

5.3.3. FATIGUE RISK ASSESSMENT

Once a fatigue hazard has been identified, the level of risk that it poses has to be assessed and a decision made about whether or not that risk needs to be mitigated. 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.

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.

Where a service provider 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.

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 5-1 presents an example of severity classification categories from ICAO’s Safety Management Manual (Doc 9859, 2013, 3rd Edition). Table 5-2 presents an associated risk assessment matrix.

Table 5-1. 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 5-2. 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, Service Providers are expected to customize the severity and likelihood categories. The value of using the severity classifications from Table 5-1 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 itself 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 customize 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.

IMPLICATIONS FOR THE STATE:

Risk-assessment methodology will vary between service providers. Regulators should ensure that the method employed by each service provider for their FRMS is consistent with the service provider's methodology used in its SMS, but adapted for fatigue risk assessment.

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 classifications may reflect "perceived fatigue levels" on the basis that the more fatigued an individual feels, the more likely their performance will decline. In Table 5-3, 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 organization, 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 5-3. Example of 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., less than 7h between duties; commencement of duties prior to 07:00), 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, a service provider 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 described³⁵ 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.

³⁵ Tritschler, K. (2015), “Fatigue risk assessment methodologies”. Paper presented at the EASA FRMS Workshop, Cologne.

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 is critical to the successful use of this methodology. By using customized 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.

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 categorization of fatigue risk according to the number of times a trip with a particular score is scheduled.

Figure 5-2 and matrices below (Tables 5-5 to 5-7) present an example of the use of this methodology.

Figure 5-2. Example of Fatigue Factor Assessment and Mitigation Table

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.				

Table 5-4. Example of 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 5-5. Example of 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 5-6. Example of Risk Assessment Matrix for Cumulative Fatigue

Relevant fatigue factors	Frequency of Exposure per Crew Member per Working Period (week)			
	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 5-2 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 5-4 categorizes 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 5-2 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 5-5 categorizes 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 5-6 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 categorization 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.

5.3.4. MITIGATION

The risk-assessment process determines whether or not a fatigue hazard requires mitigation. The most important thing to consider in choosing fatigue mitigations is the estimated level of associated fatigue risk. All mitigations require resources (effort, time, costs). Limited resources need to be prioritized where mitigations are most needed to effectively control fatigue risk.

Careful selection of effective fatigue mitigations is based on data, rather than an uninformed urge to “do something”. Identifying suitable mitigations comes from sources such as scientific studies, relevant scientific literature and FRMS experience of the service provider or other similar service providers.

Effective controls and mitigation strategies go beyond rest- and duty-times. For duties that are either very long, start very early in morning, finish late at night or go through the night, controls and mitigations need to be considered in the context of successive days and duties. Special attention needs to be given to the circadian influences on sleep- and wake-times regardless of rest- and work- times. Mitigation strategies that focus solely on an isolated duty may not address the effects of cumulative fatigue and become ineffective across a work roster. Therefore, the identification of fatigue mitigations requires a broad understanding of scientific knowledge, operational experience and applicable regulations. While a service

provider's safety management structure will influence who makes the decision about whether or not a fatigue hazard requires mitigation, it is recommended that the FSAG identify the appropriate mitigations and be consulted in all fatigue mitigation decisions.

5.3.5. MONITORING THE EFFECTIVENESS OF MITIGATIONS

Data monitored in the FRM process loop can be used to generate fatigue safety performance indicators (SPIs). SPIs provide a metric to monitor the effectiveness of fatigue controls and mitigations. If trends in SPIs indicate that current mitigations are not adequate and that a fatigue hazard remains, then a detailed risk assessment of the issue should be conducted in line with the service provider's processes and new mitigations proposed where necessary. SPIs are also a critical source of information for the FRMS safety assurance processes (see Section 0 below).

For SPIs to be useful, acceptable values and targets need to be set. These acceptable values and targets need to be appropriate to the level of risk in a given operation, and 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. 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 State during the FRMS approval process (see Section 6.2) and they may change as experience with FRMS builds and as operational circumstances alter.

Common types of fatigue SPIs include:

- operational SPIs that monitor the duty-related causes of fatigue. Examples include: the number of times the maximum scheduled duty day is exceeded; the number of flight duty periods that end in the WOCL; the number of report times earlier than 06:30 on [*] successive days;
- SPIs based on reactive fatigue data. Examples include the number of fatigue reports (e.g., on schedule or pairing), fatigue-related incidents or FOQA events (this methodology is still under development), and measures of absenteeism;
- SPIs based on proactive monitoring of actual levels of individuals' fatigue.

Examples of these SPIs are presented in the relevant Implementation Manuals.

If the mitigations perform to an acceptable standard (i.e. the relevant SPIs reach their pre-defined acceptable values or targets), they become part of normal operations. 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. 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.

5.4. COMPONENT 3: SAFETY ASSURANCE PROCESSES

FRMS safety assurance processes form the second closed loop of the operational activities of the FRMS (see Figure 5-1), monitoring 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:

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.

Within an organization, 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 Service Provider. 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, some Safety Assurance activities, such as internal audits of the FRM processes, should be undertaken by a different organizational unit than that responsible for administering it.

The State should consider the assurance functions of the FRMS as the critical component for ongoing fatigue safety performance assessment and focus on this area as part of ongoing oversight (see Section 6.2.4 below). It is through the assurance processes that the State, working with the Service Provider, may identify specific limits or patterns of work within the FRMS that may need to be changed (increased or decreased) or deleted depending on how the SPIs are performing. The State may also choose to require additional measures or limits to those proposed by the Service Provider should they consider this necessary.

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

IMPLICATIONS FOR THE STATE:

The State's oversight of the FRMS will require the ongoing monitoring of safety assurance outcomes. These outcomes may also be an indicator of the effectiveness of the Service Provider's FSAG and SMS team.

5.4.1. 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 indicators from the FRM processes (see Section 5.3.5) and the Service Provider's SMS;
- hazard reporting and investigations;
- audits and surveys; and
- reviews and fatigue studies.

When FRMS SPIs are not at an acceptable level, the controls and mitigations in use may need to be modified via the FRM processes (see Figure 5-1). A review of relevant fatigue studies might provide new ideas. Investigation of how hazard reports are followed up or examination of trends in fatigue-related hazards or incidents may be required. Audit findings may need to be reviewed, checks may need to be made to determine whether FSAG recommendations are followed, whether fatigue-related training is being delivered as expected, or whether the FSAG is functioning according to its terms of reference, 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.

The Service Provider must be able to identify and justify their choice of SPIs that it is using and the State must be able to make an assessment of the robustness of the measures proposed.

The use of different SPIs from varying sources to assess FRMS performance is discussed further below.

IMPLICATIONS FOR THE STATE:

FRMS SPIs should be discussed and agreed on between the service provider and the CASI.

These may need to be reviewed at intervals.

TRENDS IN SAFETY PERFORMANCE INDICATORS FROM THE FRM PROCESSES AND THE SMS

SPIs to measure the overall safety performance of FRMS will include some indicators identified by the Fatigue Safety Action Group as part of the FRM processes to monitor the efficacy of controls and mitigations (see Section 5.3.5 above). The nature of these will differ for different industry sectors. They may also include indicators that capture wider aspects of the safety performance of the FRMS, for example safety performance metrics within the operator's SMS. Examples include:

- number of fatigue reports in relation to other voluntary hazard reports;
- frequencies of fatigue reports associated with a specific duty or pattern of duty;
- frequency of exceeding service provider-identified buffers;
- frequency of exceedance of the agreed outer boundaries of the approved FRMS.

Specific examples of safety performance indicators are presented in the associated Service Providers' implementation manuals.

As previously mentioned (see 5.3.5), acceptable values or targets need to be set for SPIs, and these must always be within the tolerable region defined in the service provider's risk assessment process. For example, a service provider could set an FRMS safety performance target of no more than 10 duty day exceedances per month. Trends in the Service Provider's ability to maintain acceptable values or achieve targets over time can then be used to assess FRMS performance. Trends may be identified: over individual duties; patterns of work; shorter periods of time (e.g. weekly trends); longer periods of time (e.g. seasonal trends, yearly trends); and in relation to specific locations, types of operations or groups of workers.

As the FRMS matures, and as part of the continuous review requirements, more sophisticated performance indicators and targets may need to be identified to better monitor the performance of the FRMS.

When the performance of any of the FRMS SPIs are not at an acceptable level, the controls and mitigations in use may need to be modified via the FRM processes (see Section 5.3). Alternatively, a review of relevant fatigue studies might provide new ideas. Additionally, a review may be needed to examine compliance with the recommendations of the FSAG, or of the functioning of FSAG itself, 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.