Fatigue Risk Assessment Methodologies

EASA FRMS Workshop Cologne 2015
Cpt. Kristjof Tritschler
MSc Air Safety Management

Synopsis

At the EASA FRMS Workshop 2015 different methodologies were presented to provide an overview of how these may be applied to assess fatigue risk. The Fatigue Factor Assessment and Mitigation Table[1] was proposed as a fatigue-specific risk assessment methodology for a particular duty or work pattern. This methodology is based on internal scientific studies, relevant scientific literature, internal surveys and FRMS experience. The methodology starts by identifying the root causes of fatigue and provides effective mitigation measures. Mitigations include the previous night's sleep, circadian and workload factors.

Background

The aim of this paper is to complement present FRMS and SMS guidance material for the specific assessment of fatigue risk, as well as to inspire new methodologies with growing FRMS experience of the industry.

Fatigue risk assessment is one process of the Safety Management System (SMS) or Fatigue Risk Management System (FRMS) and needs to be seen in the context of the management system. Therefore this first section provides an overview of how fatigue may be managed in a system approach through hazard identification, risk assessment and risk mitigation.

Fatigue Management, SMS and FRMS

Human fatigue has been a well-known issue for many years, spanning decades even and is particularly associated with shift work. However, it has been managed to various degrees within organisations through prescriptive duty and rest time regulations and labour agreements.

Today fatigue is an accepted human factors hazard because it affects most aspects of a crewmember's ability to do their job[2]. The evolution to manage this hazard in a modern system approach is to add the "R" (risk management). Risk management is a key component of the safety management process of any SMS or FRMS.

Hazard Identification

The starting point of risk management is the identification of a hazard. Since human fatigue is already an identified human factor hazard particularly with any kind of shift work, the author proposes to identify the "causes of fatigue" of a particular duty or work pattern rather than to identify a certain duty as a fatigue hazard. In general, fatigue is not considered to occur as a random event. It conforms to expectable patterns and may be analysed and predicted in order to be properly managed.

Hazard identification may be reactive, proactive or predictive[3] [4]. This may be applied to the identification of "causes of fatigue". The methodology proposed in this paper may be used in all three categories.

- Reactive, to identify the causes of fatigue after an event
- Proactive, to identify the causes of fatigue and mitigation in current operations
- Predictive, to identify the causes of fatigue and mitigation of fatigue risk in future rotations/duties

[1] Tritschler 2015; Risk Assessment and Mitigation Methodology; FRMS Forum Luxemburg
[2] ICAO IATA IFALPA FRMS Implementation Guides 2011; Chapter 1
[3] ICAO Doc 9859 SMM 2013; Chapter 2.13.11
[4] ICAO IATA IFALPA FRMS Implementation Guides 2011; Chapter 4

Fatigue Risk Assessment

Safety/Fatigue risk management encompasses the assessment and mitigation of safety/fatigue risks. The objective of “fatigue” risk management is to assess the risk associated with fatigue as a “single hazard” to develop and implement effective and appropriate mitigations.

Different risk assessment methodologies are outlined in this paper to assist in selecting the suitable methodology for the intended purpose. All approaches have the similar purpose. The risk assessment process determines whether or not a fatigue hazard requires mitigation.

Regardless of the risk assessment methodology applied, the operational risk responsibility always rests with the operator. Therefore all of the methodologies shall be customised accordingly.

Fatigue Risk Mitigations

A selection of mitigations should be based on fatigue risk assessment results and the effectiveness of controls.

Traditionally and particularly in Europe, Flight Time Limitation Regulations (FTLs) were considered the only solution to control flight crew fatigue. Additional prescriptive and more restricting rules have been addressed primarily as a labour relation rather than safety management issue. However, this approach largely ignored individual responsibilities as well as other effective control measures [5].

This traditional strategy of flight time limitation is considered to be inefficient to manage fatigue risk effectively since fatigue is not solely the result of flight or duty time duration. It is the result of sleep obtained, time spent awake, circadian phase and workload over consecutive days. It is therefore recommended to focus on these causes of fatigue, in order to develop more effective control measures at the roots of fatigue while taking into account cumulative fatigue over several days.

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.

Evaluation of the effectiveness of controls prior implementation and monitoring the effectiveness of controls after implementation are additional and important processes for the successful management of fatigue risk. However these are not covered in this paper.

General Limitations of Fatigue Risk Assessments

The general difficulty with fatigue is that it primarily results out of individual sleep obtained and time spent awake. However these two most important variables are virtually unknown to the people doing the fatigue risk assessment or to the bio mathematical model estimating fatigue/alertness. For example: If an individual person did not sleep at night, even a dayshift might actually be of high fatigue risk, where the fatigue risk assessment process or a model shows a low fatigue risk. If an individual person has planned and obtained good sleep before a night shift, the actual fatigue risk is rather low, whereas the fatigue risk assessment process indicates an increased fatigue risk or a model calculates high fatigue values. Sleep cannot be replaced by any methodology. This should always be kept in mind.

Fatigue leads to a reduced performance capability by definition. But a general difficulty to assess fatigue risk is that it is underreported, hard to detect, difficult to measure or not identified at all.

[5] Dawson, McCulloch, 2006: “Managing Fatigue: Defences in Depth” 59th IASS, Paris October 2006

Fatigue is the second reason for severe car accidents in most countries. In contrast, after review of many airline accident reports, the author assumes that fatigue alone does not cause aircraft accidents in multi crew aircrafts without an additional threat. Some threats may be part of the flight, e.g. a difficult approach. Nevertheless many other threats are always present in aviation and are not predictable.

Traditional Assessment of Duties

The most popular attempt to assess fatigue risk associated with a particular duty is the length of the duty. If duty time is higher, it is assumed to be associated with a higher fatigue risk. But if the duration of duty would be the scale of risk, the sole strategy to lower this risk is to reduce the duty time duration. However the length of duty time is not necessarily the cause of fatigue or a scale for fatigue risk. Consequently, a reduction of duty time is very popular as a strategy to reduce fatigue risk but this strategy may be inefficient and ineffective to reduce actual fatigue risk.

Shortcoming of this approach:

- Duty time duration is an insufficient scale of fatigue impairment or risk
- Actual causes of fatigue (and mitigations) are not taken into account
- Measuring duty time duration is no risk assessment methodology

Risk assessment Methodologies

Performing risk assessments is considered to be a task of subject matter experts.

The accepted approach to assess risk is the relationship of severity x likelihood in a risk matrix. For the assessment of fatigue risk different types of severity seem appropriate to be applicable. Severity and likelihood scales should ideally be customised by the operator.

Severity Classification: Based on the Task

The severity classification related to the task is typically associated to the worst foreseeable consequences. The outcome depends on the task. If a person falls asleep in the office there are no immediate safety consequences. If an air traffic controller however, misses important traffic information during a micro sleep episode, this may lead to a mid-air collision. If a mechanic oversees a critical task in the maintenance procedure when impaired by fatigue during the WOCL it may cause an accident. If cabin attendants omit lavatory checks due to fatigue, a fire on board may be the result. If pilots are faced with a threat while in a fatigued state, problem solving skills may be impaired which can lead to an accident. Due to the nature of different tasks and associated risks, different measures apply for different professions. However in the context of operating an aircraft a “reduction of safety margins” is evident, where the worst foreseeable consequence of human fatigue is always “catastrophic”. Especially when other safety controls fail or are not taken into account. Refer to Table 1.

Shortcomings of this classification:

- The worst foreseeable consequence of human fatigue in aviation is always “catastrophic”
- Considered to be applicable only after an event/study
- Mitigations are not methodologically taken into account
- Considered impracticable for the assessment of a particular duty or work pattern
- Results vary due to subjectivity of different users

Severity Classification: Based on the Level of Fatigue Impairment

The severity classification may be related to the level of "impairment to fulfil the task", in this context due to fatigue. The "significant" and "large reduction in safety margins" or performance capability to fulfil the task/threat is directly linked to the severity classification of the risk matrix proposed by ICAO SMM. Refer to Table 1

Shortcomings of this classification:

- The impairment due to fatigue is either in the category "hazardous" or "major"
- Considered to be applicable only after an event
- Mitigations are not methodologically taken into account
- Considered impracticable for the assessment of a particular duty or work pattern
- Results vary due to subjectivity of different users

Severity Classification: Based on the Level of Fatigue Perception

In the context of assessing fatigue risk, it is appropriate to consider the level of fatigue perception to define fatigue severity. One scale to measure subjective fatigue is e.g. the Samn-Perelli Crew Status Check. This scale can be used to assess the fatigue risk of e.g. fatigue reports or survey. Table 2 presents defined categories of fatigue (SP).

Shortcomings of this classification:

- The subjective sleepiness value is often not reported or known
- Considered to be applicable only after an event/study
- Mitigations are not methodologically taken into account

Severity Classification: Based on the Causes of Fatigue

The author of this paper considers this an alternative for the specific severity classification of fatigue. This is based on the assumption that an increasing number of fatigue causes identified through scientific research (reduced night sleep, long periods of time spent awake, work at night and high workload) and/or operational experience (hassles) increases the impairment. The Fatigue Factor Assessment and Mitigation Table described in this paper is based on this approach. It has been developed for the assessment of a particular duty or work pattern. Refer to page 8.

Shortcomings of this classification:

- The number of causes/factors is not a linear function of fatigue impairment
- Only takes into account fatigue causes/factors, independent of the task
- Needs to be customised to each operation
- Customisation requires a broad understanding of fatigue (scientific and operational competences)

Severity Classification: Based on Bio-Mathematical Results

A bio-mathematical model is one fatigue-specific option to be used when estimating fatigue risk. Such a model may be a valuable assessment which takes the complex interaction of fatigue factors over consecutive days into account. The bio-mathematical approach supports or actually requires a multi-day perspective. However a bio-mathematical model does not provide concluding results for an isolated duty.

Using a bio-mathematical model, severity may be expressed in defined values to distinguish between low, moderate or high impairment due to fatigue.

Shortcomings of this classification:

- Does not work to assess an isolated duty (but consecutive duties which is an advantage)
- No model explains the results to the user, e.g. which relevant fatigue factors cause the given result
- Understanding of the results and limitations of a bio-mathematical model requires a broad understanding of fatigue (scientific knowledge)

Likelihood Classification

The most popular likelihood classification is that which is provided by ICAO SMM. Refer to Table 4. However the ICAO likelihood classification will not fit if a different type of severity classification is selected.

The likelihood scale has to correspond to the type of severity classification.

The likelihood classification needs to be customised by the operator

Alternative Likelihood Classification: Frequency of Exposure

Most often the likelihood is a subjective estimate of the user with regard to what consequences might occur. Where available, the frequency (measurable absolute number) of the exposure to a defined fatigue factor may be an objective substitute for the likelihood dimension. If the data set is large, relatives (%) should be used.

Likelihood Classification Possibly not Required

For the assessment of a single duty the likelihood or frequency is not necessarily required.

Risk Matrix (Severity x Likelihood)

This type of risk assessment methodology is part of SMS[6] and FRMS[7] EASA OPS guidance material[8]. It is used by many operators to assess any type of risk. Even though this is not fatigue specific, it may be used to assess fatigue risk in general or e.g. after an event.

Table 1: ICAO SMM Severity Classification

Safety Risk Severity		
Severity	**Meaning**	**Value**
Catastrophic	- Multiple deaths - Equipment destroyed	A
Hazardous	- A large reduction in safety margins, physical distress or a workload such that crewmembers cannot be relied upon to perform their tasks accurately or completely - Serious injury - Major equipment damage	B
Major	- A significant reduction in safety margins, a reduction in the ability of crewmembers to cope with adverse operating conditions as a result of increase in workload, or as a result of conditions impairing their efficiency - Serious incident - Injury to persons	C
Minor	- Nuisance - Operating limitations - Use of emergency procedures - Minor incident	D
Negligible	- Little consequences	E

Table 2: Severity Classification based on the Level of Fatigue Perception (Samn-Perelli Crew Status Check)

Example: Samn-Perelli Crew Status Check as Fatigue Risk Severity		
SP Status	**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
3-1	- Okay, somewhat fresh (3) - Very lively, responsive, not at peak (2) - Fully alert, wide awake (1)	E

[6] ICAO Doc 9859 SMM 3rd Edition 2013; Chapter 2.14
[7] ICAO IFALPA FRMS Implementation Guide 2011, Chapter 4.5
[8] AMC2 ORO.FTL.120 (b)(4)

Table 3: ICAO SMM Risk Matrix Severity x Likelihood/Probability

Fatigue Risk									
Risk Probability		**Risk Severity**							
		Catastrophic A		Hazardous B		Major C		Minor D	Negligible E
Frequent	5	5A	Accident	5B	Large reduction in safety margins	5C	Significant reduction in safety margins	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

ARMS Methodology

Two alternative methodologies for the assessment of risk have been developed by the Airline Risk Management Solution Working Group (ARMS). Both consider mitigations and controls as key elements. Further information and the original documents of the working group can be found at Skybrary[9].

The ARMS Event Risk Classification (ERC) is a risk assessment methodology for events that have already happened. ERC is not fatigue specific but may be used by those organisations that use the ERC in their SMS.

The safety issue risk assessment (SIRA) of the ARMS approach focuses on present and future risk. SIRA may be customised and related to fatigue risk. It may be used for a safety case. In the conceptual framework SIRA, risk controls (barriers) are taken into account where risk is calculated as the product of four factors (prevention, avoidance, recovery and minimisation of losses). The output from SIRA is a risk value for each safety issue/safety case.

SIRA evaluates four dimensions.

1. *The frequency of the triggering event(s).* FRMS example: All shifts starting or ending outside normal wake-times (before 0800LT and after 2200LT). The number of these shifts is the frequency of the triggering event.
2. *The effectiveness of avoidance barriers.* In the context of fatigue risk management, these are strategies that reduce the likelihood of fatigue-related impairment (for example applicable duty time regulations, labour agreements, specific rostering rules).
3. *The effectiveness of recovery barriers, if the avoidance barriers have failed.* In an FRMS, these are strategies that temporarily mitigate the effects of fatigue during duty (for example, trained in-flight strategies as published by NASA[10]).
4. *The severity of the potential accident outcome.*

In summery the ARMS methodologies are useful to reduce subjectivity, since the controls are systematically taken into account for the assessment of risk.

Shortcomings of SIRA:

- Needs to be customised to fatigue
- Customisation requires a broad understanding of fatigue (scientific and operational competences)
- Application of ERC and SIRA requires a subject matter expert

[9] www.skybrary.aero

[10] Managing Fatigue in Operational Settings 1; Physiological Considerations and Countermeasures; 1996

Fatigue Assessment and Mitigation Table

This new method has been developed to assess fatigue risk associated with a particular duty or work pattern due to the lack of fatigue-specific risk assessment methodologies and the shortcomings of established risk assessment methodologies.

Fatigue is a human factor topic since it impairs human performance capabilities. ICAO SMM[11] proposes a more specific analysis process for the assessment and mitigation of human factors (HF). A HF fatigue analysis should provide an understanding of the impact of human performance capabilities on the situation and should contribute to the development of comprehensive and effective mitigations. This supports the concept to develop the Fatigue Assessment and Mitigation Table.

Crewmember fatigue has been defined by the ICAO FRMS Task Force as: *A physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety related duties*.[12] This definition provides the causes of fatigue. Scientists have researched to what degree these factors contribute to the impact of human performance capabilities.

The Fatigue Factor Assessment and Mitigation Table is a specific analysis process for the assessment and mitigation of fatigue risk is based on the four causes of fatigue according to the ICAO definition. Each factor listed is referenced to at least one scientific statement to take the impact of human performance capabilities into account. Each selected factor is directly related to the type of operation.

The root cause analysis is included in the Fatigue Factor Assessment and Mitigation Table since the most relevant causes of human fatigue of this type of operations are listed to be identified. Comprehensive and effective mitigation possibilities are readily identified and easily understood when going through the list.

Conception and Science behind the Fatigue Factor Assessment and Mitigation Table

The Fatigue Factor Assessment and Mitigation Table provided in this paper is a customised methodology for the identification of fatigue causes and mitigations for particular duties or work patterns. It is based on scientific studies, relevant scientific literature, internal surveys operational experience (hassles) and FRMS experience of the author. It is tailored to the nature and complexity of this Low Cost Carrier (LCC), operating short-haul flights in the European region (EUR).

Before using this type of methodology for a different organisation, customisation is required since different operators are faced with different types of fatigue factors to various degrees. For the customisation each factor listed needs to be relevant for the type of operation and needs to be linked to a scientific study.

The applicability of scientific studies for this operator has been assessed according to a selection process for scientific literature. Studies of the highest relevance are internal studies, followed by the equivalent type of operations (LCC), similar type of operations (short-haul), similar culture/social life (Germany, Europe, western world) and basic sleep research or general scientific recommendations.

The Fatigue Assessment and Mitigation Table only takes these factors into account that have been identified to cause "additional fatigue impairment" according to scientific findings. As such a typical dayshift of eight hours duration with two sectors has the result of zero. This does not imply this duty is easy but it means that no additional fatigue factors were identified or require mitigation for this duty.

The Fatigue Factor Assessment and Mitigation Table is categorised according to the four causes of fatigue: Sleep debt, wakefulness, circadian factors and workload, consistent to the ICAO definition of fatigue. A review of the original scientific reports behind each line is recommended for the user. This is required in order to fully understand the influence of each factor as well as the complex interaction of all these fatigue factors together. The following overview of scientific literature is not exhaustive.

[11] ICAO Doc 9859 SMM 3rd Edition 2013; Chapter 2.15.6

[12] ICAO IATA IFALPA FRMS Implementation Guides 2011; Chapter 1.1

Sleep Debt

Sleep debt	Previous night sleep reduced < 4h (night: 22-08LT)	After review of basic sleep research the time of night between 2200 and 0800 LT is considered the best time for good and sufficient sleep. Own research showed acceptable performance after 6h of sleep Vejvoda [1]. However this operation is within 12h duty time and remains within the rule of thumb by Dawson [8] where 1h of sleep enables 2h of wakefulness.
	Previous night sleep reduced > 4h	Less than 4 hours of night sleep shows impairment according to Dawson's analysis [8] which corresponds to many sleep deprivation studies. Basic sleep science was complemented e.g. by Spencer [7] where sleep quality is impaired outside night hours.
	Reduced night sleep > 4h before previous night ***	At least 2 consecutive nights are relevant according to the findings of Dawson 2006 [8].
	Previous "night duty" (day sleep only)	Sleep during the daytime is less restorative than at night. Basic sleep science is complemented by Spencer [9] where sleep during the day is shorter.

Wakefulness (Time since awake prior duty plus time on task)

Wakefulness: (Time since awake plus time on task)	Time since awake > 2h prior C/I*	Time since awake is considered one of the two most relevant fatigue factors. Up to 2h are considered normal before start of duty and is therefore no additional fatigue factor. However 2 or more hours of wakefulness may become relevant for a later duty. Up to 6 hours of wakefulness before a flight duty starts combined with up to 10 h of duty time still remains below 16 h of wakefulness. Own research showed acceptable performance up to 16h wakefulness Vejvoda 2014 [1], DLR GWI Study 2009 [2].
	Time since awake > 6h prior C/I*	Time since awake of more than 6 h prior duty followed by a duty time of 10 hours would lead to more than 16 h wakefulness at duty end where fatigue impairment is higher than recommended. Own research [1] has identified time awake as a primary factor for fatigue and complements findings of Powell [13] where high fatigue has been observed for duties ending late in the evening.
	Time on task > 10h (FDT)	According to DLR [4] and NASA [3] up to 10h FDT are recommended even at night. Spencer 1999 [6] supports the recommendation that unaugmented flight duty periods should not exceed 10 hours overnight. More than 10h FDT should be limited to 4 duties above 10h per week (NASA short haul) Dinges 1996 [3] Samel 1997 [4]. Additional workload factors or high task demands like a special airport should be avoided when duty time exceeds 10h. Up to 4 sectors per duty within 12h duty time have shown acceptable results in own research [2].
	Time on task > 12h < 14h (FDT)	According to NASA & DLR more than 12h of FDT are not recommended Dinges 1996 [3] Samel 1997 [4]. Goode 2003 [5] illustrated an unproportional rise of accidents after 13h of duty time. However if there is no sleep debt and time awake is low, there is a small time frame between 0800 and 0900 LT where a duty up to 14h seems to be acceptable.

Circadian Factors

Circadian Factors	Circadian disruption > 4h	Shift-lag effect leads to circadian disruption and manifests as a decrement in performance as observed by Stewart 2003 [10][11] This shift-lag effect has been observed on day one in many studies where the first day is of higher fatigue risk than following days.
	Flight after 2300LT and/or last landing during darkness	Own research has shown a measurable circadian effect after 2300LT. Vejvoda 2014 [1]. Powell 2007/08 [12] [13] observed that Samn-Perelli value 5 is reached after 8h duty time when the top of descent is around midnight.
	Flighttime < 2h during WOCL (0300-0600LT)	This column is limited to "flighttime" since the task demands before and after a flight are considered to be low, but night sleep is reduced and marked there. Flying into the WOCL or through the WOCL superimposes the symptoms of fatigue 1997 [4]. All scientists agree that there is a performance impairment during WOCL. Basic sleep science [14]; Spencer [6] [15] [16]
	Flighttime > 2h during WOCL (0300-0600LT)	Strong performance impairment should be expected when operating through the WOCL. Gundel [17] provided simulations that show that the reduction of FDP that encroach the WOCL does not lead to the low fatigue levels of daytime flights. Therefore, the results seem to be based on an unspoken agreement that night flights are less safe than daytime flights. Spencer [16] found that the time of day pointing to the highest levels of fatigue tend to occur in the early morning

Workload Factors

Workload	3 or 4 consecutive flights/sectors	Scientists Gander 1994 [18]; Spencer 2005 [16]; Powell 2007 [12]; Bourgeois-Bourgine [20][21] agree that the number of sectors are of important influence. Own study [2] showed an increased influence after more than 2 sectors and acceptable levels of alertness up to 4 sectors.
	5 or 6 flights / or: 3 flights during night	More than 5 sectors per duty show stronger impairment according to Niederl 2007 [19]
	Known hassles	Hassle is one aspect of workload. This may be bad weather as well as a demanding airport or an aircraft change. According to research performed by Spencer [16] the strongest influence on levels of fatigue at the end of a flight was the level of hassle associated with this flight. Bourgeois 2003 [20][21]; Stewart 2006 [22]; Tritschler 2010 [23]
	Training flights	For training captains workload may be particularly high when commanding training and assessment duties according to Stewart, 2009 [24]

Purpose of the Fatigue Factor Assessment and Mitigation Table

The table may be used by the FSAG in order to:

- Identify root causes of fatigue for a particular duty or work pattern [Example 1] (Part of hazard identification process)
- Give a particular duty or work pattern a specific and comparable "fatigue value" [Example 1] (Specific fatigue "risk" assessment)
- Identify effective mitigations for a particular duty or work pattern [Example 1] (Part of the risk mitigation process)
- Make the same duty or work pattern comparable at different times of the day [Example 2 and 3]

Application of the Fatigue Assessment and Mitigation Table

In the first column 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 in the "worst case scenario" under existing conditions.

In the second column, each factor present is assessed to determine if it can be avoided as a means of mitigation. The number of remaining fatigue factors is used to determine if the mitigated scenario is acceptable. If it is acceptable, the required mitigations need to be implemented and documented according to the decision-making process of the operator.

The tables below present an example of the use of this methodology. In this example, the methodology has been applied to a specific flight duty from Cologne (CGN) to Tenerife (TFS) and back to CGN.

- Table 4 presents a Fatigue Factor Assessment and Mitigation Table which lists the fatigue factors identified by this operator.
- In the first column these fatigue factors have been scored as present (1), absent (--) or already avoided (0) under existing (documented) conditions in the "Worst Case" column.
- Table 5 categorises the assessment of different numbers of fatigue factors and the subsequent actions. Using the example acceptability categories, 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.
- In the second column, each of the fatigue factors present (in the first column) are then scored as either actively avoidable (0) or not (1) in the "Mitigated" column. A description as to how it is avoided (as a means of mitigation) is noted in the "Comment" column. In the example provided there are 6 remaining fatigue factors.
- Table 6 categorises the acceptability of the mitigated fatigue factor score. The example score of 6 means that it is acceptable but the number of remaining fatigue factors should be kept as low as reasonably practicable (ALARP).
- Table 7 presents an additional risk assessment matrix of the fatigue factors in order to examine the cumulative fatigue-related risk of repeated flying trips over a period of time.

Table 4: Fatigue Factor Assessment and Mitigation Table – Example 1

	Fatigue Factor Assessment and Mitigation Table			
	Type of Shift/Specific Duty:	CGN-TFS-CGN: Checkin 1600LT, Checkout 0300LT; FDT: 11:00h		
	Fatigue Factor:	Worst Case:	Mitigated:	Comment:
Sleep debt	Previous night sleep ** reduced < 4h (night: 22-08LT)	1**	1**	Not relevant if 1st 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 prior duty start > 2h prior C/I*	1	1	
	Time since awake prior duty start > 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	
	Flighttime <2h during WOCL	1	1	
	Flighttime > 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	
	Mark every line: 1 = relevant; 0 =actively avoided; --- =not present; (x) may be relevant			
	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	
	Factors are not fully weighted! Most important factors are sleep debt, wakefulness, circadian factors then workload in this order.			
	Tritschler 2015; EASA FRMS Workshop Cologne			

Table 5: Assessment of Fatigue Factors under Existing Conditions

Assessment of Fatigue Factors under Existing Conditions (Column 1):		
Relevant factors	**Requirement**	**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 is the outlined version of the box at the bottom of the form in Table 4. It should be noted that already with 4 or more relevant fatigue factors a check is required to mitigate the fatigue risk as low as reasonably practicable. For as safety case, each relevant factor needs to be outlined.

Table 6: Assessment of Fatigue Factors after Mitigating Actions

Acceptability of Fatigue Factors after Mitigating Actions (Column2)		
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), number of this duty is limited per crewmember per time-period; monitoring of this work period required
> 9	High	Not acceptable

Table 6 is applicable after the mitigation column has been completed to assess the acceptability of the remaining fatigue score of this duty. Higher fatigue scores require more effort and resources for mitigation.

The author proposes that there is more than one acceptable level of risk. This is because a duty through the night, as a given part of the business, is at higher fatigue risk due to the combination of sleep debt, long time spent awake and the unavoidable performance impairment during the WOCL. On the other hand, duties outside the WOCL may be managed very well (ALARP) even though the results of the worst case during daytime might have a lower fatigue score than the best case at night. This explains that acceptable high fatigue scores at night should not be acceptable during daytime.

Table 7: Risk Matrix: Frequency of Exposure x Faced Fatigue Factors

	Frequency of Exposure per Crewmember 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
1-3	low	low	low	low
4-6	moderate	moderate	low	low
7-9	high	moderate	moderate	moderate
> 9	high	high	high	high

Table 7: The “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. This means that fatigue risk is defined as: fatigue factors x frequency of exposure as shown in table 7. While the example looks only at assessing a single trip type over time, the matrix may also be used to compare the fatigue risks associated with flying different trips. The categories should be defined by each operator for their specific context.

In summary, this approach is evolutional and fatigue specific. However the listed fatigue factors are not fully weighted. This means that the quantitative number of factors is not a linear means of fatigue severity or risk.

Effectiveness of Mitigations of the Fatigue Factor Assessment and Mitigation Table

Possible mitigations are identified in the second column of the Fatigue Factor Assessment and Mitigation Table. The selection of effective mitigations is essential for effective risk management but since only those factors are listed that contribute to fatigue based on scientific research it is thus trivial. The avoidance of any factor is one known cause less that impairs human performance capabilities. The strategic concept that the sleep debt avoidance during previous nights, avoidance of shift changes and reduction of workload factors are methodologically taken into account offers smart and effective options which go beyond the isolated duty itself.

The circadian factor of a “shift change” should be pointed out because it can be strategically used as an effective mitigation. If a flight as shown in the example CGN-TFS-CGN has to be served, it is better to roster this duty after one or two late duties on the preceding days. By this the individual’s circadian clock is slightly moved towards a later sleep-wake rhythm for the late shifts. This facilitates sleep planning and duration of the individual (reduces sleep debt by sleeping longer in the morning). The preceding late duties with the associated wake-sleep pattern might even move the WOCL which reduces the circadian performance decrease towards the end of this duty. It is a previously unused option that smartly chosen preceding duties might be used as an effective mitigation. This multi day perspective needs to consider the following duties as well. Therefore it is recommended to complete the Fatigue Factor Assessment and Mitigation Table for each day in one column over consecutive days.

After the duty has been assessed and possible mitigations have been selected these need to be documented and implemented. In the given example the recommended mitigation is the following.

The example flight CGN-TFS-CGN may be served at an increased but acceptable fatigue risk after the following has been implemented:

- Prior to this duty the previous duty days shall be late duties (to avoid a shift leg effect as well as to facilitate sleep-wake patterns of the crewmembers)
- Checkout time of previous duty shall be latest at midnight (to minimize night-sleep debt)
- This flight is not scheduled more than twice per crewmember per week (limits cumulative fatigue)
- No training shall be scheduled for this flight (reduces workload)
- Fatigue management training shall include napping advice for duties ending late at night (for individual preventive sleep-wake planning strategies)
- Fatigue guidance material for crews shall contain sleep planning and napping strategies for this type of duty (for individual preventive sleep-wake planning strategies)
- The rotation is monitored and periodically analysed by the FSAG (to assess effectiveness of controls)

Monitoring Effectiveness of Implemented Mitigations

Since the flight in this example is only served twice a week the total number of flights is too small for setting up a reliable performance indicator. Since it is within regulators duty time limits a study on this flight is not considered as long as there are no observations of concern for this flight. However the flight shall be monitored for the period served concerning:

- Compliance to the rostered sequence of duties (as described above)
- Concerning delays (exceeding duty time and time awake)
- Crew reports (events that may be related to fatigue) and
- Formal fatigue reports (experienced fatigue or concerns are reported
- Monitoring of actual times of rotation flown by use of a fatigue model (performance monitoring and identification of unintended scheduling practices)

Discussion

Established risk assessment methodologies as the ICAO Risk Matrix (severity x likelihood) may be applied to assess fatigue risk in general or after an event. The ARMS methodologies are an alternative.

The Fatigue Factor Assessment and Mitigation Table is a methodology for the specific fatigue risk assessment of a particular duty or work pattern. Mitigations cover additional measures, especially on the previous nights and shifts in a multi-day perspective and workload factors, complementing the traditional strategy which is limited to a reduction of the duty length of the relevant duty.

It has been developed by the author and tailored to the specific circumstances of a specific LCC flying short haul in Europe. Therefore, it is not considered to be directly applicable for other operators without adopting the contents to their specific operation accordingly.

The listed fatigue factors may be considered less meaningful for fatigue “risk” assessment than for fatigue mitigation. Powell and Spencer [12] found that fatigue cannot be represented as a simple summation of the individual factors. This reflects the complex interaction between the timing of duty related to the circadian rhythm of fatigue and the duration of duty and its impact on the timing of sleep.

Results are conflicting regarding the definition of risk (severity x likelihood). However it may be used in addition to the traditional risk matrix where the overall fatigue risk has been assessed to be a high risk. With the Fatigue Factor Assessment Table and Mitigation Table a more specific analysis and assessment as well as mitigation is achieved.

Factors are not fully weighted. The sum of points is therefore no final risk assessment. Where each category contains 4 factors, it is not true that these are of the same influence. The most important category is sleep since it is the only measure against sleepiness and fatigue. Time awake is second most important. The circadian factors are very relevant and the effect of workload should be taken into account for a short haul operator.

A bio mathematical model may take all these factors into account at correct weights. However the models today do not provide the user with information of why a duty is of a high or low fatigue number and what is required to reduce the level of calculated alertness. Most models do not take all factors into account as listed in the Fatigue Factor Assessment and Mitigation Table. However, the cumulative fatigue over several days may be assessed very well by the use of a model as one part of a FRMS.

More factors could be taken into account which has been considered several times. However since the results shall have a direct link to science, only these factors are listed which are well researched, applicable and referenced.

The methodology may be misunderstood or misused without the scientific knowledge of the user especially since the factors are not fully weighted.

The acceptable number of fatigue factors as listed in the table is based on expert advice. There is no validation process behind these recommendations.

The Fatigue Factor Assessment and Mitigation Table has been applied within prescriptive limits of Flight and Duty Time regulations. The strategy is to keep fatigue risk as low as reasonably practicable (ALARP). It is not considered to deliver concluding results beyond regulatory limits.

In short, more validations and research are required to fully assess or calculate fatigue risk.

Appendix

Example 2: Same Rotation Compared at Different Times of Day/Night

	Fatigue Factor Assessment and Mitigation Table				
	Rotation:	CGN-TFS-CGN FDT: 11:00h			
	Type of Shift:	Checkin: 0500LT Checkout: 1600LT	Checkin: 0900LT Checkout: 2000LT	Checkin: 1600LT Checkout: 0300LT	Checkin: 2100LT Checkout: 1000LT
	Fatigue Factor:				
Sleep debt	Previous night sleep ** reduced < 4h (night: 22-08LT)	1	--	(1**)	(1**)
	Previous night sleep ** reduced > 4h	(1**)	--	(1**)	(1**)
	Reduced night sleep > 4h before previous night ***	(1***)	(1***)	(1***)	(1***)
	Previous "night duty" ** (day sleep only)**	0	0	0	(1**)
Wakefulness	Time since awake > 2h prior C/I*	--	--	1	1
	Time since awake > 6h prior C/I*	--	--	1	1
	Time on task > 10h (FDT)	1	1	1	1
	Time on task > 12h < 14h (FDT)	--	--	--	--
Circadian Factors	Circadian disruption > 4h **	(1**)	--	(1**)	1
	Flight after 2300LT or last landing during darkness	--	--	1	1
	Flighttime <2h during WOCL	--	--	1	1
	Flighttime > 2 h during WOCL	--	--	--	1
Workload	3 or 4 consecutive flights/sectors	--	--	--	--
	5 or 6 flights / or: 3 flights during night	--	--	--	--
	Known hassles	--	--	--	--
	Training flights	(1)	(1)	(1)	(1)
	Sum of factors worst case	(6)	(3)	(10)	(12)
	Sum of factors best case	2	1	5	7
	Assessment of fatigue factors: 1-3 relevant factors: accept 4-6 relevant factors: check 7-9 relevant factors: mitigate >10 relevant factors: avoid	* Crew member's responsibility ** Depending on preceding duty *** The night before 2 consecutive nights are relevant			
	Factors are not fully weighted! Most important factors are sleep debt, wakefulness, circadian factors then workload in this order.				

Appendix Example 3: Comparison of Different Shift Types

	Fatigue Factor Assessment and Mitigation Table						
	Type of Shift:	Deep Early	Early	Day	Late	Deep Late	Night
	Fatigue Factor:	Check-in < 0500LT	Check-in < 0800LT	0800LT-2000LT	Check-out < 2300LT	Check-out > 2300LT	Entire night
Sleep debt	Previous night sleep ** reduced < 4h (night: 22-08LT)	1	1	--	(1**)	(1**)	(1**)
	Previous night sleep ** reduced > 4h	1	--	--	(1**)	(1**)	(1**)
	Reduced night sleep > 4h before previous night ***	(1***)	(1***)	(1***)	(1***)	(1***)	(1***)
	Previous "night duty" ** (day sleep only)**	0	0	0	0	0	(1**)
Wakefulness	Time since awake > 2h prior C/I*	--	--	(1)	1	1	1
	Time since awake > 6h prior C/I*	--	--	--	(1)	1	1
	Time on task > 10h (FDT)	(1)	(1)	(1)	(1)	(1)	1
	Time on task > 12h < 14h (FDT)	(1)	(1)	(1)	(1)	(1)	0
Circadian Factors	Circadian disruption > 4h **	(1**)	(1)	--	(1)	(1)	1
	Flight after 2300LT or last landing during darkness	--	--	--	(1)	1	(1)
	Flighttime <2h during WOCL	1	--	--	--	(1)	1
	Flighttime > 2 h during WOCL	--	--	--	--	--	1
Workload	3 or 4 consecutive flights/sectors	(1)	(1)	(1)	(1)	(1)	(1)
	5 or 6 flights / or: 3 flights during night	0	(1)	(1)	(1)	(1)	--
	Known hassles	(1)	(1)	(1)	(1)	(1)	(1)
	Training flights	(1)	(1)	(1)	(1)	(1)	(1)
	Sum of factors worst case	(10)	(9)	(8)	(13)	(14)	(14)
	Sum of factors best case	3	1	0	1	3	6
	Assessment of fatigue factors: 1-3 relevant factors: accept 4-6 relevant factors: check 7-9 relevant factors: mitigate >10 relevant factors: avoid	* Crew member's responsibility ** Depending on preceding duty *** The night before 2 consecutive nights are relevant					
	Factors are not fully weighted! Most important factors are sleep debt, wakefulness, circadian factors then workload in this order.						
	Tritschler 2015; EASA FRMS Workshop Cologne						

Appendix: Science behind the Fatigue Factor Assessment and Mitigation Table

	Fatigue Factor Assessment and Mitigation Table		
	Fatigue Factor:	**Factor Explained:**	**Scientific Study:**
Sleep debt	Previous night sleep reduced < 4h (night: 22-08LT)	Own research showed acceptable performance after 6 hrs of sleep	Vejvoda 2014 [1] Basic sleep science, e.g.[7]
	Previous night sleep reduced > 4h	Less than 4 hours of night sleep show impairment	
	Reduced night sleep >4h before previous night ***	At least 2 consecutive nights are relevant	Dawson 2006 [8]
	Previous “night duty” (daysleep only)	Sleep during daytime is less restorative than at night	Spencer 1997 [9]
Wakefulness	Time since awake > 2h prior C/I*	Up to 2hrs is considered minimum before start of duty.	Vejvoda 2014 [1] DLR GWI Study 2009 [2]
	Time since awake > 6h prior C/I*	Own research showed acceptable performance up to 16h wakefulness	
	Time on task > 10h (FDT)	According to DLR up to 10h FDT are recommended, but only 4 duties above 10h per week (NASA short haul)	Dinges 1996 [3] Samel 1997 [4] Goode 2003 [5] Spencer 1999 [6]
	Time on task > 12h < 14h (FDT)	According NASA & DLR more than 12hrs of FDT are not recommended	
Circadian Factors	Circadian disruption > 4h	Shift-lag effect leads to circadian disr. and manifests as a decrement in performance; Effect on 1st day in many studies	Stewart 2003 [10][11]
	Flight after 2300LT and/or last landing during darkness	Circadian effect measurable after 2300LT	Vejvoda 2014 [1] Powell 2007/08 [12] [13]
	Flighttime <2h during WOCL	Performance impairment during WOCL	Basic sleep science [14] Spencer [6] [15] [16] Gundel 2011 [17] Powell [13]
	Flighttime > 2h during WOCL	Strong performance impairment	
Workload	3 or 4 consecutive flights/sectors	Number of sectors are of important influence, own study up to 4 acceptable	Gander 1994 [18] Spencer 2005 [16] Powell 2007 [12] Niederl 2007 [19] DLR GWI Study 2009 [2]
	5 or 6 flights / or: 3 flights during night	More than 5 sectors per duty show impairment	
	Known hassles	The strongest influence on levels of fatigue at the end of a flight was the level of hassle associated with this flight (Spencer)	Bourgeois 2003 [20][21] Spencer 2005 [16] Stewart 2006 [22] Tritschler 2010 [23]
	Training flights	For training captains workload may be particularly high when commanding training and assessment duties	Stewart, 2009 [24]
	Most scientific studies have investigated specific factors only. The combination of independent studies may be of conflict.		
	Tritschler 2015; EASA FRMS Workshop Cologne		

[1] Vejvoda, Plath, C. Samel, Tritschler, Basner; Relationship between Workload and Fatigue on Short-Haul Flights (unpublished)

[2] Vejvoda, Elmenhorst, Pennig, Plath, Maas, Tritschler, Basner, Aeschbach; Significance of time awake for predicting pilots' fatigue on short-haul flights: implications for flight duty time regulations European Sleep Research Society 2014

[3] Dinges, Graeber, Rosekind,A. Samel, Wegmann; Principles and guidelines for duty and rest scheduling in commercial aviation; NASA Technical Memorandum 110404; 1996

[4] A. Samel, Wegmann, Vejvoda; Aircrew Fatigue in Long-Haul Operations; Accid. Anal. And Prev., Vol. 29, No.4 pp. 439-452, 1997

[5] Goode 2003 "Are pilots at risk of accidents due to fatigue?" Journal of Safety Research

[6] Spencer, Robertson 1999; The Haj operation: alertness of aircrew on return flights between Indonesia and Saudi Arabia; DERA/CHS/PPD/CR980207/1.0

[7] Battelle Report 1998: "An Overview of the Scientific Literature Concerning Fatigue, Sleep, and the Circadian Cycle." Battelle Memorial Institute

[8] Dawson, McCulloch, 2006: "Managing Fatigue: Defences in Depth" 59th IASS, Paris, October 2006

[9] Spencer, Montgomery 1997; Sleep patterns of aircrew on charter air haulage routes; DERA

[10] Simon Stewart & Rafeef Abboud; Flight Crew Scheduling, Performance and Fatigue in a UK Airline Phase 1 (2005)

[11] Simon Stewart & Rafeef Abboud; Flight Crew Scheduling, Performance and Fatigue in a UK Airline Phase 2 (2005)

[12] Powell, Spencer, Holland, Broadbent, Petrie. 2007: "Pilot fatigue in short-haul operations: effects of number of sectors, duty length, and time of day". Aviation Space Environ Med 2007; 78: 698-701

[13] Powell, Spencer, Holland, Petrie. 2008 Fatigue in Two-Pilot Operations: Implications for Flight and Duty Time Limitations". Aviation Space Environ Med 2008, Vol 79, No11

[14] Akerstedt 1995; Work hours, sleepiness and underlying mechanism; J. Sleep Res (1995) 4. Suppl. 2, 15-22

[15] Spencer MB, Robertson KA June 1999; The Haj operation: alertness of aircrew on return flights between Indonesia and Saudi Arabia; DERA/CHS/PPD/CR980207/1.0

[16] Civil Aviation Authority. Aircrew fatigue: a review of research undertaken on behalf of the UK Civil Aviation Authority. Norwich, UK: The Stationery Office; 2005. CAA Paper 2005/04

[17] Gundel, 2011; Provision of Scientific Expertise to Submit an Assessment of the NPA on Flight Time Limitations (FTL) and to Provide Guidance and Advice to the FTL Review Group

[18] Gander, Graeber, Foushee, Lauber, Connell 1994: "Crew Factors in Flight Operations II: Psycho physiological Responses to Short Haul Air Transport Operations." NASA Technical Memorandum 108856

[19] Niederl 2007: "Investigations of Cumulative Psychic and Psycho-physiological Effects on Flying Staff Examining Short Haul Operation" DLR Forschungsbericht 2007-17

[20] Bourgeois-Bougrine, Carbon, Gounelle, Mollard, Coblentz 2003 (B): "Perceived Fatigue for Short and Long-Haul Flights: A Survey of 739 Airline Pilots." Aviat Space Environ Med 2003; 74:1072-7

[21] Bourgeois-Bougrine, Carbon, Mollard, Coblentz, Speyer 2003 (A): "Fatigue of Short-Haul Flights Aircrews in Civil Aviation: Effects of Work Schedules" Human Factors and Aerospace Safety 3(2), 177-187

[22] Stewart, Holmes, Jackson and Abboud, 2006: "An Integrated System for Managing Fatigue Risk within a Low Cost Carrier" IASS 2006

[23] Tritschler; "The Influence of Workload Factors on Flight Crew Fatigue", IASS 2010

[24] Majumdar, Stewart, Holmes 2009: "A Framework for the analysis of the workload of training captains: A short-haul airline case study" Imperial College London