implement for the Trial.

The operator must prepare a Trial Plan that details the following:

- The specific operations in which the Trial will take place.
- The anticipated additional fatigue risk associated with bringing these operations under the FRMS (as opposed to remaining within the prescriptive limits). Sources of information for estimating fatigue risk include published scientific studies on similar operations, the operator’s own experience with similar operations, and/or bio-mathematical modelling.
- The monitoring that will be undertaken to track the actual fatigue risk and the SPIs that will be used to determine the acceptability of that risk (Section 5.2.3). The operator and the regulator will need to agree on how the Trial will demonstrate an equivalent (or lower) level of fatigue risk on operations under the FRMS compared to operations that remain within the prescriptive limits. In some cases, this may require accessing independent scientific expertise to help develop a robust scientific study design to reliably compare levels of fatigue risk in different operations.
- The mitigation strategies that will be used to manage fatigue risk(s) identified through the FRMS processes.
- The duration of the trial and a timeline specifying the frequency of interim updates and the final report.

As part of preparing for the FRMS Trial, the operator should also ensure that all relevant personnel have received adequate training to enable them to undertake their roles in the FRMS. This will include crew members, staff responsible for schedule design and rostering, line managers (where appropriate), and members of the FSAG.

7.2.2. PROPOSE



The operator proposes their FRMS Trial Plan to the regulator. Some modifications to the plan may be required before it is approved and the Trial can begin.

7.2.3. CONDUCT



The FRMS Trial is conducted according to the plan and its progress is closely monitored by the regulator. This may include:

- requirement for frequent feedback from the operator (e.g., e-mail updates, reporting on SPIs);
- the regulator undertaking desktop reviews of the agreed operational SPIs;
- ongoing evaluation of the documentation of FRM processes and activities as they develop;
- on-site visits by the regulator; and
- direct inspection by the regulator of the Trial operation(s).

The regulator will also expect to see the FRMS safety assurance processes operating in a coordinated way with the operator's SMS.

7.2.4. MODIFY



Throughout the Trial, the agreed SPIs and relevant safety reports will be monitored by the regulator to confirm that the FRMS is delivering the required safety outcomes. The operator may identify improvements to the FRMS which should be discussed with the regulator. The regulator may also identify improvements to the FRMS. If major changes are needed to the FRMS, the trial may need to be reworked.

Before the final version of the FRMS can be approved and launched, the regulator has to be confident that it can deliver the required safety outcomes. In Phase II, the onus is on the operator to demonstrate that the FRMS safety assurance processes are functioning and confirming that the FRMS is delivering the required safety outcomes within the scope of the Trial.

The operator should expect to provide a final report documenting the activities and outcomes of the Trial. In addition, the regulator may check if there have been any operational or organizational changes during the Trial period that might have affected the Trial findings. The regulator may also review other relevant information, for example audits of the operator in other areas, or findings of studies on similar operations.

7.3. PHASE 3: LAUNCH

The objective of Phase III is to obtain regulatory approval for the FRMS and implement it across all the operations for which it is approved. The FRMS becomes routine in these operations, but regulatory monitoring remains more intensive to confirm that the FRMS is functioning as approved.

7.3.1. IMPLEMENT



Once the regulator is satisfied that the FRMS is fully functioning and delivering an acceptable level of safety, the regulator approves the FRMS and Phase III begins.

The operator can now activate the FRMS across all the operations that are specified in the approved FRMS. If the operator wishes to extend the scope of the FRMS to cover additional operations, they will be required to present a safety case and may be required to conduct a further Trial to demonstrate the effectiveness of the FRMS for managing fatigue risk in these additional operations, i.e., return to Phase II.

During Phase III, the level of regulatory oversight will typically be lower than during the Trial but must be sufficient to convince the regulator that the FRMS is functioning as intended in all the operations to which it applies. The regulator will require regular updates on trends in agreed SPIs. The frequency of reporting and type of information required will depend on the level of fatigue risk in the operations covered by the FRMS.

7.4. PHASE 4: MAINTAIN AND IMPROVE

During Phase IV, regulatory oversight reduces to routine levels. Regulatory audit may include review of: the operator's FRMS processes and procedures; internal audits; the activities of the FSAG including actions taken in response to SPI trends, and adjustments to outer limits and mitigations in response to data; any organizational and operational changes that may have an impact on the FRMS; and training practices.

7.4.1. REVIEW AND CONTINUALLY IMPROVE



During Phase IV, the FRMS becomes a routine part of the operations to which it applies. Ongoing review and continuous improvement of the FRMS is achieved through the FRMS safety assurance processes. As in Phase III, any extensions to the scope of the FRMS will require the operator to present a safety case and may require a new Trial, i.e., return to Phase II.

If deficiencies in the FRMS are identified, the regulator will take actions appropriate to the level of risk resulting from the deficiency. These actions may range from administrative changes or FRMS operational changes, to a withdrawal of FRMS approval.

7.5. 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 decides that it wants to operate a city pair which involves flight duty periods that exceed the prescriptive limit. Operator A therefore wishes to implement an FRMS on both of its long range fleets to cover this operation.

This example works through the steps that Operator A could follow to complete Phases I to IV above and implement a fully functional FRMS. It assumes that management at Operator A are familiar with the ICAO/IATA/IFALPA guidance materials and with their regulator's FRMS implementation requirements and guidance.

PHASE 1. PREPARATION

1. Operator notifies the regulator that they wish to implement an FRMS.
2. Regulator is satisfied with the safety performance and risk management capability of the operator's SMS and agrees to consider an application for the FRMS.
3. Responsibility for FRMS implementation assigned to a designated FRMS manager.
4. FRMS policy statement is developed and signed by the accountable executive.
5. The accountable executive allocates resources and authority to support FRMS development.
6. FRMS manager assembles an implementation team and organizes training for the team on FRMS basics and fatigue science.
7. Gap analysis undertaken by FRMS manager and implementation team.
8. FRMS Implementation Plan is developed by FRMS manager and implementation team.
9. FRMS manager identifies internal stakeholders (department representatives).
10. FRM processes and FRMS safety assurance processes are developed in collaboration with internal stakeholders.
11. FRMS documentation plan developed and first draft established.
12. FRMS communication plan developed and first draft established.
13. Training programme ready for all personnel who will be involved in the FRMS trial in Phase 2.
14. The FSAG (or equivalent) is established with documented terms of reference, and ready to undertake Phase 2.

PHASE 2. TRIAL

1. Training for all personnel involved in the FRMS Trial is undertaken.
2. FRMS Trial Plan is developed and approved by the regulator.
3. FRM processes and FRMS safety assurance processes are implemented according to the scope of the Trial.
4. Trial is undertaken according to the Trial Plan, with updates and reports on SPIs as agreed with the regulator.
5. Minor modifications to FRM processes and FRMS safety assurance processes are proposed by the operator and approved by the regulator.
6. Final report on the Trial activities and findings is presented to the regulator.

PHASE 3. LAUNCH

1. Full regulatory approval received.
2. FRMS implemented in operations for which it has been approved.
3. Compliance with all regulatory oversight requirements.

PHASE 4. MAINTAIN AND IMPROVE

1. Regulatory audit returns to routine levels.
2. Continuous improvement through FRMS safety assurance processes and feedback from regulatory audit.

APPENDIX A. ICAO FATIGUE MANAGEMENT SARPS FOR FLIGHT AND CABIN CREW

SARPs related to fatigue management in Annex 6, Part I are found in:

- Section 4.10 – Fatigue Management
- Section 2.1.2 – Operations Manual Content
- Appendix 7 – FRMS Requirements

A1.1. Section 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:*

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

Intent: Standard 4.10.1 stipulates the State’s responsibilities for establishing regulations for fatigue management. The establishment of regulations for prescriptive limitations remains mandatory, while the establishment of regulations for FRMS is necessary only where the State chooses to allow operators to apply for FRMS approval. Developing FRMS regulations is therefore optional for the State. However, both types of regulations need to address the known scientific principles (discussed in Chapter 3).

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:*

- flight time, flight duty period, duty period and rest period limitations that are within the prescriptive fatigue management regulations established by the State of the Operator; or*
- a Fatigue Risk Management System (FRMS) in compliance with 4.10.6 for all operations; or*
- 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.*

Intent: Standard 4.10.2 aims to make clear that, where the State has established regulations for FRMS, operators then have three options for managing their fatigue risks: a) they can do so solely within their State’s flight and duty time limitations regulations using existing SMS processes; b) they can choose to implement an FRMS for all operations; or c) they can implement an FRMS in part of their operations and in other operations comply with

the prescriptive flight and duty time limitations. Therefore, this Standard intends to allow the operator to decide which method of fatigue management is most appropriate for its specific types of operations.

Where the State does not have FRMS regulations, operators must manage their fatigue-related risks, as part of their existing safety management processes, within the constraints of their State's prescribed flight and duty time limitations or State-approved variations to those limitations. As fatigue is not the only hazard managed through an SMS, as is the case when using an FRMS, the expected concentration of resources to manage fatigue-related risks is significantly less.

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.*

Intent: It is recognized that prior to the FRMS Standards, many States had approved variations to the prescribed flight and duty time limitations for operators. In some cases, these variations relate to very minor extensions, and Standard 4.10.3 allows an operator to continue to have minor extensions in certain operations and manage their fatigue risks through their SMS processes without having to develop and implement a full FRMS. Approval of the variation is subject to the provision of a risk assessment acceptable to the State.

The intent of Standard 4.10.3 is to minimize "regulation through variations" and to avoid the approval of variations that meet operational imperatives in the absence of a risk assessment. It is not intended to offer a quick and easy alternative to an FRMS when a more comprehensive fatigue risk management approach is required. Importantly, it applies only in "exceptional circumstances." The type of circumstances considered "exceptional" are discussed further in Chapter 4, *Section 4.2. Developing regulations for variations to a prescribed limit.*

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.*

Intent: Standard 4.10.4 clarifies the need for the State to have a transparent FRMS approval process that requires an operator to demonstrate, as final evidence, effectively functioning FRMS processes. It aims to prevent the approval of an FRMS based only on the provision of a documented plan or a desktop review of an FRMS manual. The process for seeking and gaining approval of an FRMS from a State must be made transparent to the operator (see Chapter 6).

This Standard also makes clear that prescriptive Fatigue Management regulations provide the baseline, in terms of safety equivalence, from which an FRMS is assessed.

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.

Intent: 4.10.5 is a "change management" SARP aiming to address concerns of the potential use of unconstrained flight and duty times under the guise of an FRMS and to assist the State in the successful introduction of the performance-based regulations that FRMS requires. It sets clear expectations amongst all stakeholders, highlighting the State's ability to contain the range of flight and duty hours in which the operator using FRMS may operate.

4.10.5 a) requires the operator to identify an upper boundary which flight and duty times will not exceed and a lower boundary under which no rest period will be shortened even when using mitigations and processes within an FRMS.

4.10.5 b) provides States with a less drastic alternative to withdrawing approval for an FRMS when an adjustment will suffice to ensure that an equivalent level of safety is maintained. It intends to be proactive, in that it addresses less serious situations where an operator's data indicate a trend that suggests the values may be too high or too low.

4.10.5 c) ensures that operators who have demonstrated the responsible and comprehensive management of their fatigue-related risks through a mature FRMS are not prevented from gaining its full benefits by unnecessarily restrictive constraints.

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.*

Note 1.— Detailed requirements for an FRMS are in Appendix 7.

Note 2.— Provisions on the protection of safety data, safety information and related sources are contained in Appendix 3 to Annex 19.

Intent: 4.10.6 identifies the high level requirements of an FRMS, and directs the reader to Appendix 7 of Annex 6 Part I which details the necessary components (see Chapters 5 and 6 for further details). This Standard is presented in a similar format to that of the SMS framework (Annex 19, Appendix 2) to reflect the consistencies between FRMS and SMS.

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

Intent: 4.10.7 recognizes the relationship between FRMS and SMS. Because FRMS has a safety function, it needs to complement existing safety management processes within an operator's SMS in order to maximize their combined effectiveness, to ensure resources are being distributed appropriately across the systems and, where possible, to reduce duplicated processes for greater system efficiency. Information from an FRMS should inform an operator's SMS and vice versa.

However, it is important to recognise that they are not one and the same system. Where an operator does not wish to implement an FRMS or has had its FRMS approval revoked, the operator must use its SMS to manage fatigue-related risks within prescriptive limitations.

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.*

Intent: Irrespective of which method of fatigue management is used (i.e., compliance with prescriptive flight and duty limitations or implementation of an approved FRMS), all operators are required to maintain records of working periods, with or without flight duties, for flight and cabin crew. It is up to each State to stipulate the period of time which these records must be kept.

2. Contents

The operations manual referred to in 1 shall contain at the least the following:

2.1 General

.....

2.1.2 *Information and policy relating to fatigue management including:*

a) rules pertaining to flight time, flight duty period, duty period limitations and rest requirements for flight and cabin crew members in accordance with Chapter 4, 4.10.2 a); and

b) policy and documentation pertaining to the operator's FRMS in accordance with Appendix 7.

Intent: 2.1.2 aims to ensure that the operations manual identifies the fatigue management policies of the organization. It requires that operator-adjusted flight and duty time limits for particular operations (either within the constraints of prescribed regulations or in accordance with their FRMS) are identified.

It is not expected that the operations manual contain the entire set of FRMS documentation, but provides a high level description and references the necessary FRMS documentation.

A Fatigue Risk Management System (FRMS) established in accordance with Chapter 4, 4.10.6, shall contain, at a minimum:

1. 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 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 the Safety Management Manual (SMM) (Doc 9859).

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 programmes, 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*

Note.— Significant deviations are described in the Fatigue Risk Management Systems Manual for Regulators (Doc 9966).

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

2. Fatigue risk management processes

2.1 Identification of hazards

Note.— Provisions on the protection of safety data, safety information and related sources are contained in Appendix 3 to Annex 19.

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

2.2.1 *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.*

2.2.2 *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

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.*

3. FRMS safety assurance processes

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 that 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.*

4. FRMS promotion processes

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 programmes 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.*

Intent: Appendix 7 of Annex 6, Part I details the minimum requirements for each of the four components of an FRMS: 1) FRMS policy and documentation; 2) Fatigue Risk Management processes; 3) FRMS safety assurance processes; and 4) FRMS promotion processes. This Standard is presented in a similar format to that of the SMS framework (Annex 19, Appendix 2) to reflect the consistencies between FRMS and SMS.

APPENDIX B. MEASURING CREW MEMBER FATIGUE

In operations where fatigue is managed under an FRMS (and potentially operations under a prescriptive approach), it will sometimes be necessary to measure crew member 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)⁴⁵;
- they do not jeopardize crew members' 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, crew members, 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 crew members' 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. CREW MEMBERS' RECALL OF FATIGUE

B1.1. Fatigue Reports

Fatigue reports allow individuals to give vital feedback on fatigue hazards where and when they occur in an operation. People are encouraged to do this by an effective safety reporting culture in which there is a clear understanding of the defining 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. Crew members also need to be confident that reports will be acted on, which requires feedback from the FSAG, and they need to believe 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 FSAG.

An example of a fatigue report form can be found on the next page. This shows the information that needs to be gathered for fatigue to be evaluated, and it should also be included in mandatory incident/accident reporting forms. An operator may have different reporting processes, for example for events where fatigue is a safety concern, versus not a safety

⁴⁵ Gander PH, Mulrine HM, van den Berg MJ, et al. Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators. *Journal of Sleep Research* 24:110-119,2015.

concern, or for calling in too fatigued to take or continue a duty period. Information on how to report should be covered in fatigue management training.

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	How much sleep did you have in the <u>24 hrs</u> before the event?	hrs mins
Home	Yes / No	How much sleep did you have in the <u>72 hrs</u> before the event?	hrs mins
Duty itself	Yes / No	flight deck nap? Yes / No	If yes, when start end
In-flight rest	Yes / No		
Disrupt	Yes / No		
Personal	Yes / No		
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			

When 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 safety performance indicators may need to be evaluated (see Chapter 5, Section 5.4) to decide whether the increase in reporting should trigger further action.

B1.2. Retrospective Surveys

Retrospective surveys are a comparatively cheap way to obtain information from a group of crew members 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 crew members to be compared across time, or with other groups.⁴⁶

For example, the Epworth Sleepiness Scale (Figure B-1) 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 sleepiness⁴⁷, and information is available on its distribution in large community samples⁴⁸. The crew member 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.

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

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 (for paper-based surveys) and analyzing the data.

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 crew members are asked to accurately recall details of past events, feelings, or sleep patterns. This is not to question crew members’ integrity – inaccurate recall of past events is a common and complex human problem. Concerns about whether some crew members might exaggerate in their responses, for personal

⁴⁶ 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.

⁴⁷ Johns MW. Sleepiness in different situations measured by the Epworth Sleepiness Scale. *Sleep* 17:703-710, 1994..

⁴⁸ Gander PH, Marshall NS, Harris R, Reid P. The Epworth sleepiness score: Influence of age, ethnicity and socioeconomic deprivation. *Sleep* 28:249-253, 2005.

or industrial reasons, should be minimal in an effective safety reporting culture. In addition, extreme ratings are obvious when compared with group averages.

Crew members' 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.

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 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	3 <input type="checkbox"/>
watching TV	0 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	3 <input type="checkbox"/>
Sitting inactive in a public place (e.g., theatre, meeting)	0 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	3 <input type="checkbox"/>
As a passenger in a car for an hour without a break	0 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	3 <input type="checkbox"/>
Lying down in the afternoon when circumstances permit	0 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	3 <input type="checkbox"/>
Sitting and talking to someone	0 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	3 <input type="checkbox"/>
Sitting quietly after a lunch <u>without</u> alcohol	0 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	3 <input type="checkbox"/>
In a car, while stopped for a few minutes in traffic	0 <input type="checkbox"/>	1 <input type="checkbox"/>	2 <input type="checkbox"/>	3 <input type="checkbox"/>

Figure B-1. The Epworth Sleepiness Scale

B2. MONITORING CREW MEMBER FATIGUE DURING FLIGHT OPERATIONS

B2.1. Subjective Fatigue and Sleepiness Ratings

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

- Is the scale quick and easy to complete?
- Is it designed to be completed at multiple time points, e.g., across a flight?
- 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?
- Is it predictive of objective measures such as performance or motor vehicle crash risk?
- 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 now⁴⁹. 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 B-2. The Karolinska Sleepiness Scale (KSS)

⁴⁹ Åkerstedt T, Gillberg M. Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience* 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. *Journal of Sleep Research* 11(2):141-151, 2002.

Gillberg M. Subjective alertness and sleep quality in connection with permanent 12-hour day and night shifts. *Scandinavian Journal of Work Environment and 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 B-3 shows KSS ratings from 25 flight crew members across ultra-long range flights from Singapore to Los Angeles⁵⁰. 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 crew member's 1st in-flight rest period; rating 4 - after each crew member's 1st in-flight rest period; rating 5 - before each crew member's 2nd in-flight rest period; rating 6 - after each crew member'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 patterns.

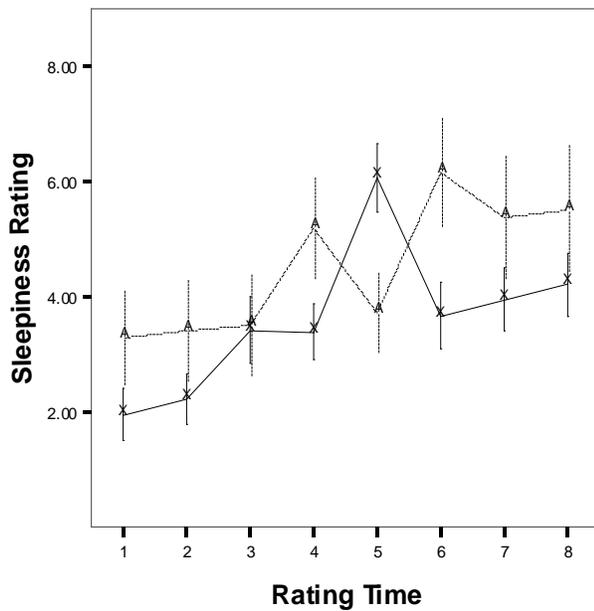


Figure B-3. KSS sleepiness ratings on flights from Singapore to Los Angeles (solid line – data for the command crew; dotted line – data for the relief crew)

⁵⁰ 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.

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.⁵¹

- 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 B-4. The Samn-Perelli Crew Status Check

Figure B-5 shows Samn-Perelli ratings for the same ULR crew members on the same flights as in Figure B3.

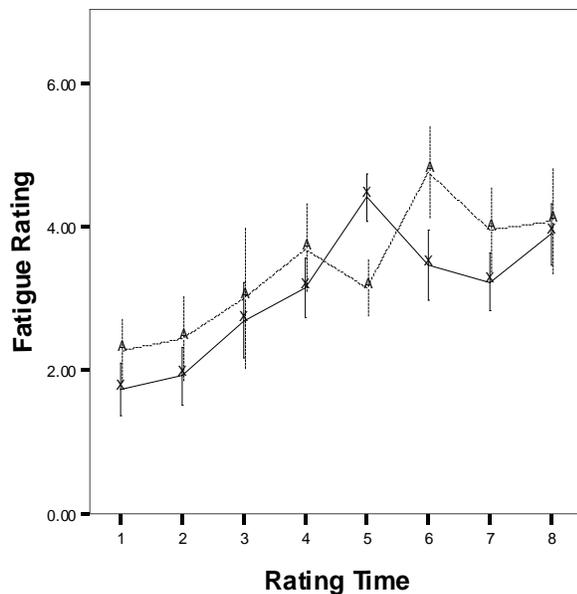


Figure B-5. Samn-Perelli fatigue ratings on flights from Singapore to Los Angeles (solid line – data for the command crew, dotted line – data for the relief crew)

⁵¹ 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. Aircrew fatigue in long-haul operations. *Accident Analysis and Prevention* 29(4): 439-452, 1997.

Gander PH, Mulrine HM, van den Berg MJ, et al. Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators. *Journal of Sleep Research* 24:110–119, 2015.

Both the KSS and the Samn-Perelli fatigue scale have been shown in laboratory studies to be influenced by prior sleep history and the circadian body clock cycle.⁵² A recent study confirmed both scales are also influenced by prior sleep history and the circadian body clock cycle for ratings made pre-flight and at TOD on long range and ultra-long range flights (237 pilots in 4-pilot crews, 730 out-and-back flights between 13 city pairs, 1-3 day layovers)⁵³.

STRENGTHS AND WEAKNESSES OF SUBJECTIVE RATINGS

Subjective sleepiness and fatigue ratings are relatively cheap and easy to collect and analyze. Furthermore, how a crew member feels is likely to influence his/her 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 crew members 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 crew members;
- 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 crew members' experience of fatigue.

Decision-making by the FSAG can be guided by comparing averages and/or extreme ratings with data gathered on other operations. For example, Figure B6 shows the percentage of pilots rating KSS at least 7 at pre-flight and at top of descent⁵⁴. (In laboratory studies, ratings of 7-9 have been associated with the onset of micro-sleeps)⁵⁵. Figure B6 includes data from 82 landing crew members on 2 long range and 3 ultra-long range trips (4-person crews, 3 airlines, 220 flights).

⁵² Fergusson SA, Paech GM, Sargent C, Darwent D, Kennaway DJ, Roach GD. The influence of circadian time and sleep dose on subjective fatigue ratings. *Accident Analysis and Prevention* 455:50-54, 2012.

⁵³ Gander PH, Mulrine HM, van den Berg MJ, Smith AAT, Signal TL, Wu LJ, Belenky G. Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators. *Journal of Sleep Research* 24:110–119, 2015.

⁵⁴ Gander PH, Mangie JM, van den Berg MJ, Smith AAT, Mulrine HM, Signal TL. Crew fatigue safety performance indicators for fatigue risk management systems. *Aviation, Space and Environmental Medicine* 85: 139-147, 2014.

⁵⁵ Åkerstedt T, Gillberg M. Subjective and objective sleepiness in the active individual. *International Journal of Neuroscience* 52:29-37, 1990.

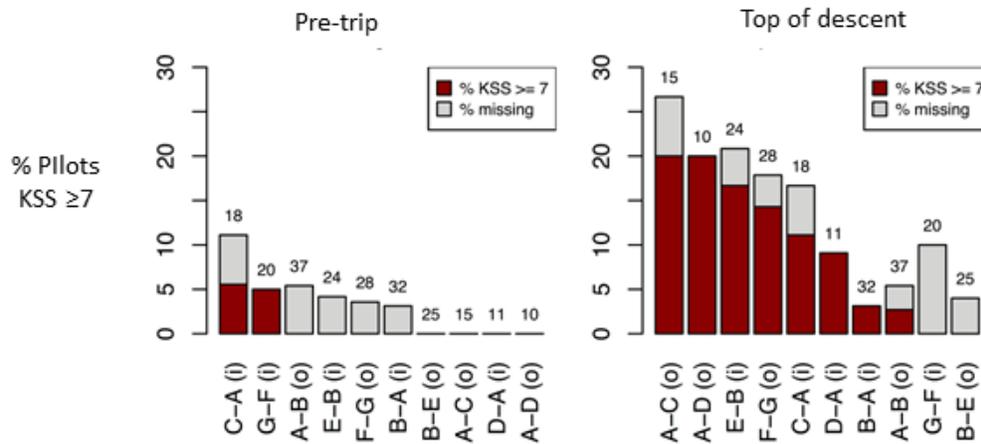


Figure B-6. Percentage of landing pilots in 4-pilot crews who rated their sleepiness at least 7 on the KSS, for 10 long range and ultra-long range flights (adapted from Gander et al, 2014⁴⁹).

Dark bars – percentage of pilots who rated themselves above 7. Grey bars – percentage of pilots in the studies who did not provide a rating at that time point. Letters A through G – different cities. A-B indicates a flight from city A to city B, etc. o = outbound; I = inbound. Values above each bar plot indicate number of crew members included.

For example, one SPI might be that no long range or ULR flight has more than 15% of landing pilots rating their KSS sleepiness as 7 or higher at TOD. A higher percentage on any flight would trigger the FSAG to undertake a risk assessment and examine whether additional mitigation strategies are needed on that flight.

B3. 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 crew members 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 crew member’s capacity to carry out his or her duties.

The following points should be considered when choosing performance tests for monitoring crew member fatigue and sleepiness during flight operations.

- How long does the test last?
- Can it be completed at multiple time points (e.g., a number of times across a flight), without compromising a crew member’s ability to meet duty requirements?
- 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?
- 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.)
- Has it been used in other aviation operations, and are the data available to compare performance levels?

One performance test that has been well-validated in the laboratory and is widely used in field studies is the Psychomotor Vigilance Task or PVT.⁵⁶ The most widely used version in recent airline studies is a 5-minute version of the PVT programmed on a smart phone.

Figure B-7 shows mean reaction times on the PVT for the same ULR crew members on the same flights as in Figures B-3 and B-5. This study used a 10-minute version of the test on a purpose-built hand held testing device. PVT tests were done at the following times:

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

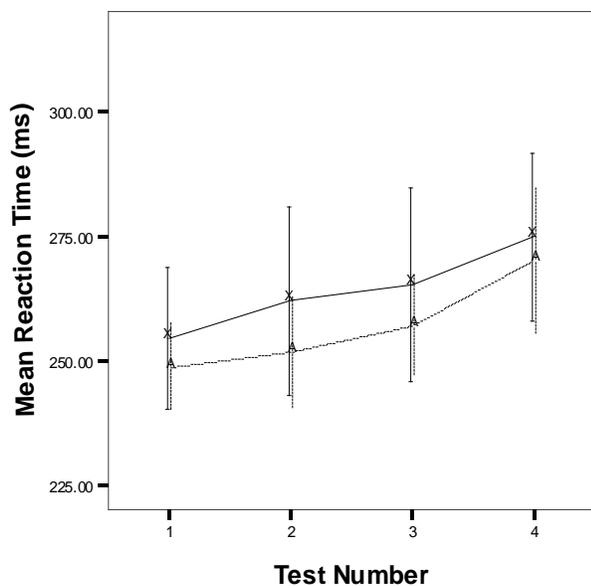


Figure B-7. Mean Reaction Time on the PVT Task on Flights from Singapore to Los Angeles. (Solid line – data for the command crew; dotted line – data for the relief crew)

STRENGTHS AND WEAKNESSES OF THE PVT

The PVT 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 crew members know how to operate the testing device.

⁵⁶ Dinges DF, Powell JP. Microcomputer analysis of performance on a portable, simple visual RT task during sustained operation. Behavior Research Methods, Instruments, and Computing 17: 652-655, 1985.

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

The PVT requires a crew member's constant attention during the test. In the study in Figure B-7, for example, this meant that crew members 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 shown in Figure in B-7, crew members 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 B-7 is significantly different from any of the others.

In combined analyses of data from four studies of long range and ULR operations (237 pilots, 730 out-and-back flights between 13 city pairs, 1-3 day layovers), PVT response speed was not related to sleep/wake history at TOD although it varied as expected with circadian phase. This unanticipated finding may reflect relatively low levels of fatigue at TOD and/or atypically fast PVT response speeds among these pilots.⁵⁷

B4. MONITORING SLEEP

Sleep loss is a key contributing factor to fatigue. In addition, crew members 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 crew members 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.

Crew members may also be asked to rate their sleepiness and fatigue before and after planned sleep periods. When sleep is being monitored during flight operations, crew members may also be 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 smart phone or tablet). The layout of diary pages may need to be adapted to collect different types of information at different times in a study, for example pre-trip, during flights, and during layovers.

⁵⁷ Gander PH, Mulrine HM, van den Berg MJ, Smith AAT, Signal TL, Wu LJ, Belenky G, Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators. *Journal of Sleep Research* 24:110–119, 2015.

Figure B-8 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.

In Flight

Date (UTC) // 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

Date (UTC) // 0000 0200 0400 0600 0800 1000 1200 1400 1600 1800 2000 2200 2400

REST 1			REST 2			REST 3		
START	PDA test score	Right deck back Left deck back	START	PDA test score	Right deck back Left deck back	START	PDA test score	Right deck back Left deck back
Time (UTC) hrs mins	Fatigue rating: 1 2 3 4 5 6 7	<input type="checkbox"/> <input type="checkbox"/>	Time (UTC) hrs mins	Fatigue rating: 1 2 3 4 5 6 7	<input type="checkbox"/> <input type="checkbox"/>	Time (UTC) hrs mins	Fatigue rating: 1 2 3 4 5 6 7	<input type="checkbox"/> <input type="checkbox"/>
	Sleepiness rating: 1 2 3 4 5 6 7 8 9			Sleepiness rating: 1 2 3 4 5 6 7 8 9			Sleepiness rating: 1 2 3 4 5 6 7 8 9	
END	Fatigue rating: 1 2 3 4 5 6 7		END	Fatigue rating: 1 2 3 4 5 6 7		END	Fatigue rating: 1 2 3 4 5 6 7	
Time (UTC) hrs mins	Sleepiness rating: 1 2 3 4 5 6 7 8 9		Time (UTC) hrs mins	Sleepiness rating: 1 2 3 4 5 6 7 8 9		Time (UTC) hrs mins	Sleepiness rating: 1 2 3 4 5 6 7 8 9	
	Sleep Quality: 1 2 3 4 5 6 7			Sleep Quality: 1 2 3 4 5 6 7			Sleep Quality: 1 2 3 4 5 6 7	
Total duration of sleep (excluding awakenings)		hrs mins	Total duration of sleep (excluding awakenings)		hrs mins	Total duration of sleep (excluding awakenings)		hrs mins

REST 4			REST 5			REST 6		
START	PDA test score	Right deck back Left deck back	START	PDA test score	Right deck back Left deck back	START	PDA test score	Right deck back Left deck back
Time (UTC) hrs mins	Fatigue rating: 1 2 3 4 5 6 7	<input type="checkbox"/> <input type="checkbox"/>	Time (UTC) hrs mins	Fatigue rating: 1 2 3 4 5 6 7	<input type="checkbox"/> <input type="checkbox"/>	Time (UTC) hrs mins	Fatigue rating: 1 2 3 4 5 6 7	<input type="checkbox"/> <input type="checkbox"/>
	Sleepiness rating: 1 2 3 4 5 6 7 8 9			Sleepiness rating: 1 2 3 4 5 6 7 8 9			Sleepiness rating: 1 2 3 4 5 6 7 8 9	
END	Fatigue rating: 1 2 3 4 5 6 7		END	Fatigue rating: 1 2 3 4 5 6 7		END	Fatigue rating: 1 2 3 4 5 6 7	
Time (UTC) hrs mins	Sleepiness rating: 1 2 3 4 5 6 7 8 9		Time (UTC) hrs mins	Sleepiness rating: 1 2 3 4 5 6 7 8 9		Time (UTC) hrs mins	Sleepiness rating: 1 2 3 4 5 6 7 8 9	
	Sleep Quality: 1 2 3 4 5 6 7			Sleep Quality: 1 2 3 4 5 6 7			Sleep Quality: 1 2 3 4 5 6 7	
Total duration of sleep (excluding awakenings)		hrs mins	Total duration of sleep (excluding awakenings)		hrs mins	Total duration of sleep (excluding awakenings)		hrs mins

Fatigue rating:

1= fully alert, wide awake.
2= very lively, responsive, but not at peak.
3= okay, somewhat refreshed.
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.

Sleep Quality:

1= extremely good
7= extremely poor

Sleepiness rating:

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.

ID

Figure B-8. 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. Electronic diaries that can be downloaded avoid this problem. Analysis of diary data also 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 crew members in a layover hotel and in flight.⁵⁸ For in-flight sleep:

- *average sleep durations* from diaries were similar to those recorded using polysomnography (the accepted gold standard for recording sleep); but

⁵⁸ Signal TL, Gale J, Gander PH. Sleep Measurement in Flight Crew: Comparing actigraphic and subjective estimates of sleep with polysomnography. Aviation Space and Environmental Medicine 76(11):1058-1063, 2005.

- the variability among individuals was high. Some crew members over-estimated how long they slept, and others underestimated; and
- crew members' estimates of how long they took to fall asleep, and their ratings of sleep quality were not reliably related to polysomnography measures.

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 crew members. 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 downloaded to a computer for analysis.

A new generation of actigraphs is coming onto the market which are much cheaper than older models and have a variety of options including: an event marker button (to place a time mark in the data file, for example when going to bed); light sensors (although if they are worn inside a shirt sleeve this may not be reliable); and a regular watch face so that the wearer does not need to wear a normal watch as well, to keep track of time. Each type comes with custom software that scans through the activity record and decides whether the person was asleep or awake in each recorded epoch (for example every minute).

There are a number of important considerations when choosing actigraphs for use in aviation field studies.

- Validation – actigraphs monitor movement, not sleep. They provide a string of activity counts. For actigraphy to be a reliable measure of sleep, the computer algorithm that decides whether the wearer was awake or asleep in each epoch has to have been validated against polysomnography, the gold standard for measuring sleep (see next section).¹³ An actigraph that has not been validated against polysomnography cannot be considered to provide reliable information on sleep patterns.
- Battery maintenance - available options include batteries that the user replaces as needed, and batteries that the user recharges but cannot remove and that are replaced e.g., annually, by the manufacturer. This requires taking the actigraph out of circulation while it is sent back to the manufacturer.
- How data are downloaded – this is usually done by the user, but some new models require the data to be downloaded by the manufacturer, which can raise issues around data ownership and confidentiality.

Figure B-9 shows an example of an actigraphy record from a Boeing 777 pilot over a three-week period during which he flew a return trip between Atlanta and Johannesburg (crossing 6 time zones) followed by 6 nights in Atlanta and then a return trip between Atlanta and Dubai (crossing 8 time zones).

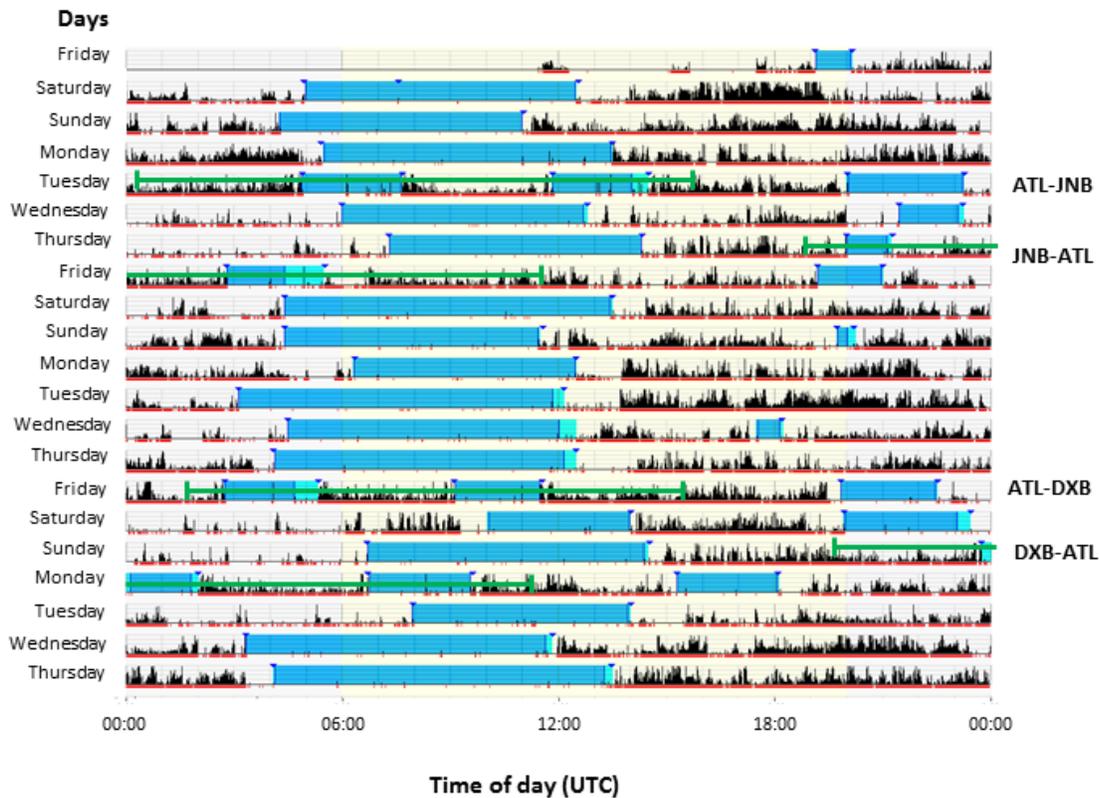


Figure B-9: Actigraphy record from a Boeing 777 pilot

- Black vertical bars - minute-by-minute activity counts
- Blue horizontal bars - sleep as identified by actigraphy
- Turquoise horizontal bars - times attempting to sleep but not asleep by actigraphy
- Red horizontal bars - times awake as identified by actigraphy
- Green horizontal lines - times on duty

Note that during the ATL-JNB flight, this pilot slept (blue horizontal bars) in the 2nd and 4th in-flight rest periods. In this operation, this distribution of rest periods indicates that he was a member of the landing crew. Conversely on the JNB-ATL flight, he slept in the 1st and 3rd rest periods, indicating that he was in the relief crew for landing on this flight. He was in the relief crew for landing on the ATL-DXB flight (1st and 3rd rest periods) and in the landing crew on the DXB-ATL flight (2nd and 4th rest breaks).

STRENGTHS AND WEAKNESSES OF ACTIGRAPHY

As Figure B-9 illustrates, actigraphy is very useful for obtaining objective records of the sleep/wake patterns of crew members across multiple days. This is currently the most practical and reliable way to look at whether a crew member 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 also compared actigraphy and polysomnographic sleep recordings from the 21 B-777 flight crew members. For both hotel sleep and bunk sleep:

- *average sleep durations* calculated from actigraphy were similar to those recorded using polysomnography; but
- *for individual crew members, actigraphy could overestimate or underestimate polysomnographic 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 crew members 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 crew members, both in the air and on the ground.

At present, the accepted standard for analyzing actigraphy records is to use a sleep diary to identify when a crew member was trying to sleep (as opposed to just sitting still or not wearing the watch). The sections of the record where the crew member 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 polysomnography) remains to be demonstrated.

Some operators using FRMS 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 FSAG.

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 B-10 shows a flight crew member on the flight deck wearing polysomnography electrodes, which the researcher is connecting to a portable recording device.



Figure B-10: Polysomnographic recording in flight

Figure B-11 shows an analysis of the polysomnography record of a flight crew member during his first in-flight sleep period on a SIN-LAX flight. Figure B-11 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 crew member was awake, or in which type of sleep he spent most of that 30 seconds. Figure B-11 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 slow-wave sleep (non-REM S3 and S4), or Rapid Eye Movement (REM) sleep.

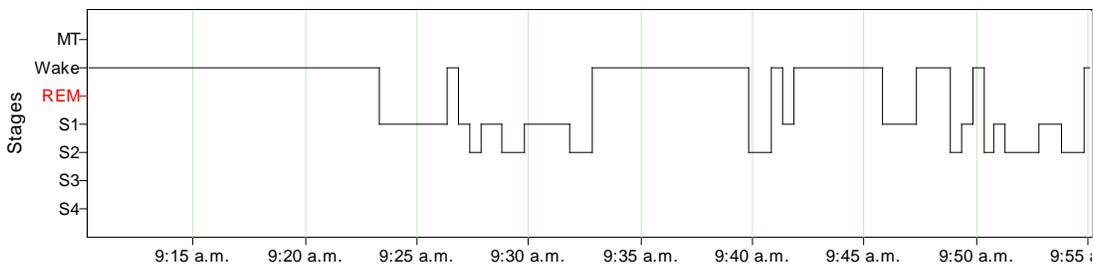


Figure B-11: Polysomnographic record for a crew member's first in-flight rest period on a SIN-LAX flight

Figure B-12 shows the polysomnographic record for the same crew member during his second in-flight rest period on a 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 totalled 52 minutes. He spent 1.5 minutes in slow-wave sleep, 2 minutes in REM sleep, and the rest of the time in light non-REM sleep (S1 and S2).

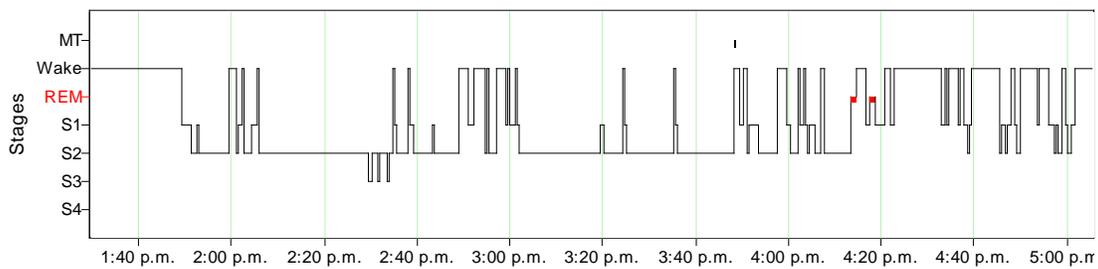


Figure B-12: Polysomnographic record a crew member's second in-flight rest period on a SIN-LAX flight (same crew member as in Figure D-11)

STRENGTHS AND WEAKNESSES OF POLYSOMNOGRAPHY

Figures B-11 and B-12 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 crew members 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. Crew members 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 crew members 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 crew member 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 B-11 and B-12.

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 Civil Aviation Authority of Singapore agreed that a subgroup of crew members would have their sleep monitored by polysomnography during the operational validation of the SIN-LAX route⁵⁹.

⁵⁹ The data in Figures B-3, B-5, B-7, B-11, and B-12 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.

B5. MONITORING THE CIRCADIAN BODY CLOCK CYCLE

The circadian body clock cycle is a key contributing factor to crew member 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, measured by an ingested core temperature pill or rectally-inserted probe; 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 crew members by tracking the rhythm of core body temperature. Figure B-13 shows the times of the daily temperature minimum of one participating B-747 crew member across an 8-day long-haul trip pattern⁶⁰.

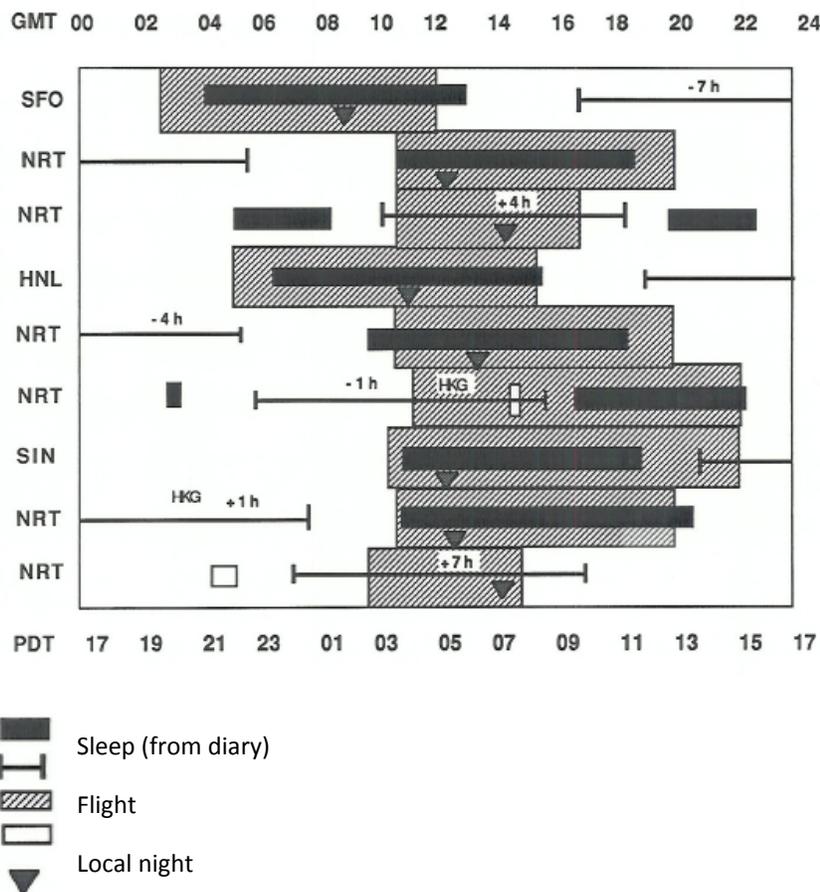


Figure B-13: Sleep times (diary data) and times of the circadian temperature minimum of a crew member during a long-haul trip pattern

⁶⁰ 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.

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 crew member arrived back in SFO at the end of the trip, it had drifted about 6 hours later. Thus, when he got home, the crew member'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 crew member 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.

Clearly, Figure B-13 provides valuable information that can be related to the crew member'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 B-13).

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 crew member is exposed to daylight during his/her "biological night" (for example, a few hours either side of the of the temperature minimum in Figure B-13), melatonin secretion will stop. This makes it impossible to track its normal circadian cycle across a trip such as that in Figure B-13. Analyzing for hormone levels in body fluids is a highly skilled task that needs to be done 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 crew members 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.

B5.1. Workload

At present, there is no clear operational definition of workload or agreed ways of measuring it for flight or cabin crew members. Two more commonly used measures are the NASA Task Load Index (Figure B-14) and the Overall Workload Scale (Figure B-15).⁶¹

Place an 'X' in the position that best describes your experience. Note that 'your success in accomplishing tasks' is rated from 'good' to 'poor'.

How mentally demanding was the flight?	Low		High
How physically demanding was the flight?	Low		High
How hurried or rushed was the pace of the flight?	Low		High
How successful were you in accomplishing what you were asked to do?	Good		Poor
How hard did you have to work to accomplish your level of performance?	Low		High
How insecure, discouraged, irritated, stressed and annoyed were you?	Low		High

Figure B-14: The NASA Task Load Index

Overall workload on this flight:
(Please complete on flight deck)

Low		High
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Figure B-15: The Overall Workload Scale

B6. EVALUATING THE CONTRIBUTION OF FATIGUE TO SAFETY EVENTS

The primary aim of investigating the role of crew member fatigue in safety events is to identify how its occurrence or effects could have been mitigated, in order to reduce the likelihood of similar events in the future. There is no simple formula for evaluating the contribution of fatigue to a safety event. To establish that fatigue was a contributing factor, 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.

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.

⁶¹ Hill SG, Iavecchia HP, Bittner AC, Zaklad AJ, Christ RE. Comparison of four subjective workload rating scales. Human Factors 34:429-439, 1992.

B6.1. Basic Information

To establish whether a crew member was likely to have been fatigued at the time of an event, four pieces of information are needed.

1. The time of day that the event took place. If it was in the WOCL (0200-0600), than fatigue may have been a factor.
2. Whether the crew member's normal circadian rhythm was disrupted (for example, if in the last 72 hours they had been on duty at night, or had flown across time zones).
3. How many hours the crew member has been awake at the time of the occurrence. (It may be more reliable to ask 'what time did you wake up from your last sleep period before the event?'). If this is more than 16 hours, then sleepiness may have been a factor.
4. Whether the 72-hour sleep history suggests a sleep debt. As a rough guide, if the average adult requires 7-8 hours of sleep per 24 hours, then a crew member who has had less than 21 hours sleep in the last 72 hours was probably experiencing the effects of a sleep debt. If information on sleep history is not available, duty history can provide information on sleep opportunities.

B6.2. Investigating Fatigue in Depth

If answers to the four questions above suggest that the crew member was fatigue at the time of the event, then more in-depth investigation requires looking at whether the person or crew took particular actions or decisions that were causal in what went wrong, and whether those actions or decisions are consistent with the type of behavior expected of a fatigued person or crew. The following two checklists provide one example of how this can be done.

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 behavior 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)

Irregular Schedules		
establish whether the scheduling was problematic with regards to its impact on quantity and quality of sleep		
Was crew member a shift worker (working through usual sleep times)?	No (The circadian body clocks and sleep of shift workers do not adapt fully)	<input type="text"/>
If yes, was it a permanent shift?	Yes -days	<input type="text"/>
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	<input type="text"/>
How are overtime or double shifts scheduled?	Scheduled when crew members are in the most alert parts of the circadian body clock cycle (late morning, mid evening)	<input type="text"/>
Scheduling of critical safety tasks?	S Scheduled when crew members are in the most alert parts of the circadian body clock cycle (late morning, mid evening)	<input type="text"/>
Has crew member had training on personal fatigue mitigation strategies?	Yes	<input type="text"/>
Jet Lag		
establish the existence and impact of jet lag on quantity and quality of sleep		
Number of time zones crossed?	one	<input type="text"/>
If more than one, at what rate were they crossed?	the slower the better	<input type="text"/>
In which direction was the flight?	westward	<input type="text"/>

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	

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, but used in conjunction with other fatigue countermeasures, as needed, in response to unanticipated fatigue experienced during operations.

- Use of controlled rest on the flight deck should result in a fatigue report to enable the FSAG or Safety Management System process (as applicable) to evaluate whether existing mitigation strategies are adequate.
- It is only intended to be used during low workload phases of flight (e.g., during cruise flight) at times when it does not interfere with required operational duties.
- 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 fatigue training programme.

The following recommended procedures are based on a survey of major air carriers. They represent considerable experience in many regions of the world 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 its regulator to define appropriate procedures.

C1. PLANNING

- 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.
- 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 captain requires it, the rest may be terminated at any time.
- The captain should define criteria for when his/her rest should be interrupted.
- Hand-over of duties and wake-up arrangements should be reviewed.
- Flight crews may only use controlled rest if they have completed the appropriate training.
- Some operators involve a third crew member (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 crew member on the flight deck throughout controlled rest.
- Controlled rest should only be planned during the cruise period from the top of climb to 30 minutes before the planned top of descent. This is to minimize the risk of sleep inertia, and allow sufficient time for operational briefings and increasing workload prior to commencing descent.
- 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 shall perform the duties of the pilot flying and the pilot monitoring, and cannot leave his/her seat for any reason, including physiological breaks.
- A sufficient period of time should be allowed following the controlled rest to overcome the effects of sleep inertia and allow for adequate briefing.

- The planned rest period should be no longer than 40 minutes, to facilitate enhanced alertness but not detract from operations.
- Personal equipment (such as eye shades, neck supports, ear plugs, etc.) is permitted for the resting pilot.

C2. RECOMMENDED RESTRICTIONS

- The autopilot and auto-thrust systems (if available) should be operational.
- One pilot shall be fully able to exercise control of the aircraft at all times and maintain situational awareness.
- Only one operating flight crew member may rest on the flight deck at a time.
- Both operating pilots should remain at their stations.

APPENDIX D. RECOMMENDED FATIGUE TRAINING TOPICS

Table D-1. Some recommended fatigue management-related topics for inclusion in training programmes when using a prescriptive approach and when using an FRMS to manage fatigue

Prescriptive Approach	FRMS
Target Group: Flight and Cabin Crew	
<ul style="list-style-type: none"> • The scientific principles that underpin fatigue management. • Individual responsibilities and those of the Service Provider, for managing fatigue. • Causes and consequences of fatigue in the operation(s) in which they work. • How to identify fatigue in themselves and others. • How to use fatigue reporting systems, including how to report that they are too fatigued to undertake safety-critical duties. • 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. • Sleep disorders and their treatment, where to seek help if needed, and any requirements relating to fitness for duty. 	<ul style="list-style-type: none"> • An overview of the FRMS structure and how it works in the Service Provider’s organization, including the concepts of shared responsibility and encouraging effective reporting. • Their responsibilities and those of the Service Provider, in the FRMS. • The scientific principles that underpin 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. • Sleep disorders and their treatment, where to seek help if needed, and any requirements relating to fitness for duty.
Target Group: Personnel involved in schedule (roster) design and management	
<ul style="list-style-type: none"> • The scientific principles that underpin fatigue management. • 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. • Use and limitations of any scheduling tools and bio-mathematical models or other algorithms that may be used to predict an individual’s fatigue across a schedule/roster. • How to identify fatigue in themselves and others. • How fatigue reports are generated and analysed. • 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. 	<ul style="list-style-type: none"> • An overview of the FRMS structure and how it works in the Service Provider’s organization, including the concepts of shared responsibility and encouraging effective reporting. • The scientific principles that underpin FRMS. • 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. • Use and limitations of any scheduling tools and bio-mathematical models or other algorithms that may be used to predict the levels of an individual’s fatigue across rosters/schedules. • Their role in the FRMS in relation to fatigue hazard identification and risk assessment. • Processes and procedures for planned schedule changes, including: <ul style="list-style-type: none"> ○ assessing the potential fatigue impact of planned changes; ○ early engagement of the FSAG in the planning of changes with significant potential to increase fatigue risk; and ○ implementing changes recommended by the FSAG.

Prescriptive Approach**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.

Target Group: Executive decision-makers and operational risk managers

- The scientific principles that underpin fatigue management
 - An overall understanding of crew member or controller fatigue and the safety risk that it represents to the organization.
 - The responsibilities and accountabilities of different stakeholders in fatigue management, including themselves.
 - Linkages between fatigue management and other parts of the Service Provider's safety management system.
 - Regulatory requirements for fatigue management.
 - 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 so they can make organizational decisions about how to manage affected individuals.
- An overall understanding of the scientific principles that underpin FRMS and the safety risk that fatigue 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 FSAG.
 - 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 Service Provider's safety management system.
 - Linkages between the FRMS and other parts of the organization, for example the scheduling department, operational sections, medical department, safety 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, their treatment, and where to seek help if needed, so they can make organizational decisions about how to manage affected individuals.

Target Group: FSAG members

Not Applicable

- All FRMS components and elements.
 - The responsibilities and accountabilities of different stakeholders in the FRMS.
 - Linkages between the FRMS and other parts of the Service Provider's SMS.
 - Linkages between the FRMS and other parts of the organization, for example the scheduling department, flight operations, medical department, safety department, etc.
 - Regulatory requirements for the FRMS.
 - The scientific principles that underpin 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, so they can make organizational decisions about how to manage affected individuals.
-

APPENDIX E. EXAMPLE OF FRM PROCESSES

This example works through FRM 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 template. The accepted approach for ULR operations is to evaluate each city pair to be flown⁶². The operation here is between City A and City B (described here as the A-B-A route). Figure E-1 summarizes the FRM processes, which are explained in more detail in the text.

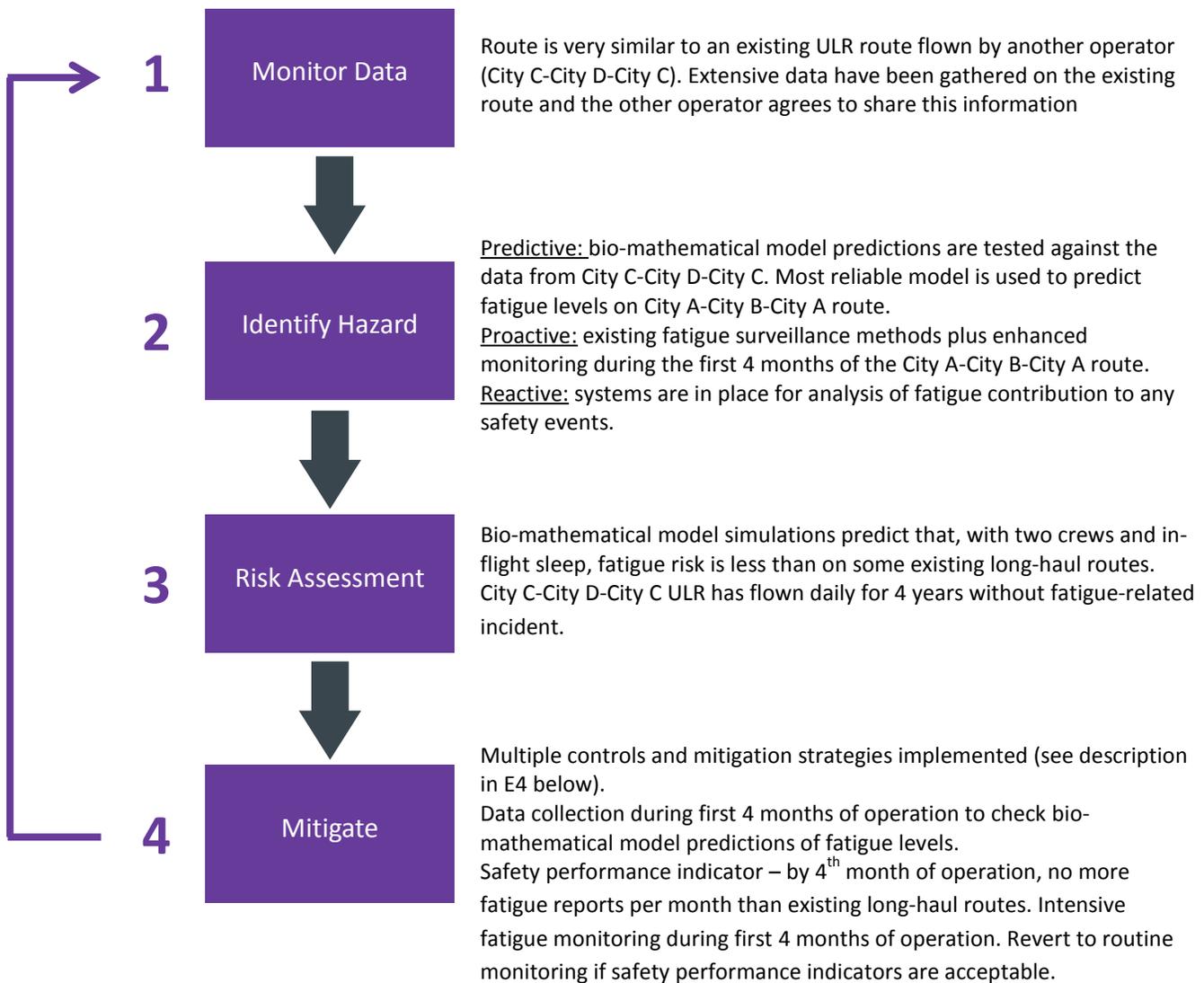


Figure E-1. FRM processes for setting up a new ULR route

⁶² Flight Safety Foundation. Flight Safety Digest 26, 2005.

E1. STEP 1. MONITOR DATA

Because the operation has not yet started, there are no data available on it. However, information and data are 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 crew members 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 crew member sleep and fatigue. 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.)

E2. STEP 2. HAZARD IDENTIFICATION

E2.1. 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 defines 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 crew member 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 crew members before, during, and after ULR operations.

One model (which has not been validated for aviation operations) makes the following predictions for the C-D-C route: that crew member 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 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 (which has been developed using flight crew data) reliably predicts the duration of in-flight sleep on the C-D-C route (to within the range of variability seen among the crew members monitored). This model is chosen to predict crew member alertness on the A-B-A route.

E2.2. 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.

- Crew members are reminded about and encouraged to use existing fatigue reporting forms.
- For the first month of the operation, a senior flight crew member and a senior cabin crew member will be present in the Flight Operations Centre, or on call, 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 crew member 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 crew members 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 crew members 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 crew member 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.

E2.3. 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 the 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.

E3. STEP 3. RISK ASSESSMENT

The bio-mathematical model used to predict crew member 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.

E4. STEP 4. 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 crew members flying the new operation are domiciled in the departure city.
- All crew members 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 crew members 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.

- There is a clear policy on the distribution of in-flight rest opportunities, so that crew members can plan how best to use them.
- Each crew member 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 crew members.
- 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:

1. 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 crew member fatigue and alertness levels are in the range predicted.
2. 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 high risk fatigue reports should be received.

To monitor the effectiveness of the mitigations, there is a defined validation period for the first four months of the operation that involves more intensive monitoring. The FSAG 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 recommended for fatigue risk monitoring and management on the A-B-A route. This report will be available to all interested parties.

During the validation period, the FSAG will ensure that the FRMS safety assurance team is provided monthly with a summary of SPI data and any actions relating to fatigue reports or validation data. The FSAG will also brief the FRMS safety assurance team on the findings and recommendations of the validation report. If the validation report and the safety performance indicators are acceptable, the FRMS safety assurance team will approve that the A-B-A operation reverts to routine monitoring under the FRM processes.

APPENDIX F. EXAMPLES OF FRMS SAFETY ASSURANCE PROCESSES

F1. EXAMPLE 1

In the example summarized in Figure F-1, the FSAG sets a maximum duty length of 14 hours as one of its SPIs. The following are the steps in the FRMS safety assurance processes when an increasing trend is identified in exceedances of this SPI in the B-747 fleet.

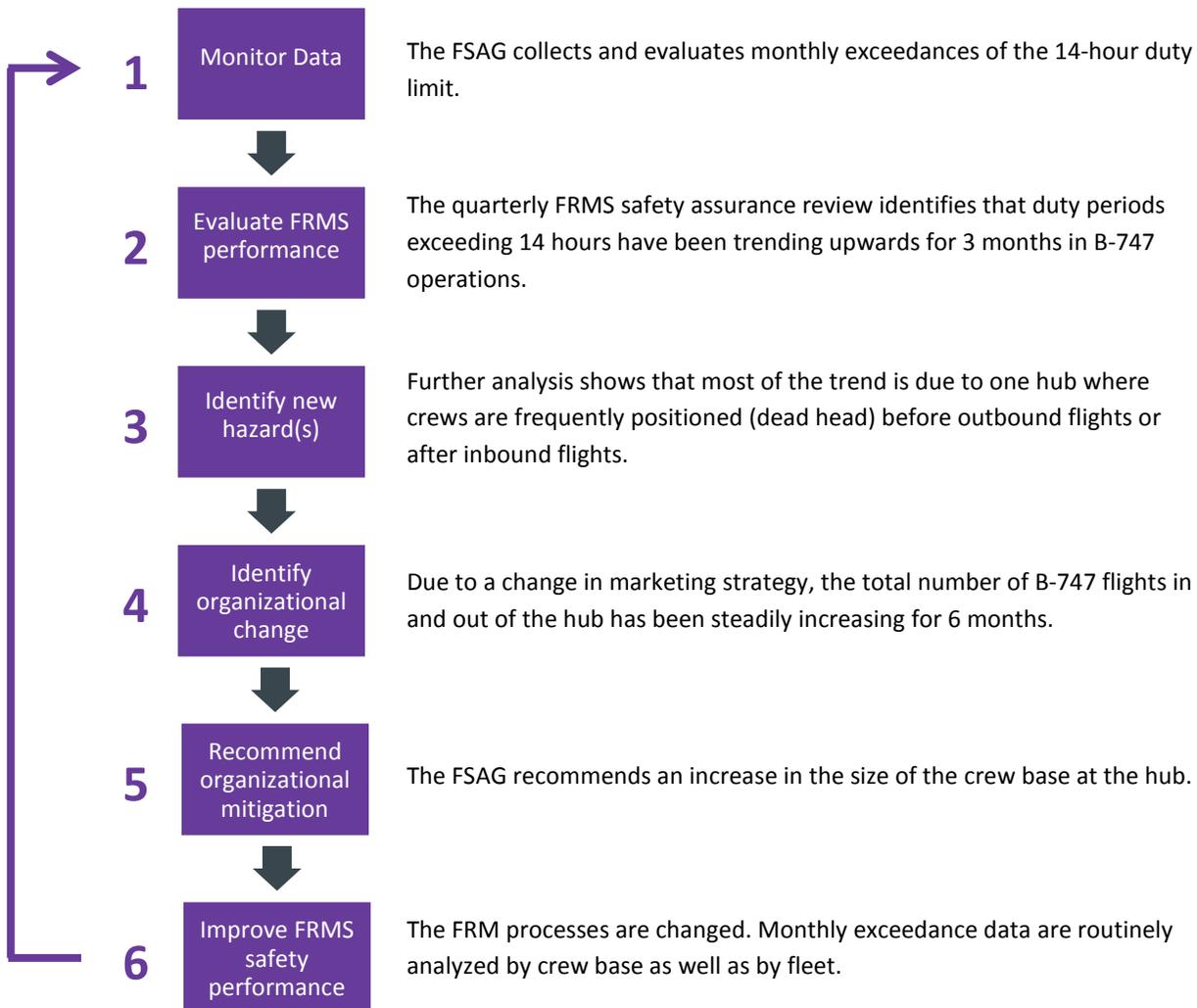


Figure F-1. Example of FRMS safety assurance processes (long-haul, maximum duty period exceedances)

F2. EXAMPLE 2

A short-haul example is described in Figure F-2. Here, the use of captain's discretion is tracked as an FRMS SPI. (Most State regulations allow for maximum flight duty periods to be increased on the day of operation at the discretion of the pilot in command).

In this example, in the FRM processes, the FSAG has conducted a risk assessment and decided to set the following thresholds for short-haul flights:

- intolerable region - discretion used on at least 25 % of flights;
- tolerable region - discretion used on 10-25 % of flights;
- acceptable region - discretion used on less than 10% of flights.

In addition, delays of more than 2 hours must be logged and presented to the FSAG. Data on use of discretion are collected in a 'Discretion 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 crew member availability at a particular crew base. Data are also analyzed by crew member rank, category, and qualifications to see, for example, if trips with more frequent use of discretion are avoided by more senior crew members.

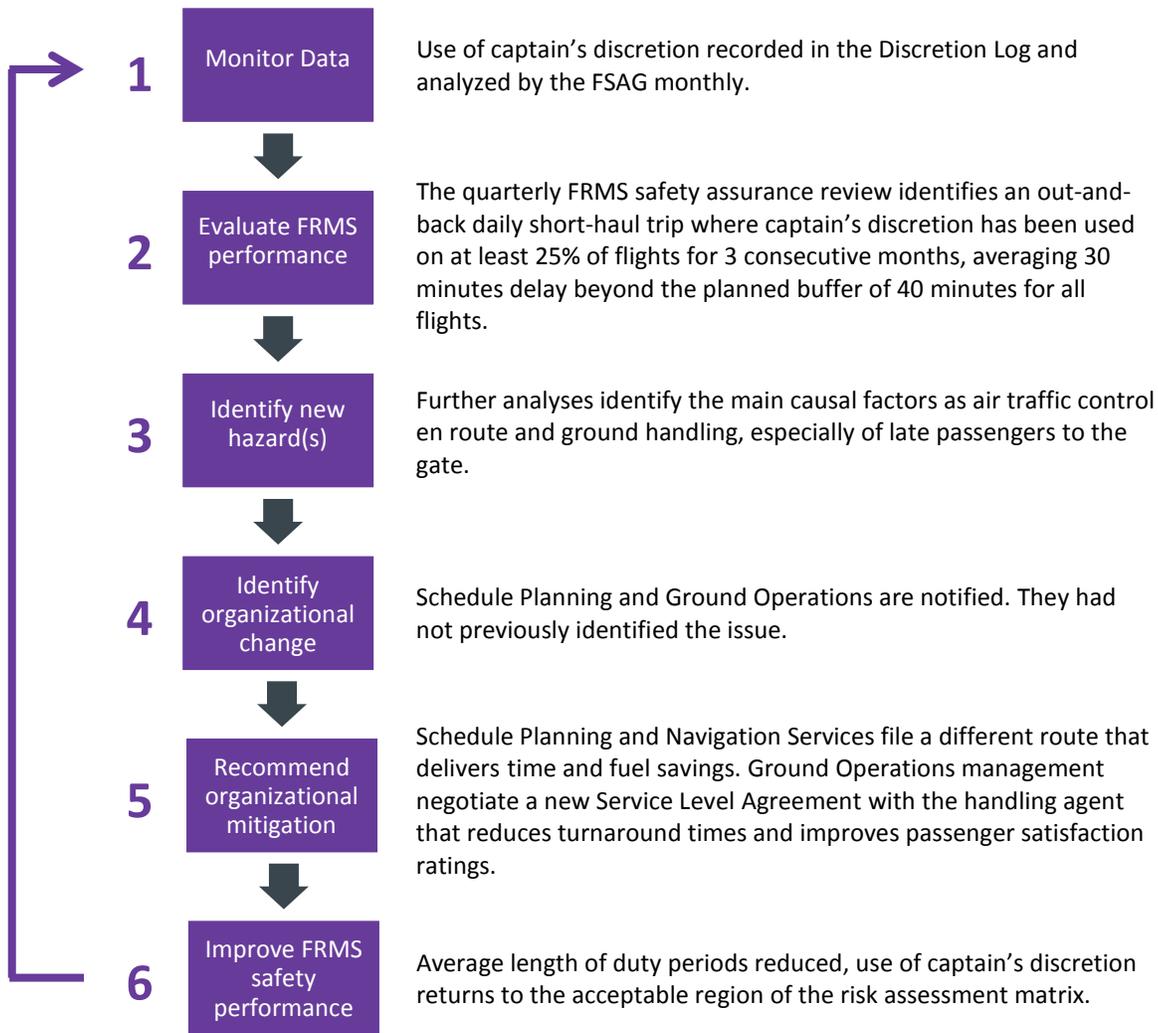


Figure F-2. Example of FRMS safety assurance processes (short-haul, overuse of captain’s discretion)

F3. EXAMPLE 3

This example (Figure F-3) looks at a situation where, at a particular crew base on one day, there are multiple exceedances of the maximum flight time and duty limits specified in the FRMS. Each exceedance requires submission of a report to the FSAG, 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.

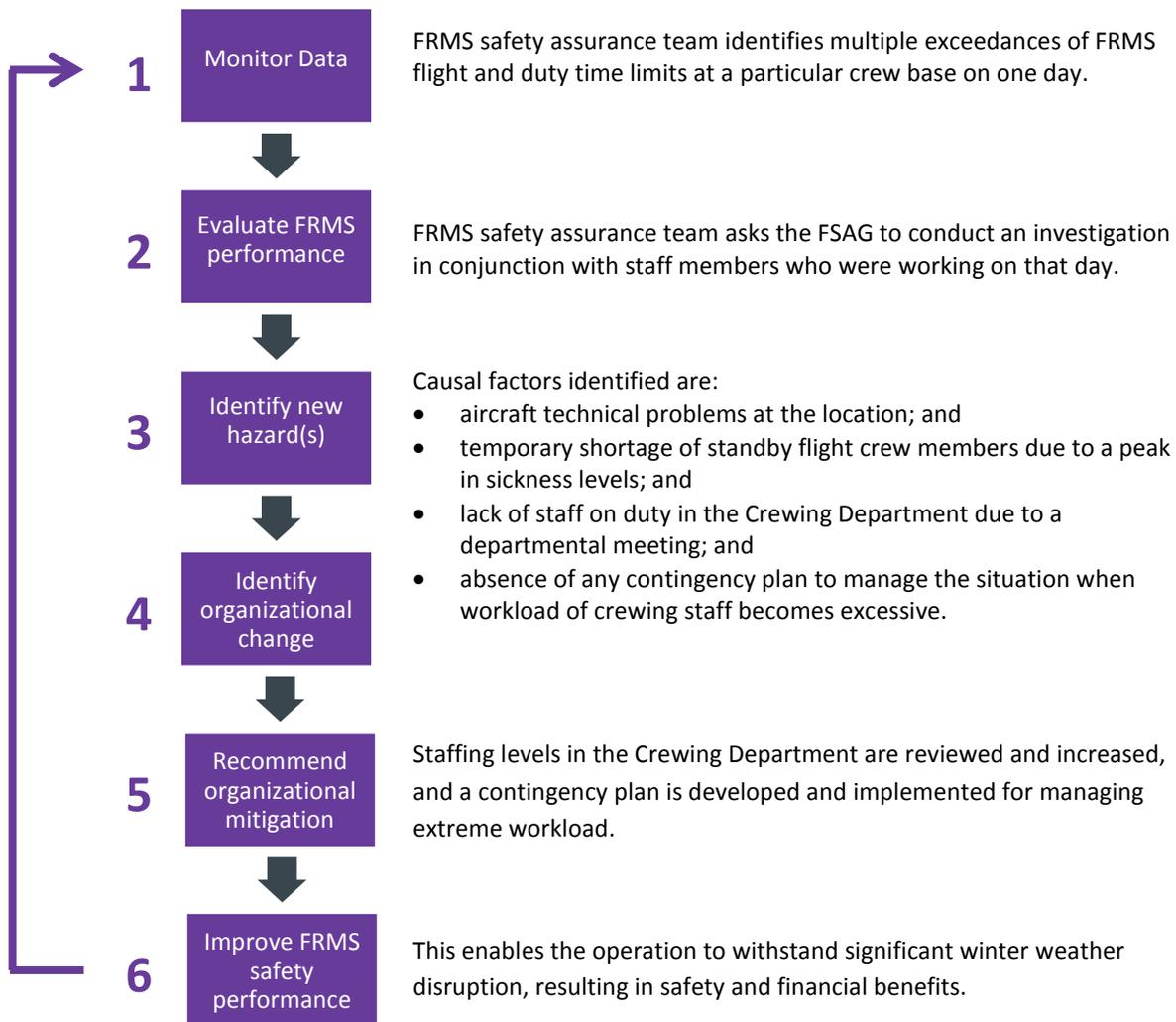


Figure F-3. Example of FRMS safety assurance processes (multiple flight and duty time exceedances at a particular crew base on one day)

Note: Exceedances of the agreed flight and duty time limits should be rare events but it is unrealistic to expect that they will never happen. In a large organization, it may be useful to specify categories of exceedances which generate differing levels of follow-up action. (All exceedances need to be documented for regulatory audit). For example, the following two categories might be defined:

1. Level 1 exceedances are preventable and have potentially serious consequences. They require a full investigation directed by the team (or person) responsible for FRMS safety assurance processes, and the preparation of a summary report of the investigation's findings. This report must be completed within a specified time frame and added to the FRMS documentation.
2. Level 2 exceedances could not reasonably have been foreseen or corrected. They do not represent a systemic problem or have potentially serious consequences. A report needs to be submitted to the Fatigue Safety Action Group and added to the FRMS documentation, but a full investigation is not required.

Monthly analyses of exceedances of the flight and duty time limits specified in the FRMS could consider:

- the total number of Level 1 and Level 2 exceedances;
- the areas of the organization involved in exceedances;
- causes and extenuating circumstances; and
- patterns of overdue submission of reports on exceedances.

The FSAG is responsible for developing and implementing any recommended mitigations, in consultation with the FRMS safety assurance team.

F4. EXAMPLE 4

Figure F-4 describes an example that uses another type of FRMS safety performance indicator - a code incorporated in the rostering software that indicates when a crew member is approaching the monthly flight hour limit. If the code is set to trigger below the flight hour limit defined in the FRMS policy, then this provides a buffer that enables some flexibility and reduces the risk of exceedances.

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, crew member 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 crew member rank.

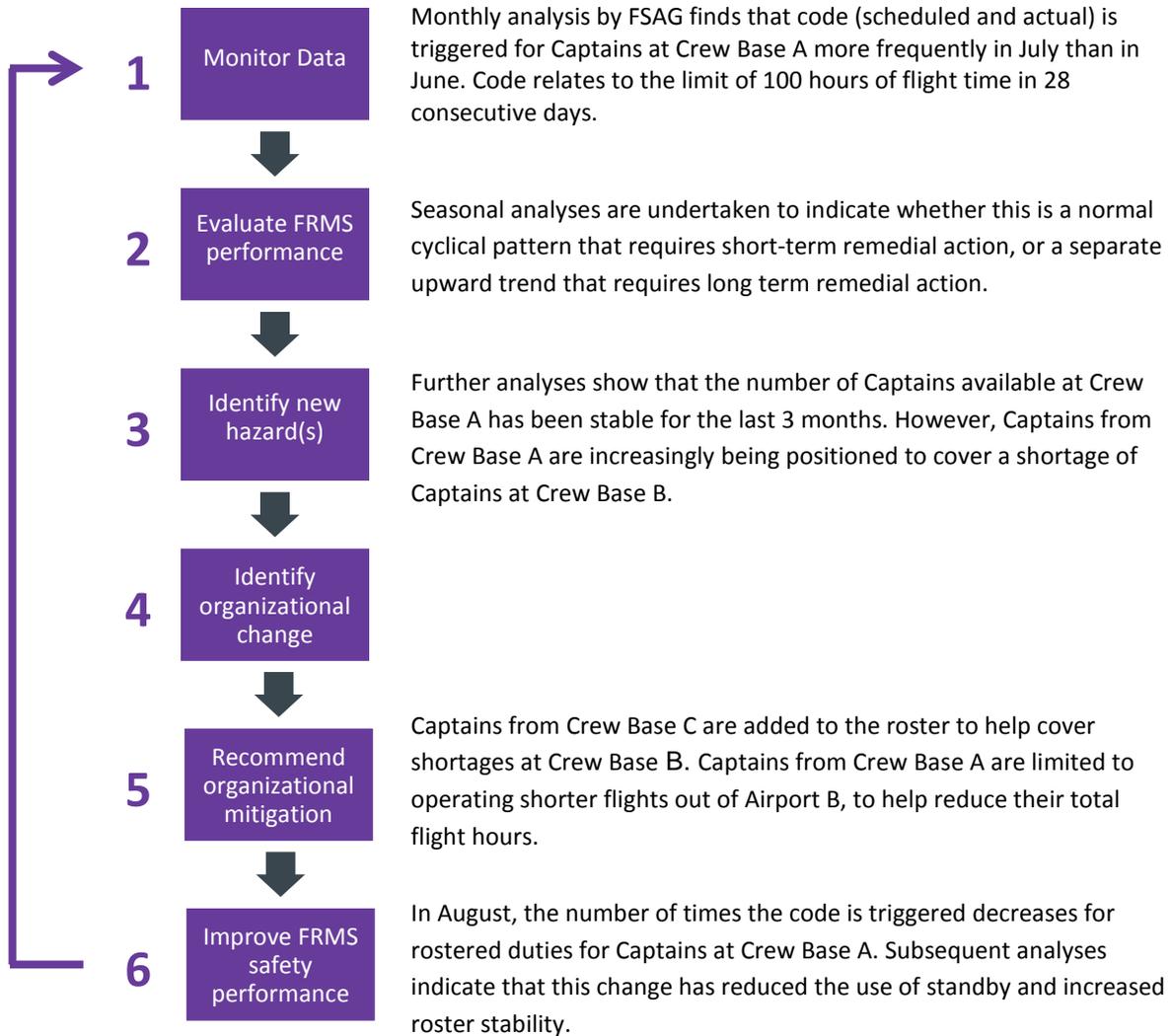


Figure F-4. Example of FRMS safety assurance processes (code in the rostering software that indicates when a crew member is approaching the maximum monthly flight hour limit)

APPENDIX G. EXAMPLES OF CREW MEMBER SAFETY PERFORMANCE INDICATORS

In this example, two safety performance indicators (SPIs) are compared for flights between 10 city pairs (2 long range and 3 ultra-long range trips with 2-day layovers)⁶³:

- total sleep in the 24 hours prior to duty start (an SPI relating to the fatigue status of flight crew members at duty start): and
- total sleep time in the 24 hours prior to time of descent (TOD) (an SPI relating to fatigue status at TOD).

All flights had 4-person crews and the data are from 133 landing crew members monitored on a total of 220 flights. Figure G-1 presents these SPIs in the form of box plots.

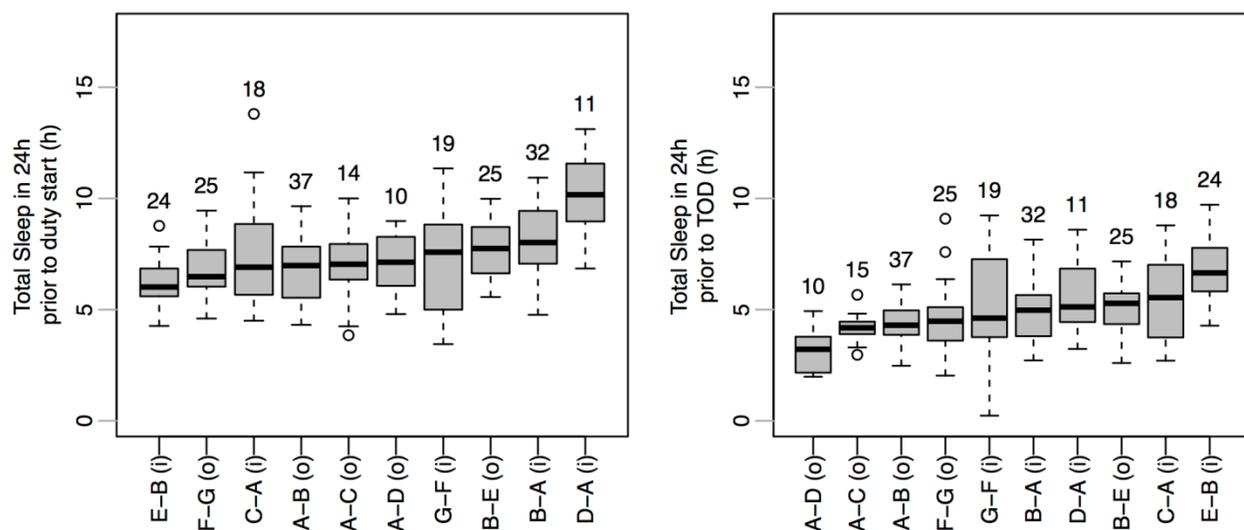


Figure G-1: Comparing total sleep in the 24 hours prior to duty start (left panel), and in the 24 hours prior to TOD (right panel), on 10 long range and ultra-long range flights

Each shaded box on the plot depicts data from one flight, identified by the city pair shown below the box. The number above the box is the number of crew members who provided data for that flight.

- Black horizontal bars show the median total sleep time for each flight.
- Grey boxes contain the values for the middle 50% of crew members on that flight. A taller box indicates more variability among crew members on that flight.
- The variability among crew members on a given flight is also depicted.
 - The taller the grey box for a flight, the greater the variability among crew members in their total sleep time on that flight.

⁶³ Gander PH, Mangie JM, van den Berg MJ, Smith AAT, Mulrine HM, Signal TL. Crew fatigue safety performance indicators for fatigue risk management systems. *Aviation, Space and Environmental Medicine* 85: 139-147, 2014.

- The vertical line above the box indicates the highest value that is above the box by an amount that is no more than 1.5 times the height of the box. Values above that (circles) are classed as outliers. Thus the longer the vertical line above the box, the greater the variability among crew members in their total sleep time.
- Similarly, the vertical line below the box indicates the lowest value that is below the box by an amount that is no more than 1.5 times the height of the box. Values below that (circles) are classed as outliers. Thus the longer the vertical line below the box, the greater the variability among crew members in their total sleep time.

Flights B-A, B-E, and G-F have scheduled flight times longer than 16 hours. Notice that E-B is the flight on which crew members have the least sleep in the 24 hours prior to duty start (left panel), but the most sleep in the 24 hours prior to TOD (right panel), which includes in-flight sleep.

The box plots in Figure G-1 do not represent statistical analyses, but they do enable some quantitative comparisons to be made. For example in the left-hand panel, 75% of the crew members on E-B flights (those whose values were below the top of the box for E-B) had less sleep in the 24 h prior to duty start than all the crew members on D-A flights (all D-A values lie above the top of the box for E-B).

The data in Figure G-1 can also be compared statistically between flights using simple statistical tests. Some operators will have staff capable of conducting these tests in-house. For example, in the 24 hours prior to duty start, crew members on E-B obtain significantly less sleep than crew members on all flights except F-G and G-F. The difference between E-B and G-F is not statistically significant because of the high variability among crew members on the G-F flight (it has the tallest grey box in the left panel of Figure G-1).

These types of SPIs are intended to be used comparatively in an FRMS. For example, they can be used to compare data from new flights or flights where fatigue reports suggest there is a hazard, with well-established flights where fatigue is not considered to be a hazard. Values from well-established flights with low fatigue risk could be set as acceptable values or targets in the FRMS.

One strength of the data in Figure G-1 is that it combines information from flights by three different operators. A combined database of SPI values shared among participating operators would be a valuable industry resource to provide information for making FRMS decisions.