

## ON REDUCING AND PREVENTING CREW FATIGUE



**Flight departures**

Time	Destination	Flight	Distance	Gate	Remarks
09:53					
11:05	Chicago	UA 909			
11:05	Paris de Gaulle	AF 1341	✈ 15 min.	G3	
11:05	New Delhi	KL 0871	✈ 22 min.	C5	
11:10	Philadelphia	US 749	✈ 15 min.	D53	
11:10	Antalya	SHY 590	✈ 20 min.	G5	
11:10	Entebbe	AF 8417	✈ 10 min.	D22	
11:10	San Francisco	KL 0605	✈ 10 min.	D47	
11:15	Trondheim	KL 1173	✈ 10 min.	B	
11:20	Aruba	TFL 860			
11:20	Zagreb	QF 111			
11:20	London Hrow				
11:20	Tallinn				
11:20	Detroit				
11:35	Istanbul				
11:40	London Heathrow				
11:45	Londo				
11:50	Edinb				
11:50	No				
11:55	He				
11:55	Si				
11:55	M				
11:55	L				
12:00	L				
12:00	L				
12:00	L				
12:00	L				
12:	L				
12:	L				
1:	L				

# Flightcrew Fatigue

Recommendations for airlines  
on reducing and preventing crew fatigue

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*"My mind clicks on and off. I try letting one eyelid close at a time while I prop the other with my will. But the effect is too much, sleep is winning, my whole body argues dully that nothing, nothing life can attain is quite so desirable as sleep. My mind is losing resolution and control."*

***A quote from Charles 'Lucky Lindy' Lindbergh about  
the flight from New York to Paris***

*Passengers put their trust in pilots and cabin crew,  
and they in turn put their trust in the airplane.  
But you don't want them to fall asleep on the job.  
And remember, in the case of an emergency  
the flight crew is still your last line of defence.*

## Thank you

Finishing this graduation project would never have been possible without the support of my family and close friends. I would especially like to thank my partner Annemarie and my parents Piet and Ria. They have supported me on countless occasions and in many different ways. I have no doubt that they know how much I appreciated them. And to everybody who, over the many years, remained confident that I would wrap up my studies: thanks!

A word of thanks also goes out to the members of my graduation committee for their valuable time and the useful feedback I received during our meetings.

Raymond

Vlaardingen, september 2008

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## Definitions and abbreviations

<i>Hyper-vigilance</i>	<b>an enhanced state of sensory sensitivity accompanied by an exaggerated intensity of behaviours whose purpose is to detect information</b>
<i>Hypo-vigilance</i>	<b>a decreased state of sensory sensitivity accompanied by a low intensity of behaviours to detect important information</b>
<i>Flight crew</i>	<b>Both cockpit and cabin crew</b>

<i>AECS</i>	<b>Average Eye Closure Speed</b>
<i>ALPA</i>	<b>Airline Pilot Association</b>
<i>ATC</i>	<b>Air Traffic Control</b>
<i>BIP</i>	<b>Basis Indelings Patroon</b>
<i>CIS</i>	<b>Checklist Individual Strength</b>
<i>CLA</i>	<b>Collective Work Agreement</b>
<i>CRM</i>	<b>Crew Resource Management</b>
<i>EASA</i>	<b>European Aviation Safety Agency</b>
<i>ECA</i>	<b>European Cockpit Association</b>
<i>EU-OPS</i>	<b>EUropean OPerational Standards</b>
<i>ESS</i>	<b>Epworth Sleepiness Scale</b>
<i>FTL</i>	<b>Flight Time Limitations</b>
<i>IATA</i>	<b>International Air Transport Association</b>
<i>JAA</i>	<b>Joint Aviation Authorities</b>
<i>JAR-OPS</i>	<b>Joint Aviation Requirement for Operations</b>
<i>LHF</i>	<b>Long Haul Flight</b>
<i>MSLT</i>	<b>Mean Sleep Latency Tests</b>
<i>MWT</i>	<b>Maintenance of Wakefulness Test</b>
<i>NTSB</i>	<b>National Transportation Safety Board</b>
<i>OCR</i>	<b>Overhead Crew Rest</b>
<i>PERCLOS</i>	<b>PERcentage of time the eye is CLOSed</b>
<i>PST</i>	<b>Psychomotor Vigilance Test</b>
<i>PVT</i>	<b>Psychomotor/Performance Vigilance Test</b>
<i>SFS</i>	<b>Situational Fatigue Scale</b>
<i>SHF</i>	<b>Short Haul Flight</b>
<i>SSS</i>	<b>Stanford Sleepiness Scale</b>
<i>TCAS</i>	<b>Traffic alert and Collision Avoidance System</b>
<i>WTR</i>	<b>Working Time Regulations</b>

## Summary

Fatigue is an insidious threat to safety. Its effects are usually subtle but non the less very real. In the face of 'aviation culture' and job dependence, fatigue is an underreported and difficult matter that often does not receive the attention that it should. There are several examples of fatigue in aviation and in June of 2008 there was yet another example. Both commercial pilots fell asleep and flew straight past the airport of New Delhi, only to be woken up by frantic calls from ATC. More examples are presented in this report. This research has been written to formulate generic recommendations with which airlines will be able to reduce and prevent human fatigue in flight crew.

The first stage of the report is aimed at getting a good view of the phenomenon of fatigue. Its definition, different forms and related factors are presented. As with accident investigations, the causes and the effects on the human body and daily operations were investigated. Different forms of countermeasures were also collected and described. An important finding is that the major cause of fatigue is inadequate sleep.

The next stage was on collecting different ways of measuring or determining human fatigue. The methods were categorised into subjective, objective and predictive methods. The group of subjective methods consists of seven different scales used to rate sleepiness and fatigue. A multi-criteria analysis was performed to rank the scales best suited for crew fatigue. The result was that there is relatively little difference in the top ranking scales. The Stanford Sleepiness Scale and the Samn-Perelli Fatigue Scale scored equally well. The same analysis was done for the objective methods, they were separated in methods with a focus on the causes and on the effects of fatigue. A total of fifteen different products were ranked. Overall the actigraph 'watches' ranked highest of all products. These watches measure periods of sleep and activity as well as many other environmental parameters.

The third stage was writing an actor analysis. The goal of this analysis was to get a clear picture of the stakeholders and their relations surrounding the issue of crew fatigue. After a scan of all possible actors a selection was made based on several selection criteria. The result was an understanding of interest, standpoints, influence and core-values of the four 'key' actors: cockpit crew (represented by their unions), cabin crew (also represented by their unions), airline management and aviation safety research institutes. Based on this knowledge and the findings acquired in the previous stages, several recommendations were made.

The first recommendation is to establish an open culture on fatigue, this is an essential condition to progress. An employer that is committed to reducing fatigue and who maintains a visible fatigue/safety program will raise employee awareness and motivation. Because fatigue is a shared responsibility between airline management en flight crew, the second recommendation is to establish or clarify these responsibilities. Responsibilities about sleep, the identification of situations with high levels of fatigue, the mitigation of its occurrence and effects as well as education should be put in writing and communicated throughout the organisation. On top of this a health and lifestyle program is encouraged. Such a program should educate people throughout the entire organisation on the fundamentals of crew fatigue. The next recommendation is to introduce sleep schedules. These schedules should be based on scientific knowledge of fatigue and be published together with duty schedules. Next, it is recommended that flight crew should be able to file non-punitive, anonymous Fatigue Report Forms. The final recommendation is the use of the Fatigue Reduction Cycle. This process is designed to be a collaborated effort between airline management, unions, flight crew and aviation safety research institutes to find, measure and solve fatigue inducing schedules, to apply these solutions and to learn from them.



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# 1 INTRODUCTION

Everyone who has had to get up in the middle of the night to catch a flight and perhaps travel through many time zones knows how it feels to be fatigued onboard an airplane. For most occasional travellers this is just uncomfortable, since they usually do not have to travel on a daily or weekly basis. For some businesspeople it may have become a problem as they frequently need to travel for business. But what about those who woke up at the same time and travelled through the same time zones but have to work inside the same pressurised cabin because it is their profession? For pilots and cabin crew fatigue is a very real problem that usually does not go away with a single good night of sleep. Being fatigued has almost become a daily routine. Think of this: just when you are rested from a three day trip from Amsterdam to Chicago there is a new, ten hour flight waiting to Tokyo. And this continues year after year.

This form of daily routine has become common in aviation. Cockpit and cabin crew have to fly these kinds of rosters all year round. This has not only caused cabin crew to fall asleep during landing but there are many stories of crew falling asleep in their car when driving home. Fatigue and the responsibilities for employer and employee are difficult issues. They are far more complex than for example the responsibilities for the use of alcohol. We all know that we should not drink-and-drive, big fines and the revocation of one's driver license are common penalties. Of course, working in an airplane after having consumed alcohol is equally 'not done' and punishable. But as we will see, the effects of alcohol are very similar to those of fatigue. Suppose a captain asks a member of his crew: "are you ready to go?" and he or she answers "sure, just a little bit drunk". What would you think?

From practical day-to-day situations, more and more signals can be heard about crew fatigue in aviation. These signals come from different sectors. New situations arise from technological developments while changes in market demand influence the relation between employer and employee. This chapter gives an outline of these changes and how they impact crew fatigue. Some of them centre around the possible causes of fatigue while others reflect on the effects. It will also talk about why crew fatigue, and the safety risk it imposes (NASA, 2000), should be taken seriously. Because after all, operators who are alert and awake are sure to perform better than those who are drowsy, fatigued and sleepy.

In this chapter, the SHELL model is used as a guide to categorize the many different observations regarding fatigue in flight crew. This model was invented by professor Elwyn Edwards and later modified by Frank Hawkins. Using this model as a guide shows how intricate the issue of human fatigue is. The abbreviation SHELL stand for the factors:

**Software:** checklists, procedures, training etc.

**Hardware:** equipment, tools etc.

**Environment:** Physical and psychological impacts etc.

**Liveware:** The human operator

These four factors are obviously not perfect. People have varying levels of performance, procedures and training can not encompass every possible situation, hardware design is restricted by space, time and money and the environment (i.e. the weather) varies constantly. This means that the interaction between these factors is very important and in many cases this relation is negatively influenced by fatigue.

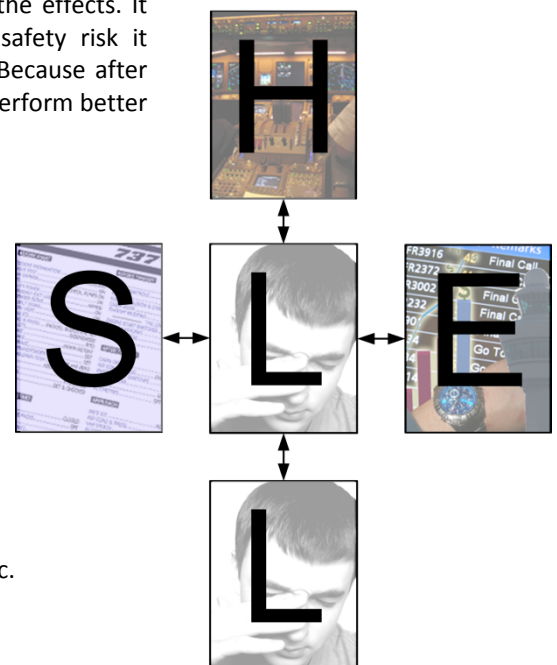


Figure 1 SHELL model

Central in the SHELL model are the operators (liveware) that work at the front lines of daily operations. Although human behaviour is very adaptable it can also vary considerably. People do not perform on the exact same level at every moment of the day. So the manner in which they interact with other factors is very important. To ensure the highest level of safety it is important that these imperfections and relations are recognized and understood. One of these imperfections is that people can become fatigued and perform less than optimal. The general factors that influence fatigue and human performance and which provide the starting point for further investigation are:

- *Psycho-physiological factors:*

These are the factors that influence the physical (body) and psychological (mind) state of humans. The physical and psychological processes interact with each other and both have an effect on the level of human performance.

Factors influencing the physical state are for example: work in a pressure cabin, alcohol, smoking, exercise, sleep deprivation and fatigue. If an operator is in a sleep deprived state, this can have an effect on the psychological/cognitive state of this individual. One of the effects of sleep deprivation is that the short-term memory is degraded (Neri, et al., 1997).

We can also view this interaction the other way around; how psychological factors influence the physiological state. Examples of factors having an effect on the psychological/cognitive state are training and mental workload. If an operator works in a very high workload setting, this has an effect on the psychological/cognitive state. When this situation continues long enough the body becomes physically fatigued.

- *Psycho-social factors:*

The psycho-social factors that affect human performance can be split in work and non-work related groups. Examples of work related factors are disagreements at work superiors or tension between co-workers. Financial problems, loss of family members and marital disputes are examples of non-work related factors that influence performance.

- *Physical factors:*

The physical factors that influence human performance are relatively straight forward. They include a person's physical characteristic such as height, weight and sight. Overweight for example means that the body needs to use extra resources for movement and overweight people are usually quickly exhausted.

### **How this report is constructed**

After discussing several observations in the chapter, the next chapter describes the research method in more detail. Its focus is on the research goal, what questions need to be answered to achieve this goal and how these answers are to be obtained. Chapter three is mainly on the phenomenon of human fatigue in an aviation setting. Because fatigue is hard to understand an attempt is made to give a definition, to distinguish it from related phenomenon. The different causes and effects, as well as countermeasures, are described. The next chapter, chapter four, deals with the many different ways in which fatigue can actually be measured. All the methods are compared and ranked. Chapter five aims to give an insight into the different parties, the different 'actors', which surround the issue of crew fatigue. The result of this actor analysis is an identification of crucial actors and exploration of their unique characteristics. Chapter six presents several findings, the recommendations and a general discussion.

But first, chapter one describes several signals and current developments that emphasize the importance of crew fatigue. These are categorized using the well known SHELL model. After that it discusses several reasons why it is important to address crew fatigue. It is put into the context of legal issues, responsibilities, cost, passenger business and safety.

## 1.1 Signals and developments

When we look at the psycho-physiological factors influencing performance, the SHELL model can be used to provide a better understanding of the importance of crew fatigue. There are several signals and developments that should urge airlines to look closely at crew fatigue. In the next paragraphs the blocks and relations of the SHELL model will be used as a guideline to categorize these signal and developments.

### 1.1.1 *Hardware – Liveware*

#### **Customer demand and new types of aircraft**

Customer demand is very important in the airline industry. Customers are not willing to change airplanes anymore, they want to reach the destination as quickly as possible and avoid delays due to changing airplanes. They also want to be able to fly to as much destinations as possible, and not just depart from the large national airports but also from airports closer to home. This means a shift towards many 'long thin routers' departing from and arriving at regional airports. 'Long' because these routers are mainly (ultra) long-haul and 'thin' because the amount of passengers per flight is relatively low. When putting this against the backdrop of an ever increasing volume of passengers it means that the amount of flights will most likely show a significant rise.

Technological developments are making this change possible. New airplanes fly further and longer than ever before. Especially the new Dreamliner (compared to the 747 or the Airbus A380 a relatively small but very economical aircraft) and the 777 models from Boeing are made to fly more efficient. They can be configured for a flying range of up to 14.000 kilometres. In some cases up to 20 hour ultra long-haul flights are possible. Because of this new customer demand and the need for highly efficient aircraft, aging aircraft are gradually but surely being replaced or refitted to meet this demand.

These ultra long-haul flights have an effect on the crew. The time a crew spends in the airplane environment is increasing and more time-zones can be crossed in a single flight. These factors can contribute to an increased amount of fatigue in both cockpit- and cabin crew. As most passengers know, resting or sleeping in an airplane is not very comfortable. The OCR (Overhead Crew Rest) facilities give only modest comfort to crew and sleeping on the job is never a guarantee.

#### **The physical environment**

The typical characteristics of the relatively small and pressurized cabin (the work environment of cockpit- and cabin crew) can increase the speed at which fatigue accumulates in crew. These include very low humidity, movement restrictions, low air pressure, noise, vibrations and lighting conditions.



### 1.1.2 *Environment – Liveware*

#### **Off-time at a destination**

The time that crew spend at the destination is private and thus non-working. They receive a daily allowance to pay for food, drinks and snacks. Because this is private time, an airline has very little influence on what happens at the destination. There is no way to check whether crew is taking enough rest and sleep. This is primarily left to the responsibility of the crew themselves.

#### **Policy changes**

National and international attention for crew fatigue is growing in the public debate. The Dutch Ministry of Transport, Public Works and Water Management refers to crew fatigue in its 2005-2010 policy agenda several times. In this document the ministry acknowledges the relation between advances in technology, that is airplanes being capable of flying even greater distances for a long period of time, and the fact that fatigue is, or may become, a significant

problem. They also state that work and rest times are strongly related with fatigue. In its action program for these years a specific action is described as: *to improve the attention for aspects of crew fatigue. This is done by developing a vision on crew fatigue with the Dutch ALPA and by trying to put the subject back on the European agenda.*

A development which has been ongoing over the last several years is the transition from the JAA to EASA. JAA has long been the umbrella organization for many European countries but by 2008 EASA has taken over all functions from JAA. The goal of EASA is to harmonise rules and regulations between European countries. As a part of this transition the JAR-OPS have been replaced by EU-OPS, to be effectuated by airlines before July 2008. After developing the EU-OPS it received a respectable amount of criticism from pilot organisations aviation safety institutes. This criticism was mainly about:

- education, rest times and flight time limitations for cockpit and cabin crew,
- the fact that some EU member states are taking a risk by lowering their safety standards to the minimum EU-OPS and
- the point that not enough scientific knowledge is available about the accumulation of fatigue in pilots when schedules have not been specifically evaluated for fatigue.

The European Transportation Safety Council confirmed this view in a paper that discusses the role of EU-FTL legislation in reducing cumulative fatigue in civil aviation (Akerstedt, et al., 2003). One of the striking points is that the scope is limited to short-haul European flights. In a reaction to the points of criticism EASA is carrying out a scientific and medical evaluation of the FTL. This evaluation has to be done by the end of 2008.

More about some of these points about the EU-OPS can be read on the website of the ECA with some noticeable headlines like “*No Lowering of National Safety Standards*” and “*Pilots Support European FTL – but Safety Has Been Largely Ignored*”

#### Economy

Although the price of fuel has no direct influence on crew fatigue, it does continuously pressure airlines to look into the cost side of the operation. According to an IATA report (IATA, 2007) 2006 was the first year that (in Asia) fuel costs were larger than labour cost. This report compared 45 major airlines in North America, Europe and Asia. The overall result is that fuel prices are up from 13.6% (2001) to 25.5% (2006) but at the same time labour costs are down from 28.3% (2001) to 23.3% (2006).

Besides fuel prices and maintenance, total crew cost is a very large portion of the total operation cost. Since fuel prices and maintenance are not very ‘manageable’, crew cost is the main focus of attention for cutting total operational cost. This ‘drive’ towards high human efficiency has the potential to become problematic with regard to crew fatigue.



	North America		Europe		Asia Pacific		All Major Airlines	
	2001	2006	2001	2006	2001	2006	2001	2006
Labour	36.2%	25.2%	27.2%	25.8%	17.2%	17.2%	28.3%	23.3%
Fuel	13.4%	26.6%	12.2%	20.5%	15.7%	30.4%	13.6%	25.5%
Aircraft Rentals	5.5%	3.7%	2.9%	3.1%	6.3%	2.4%	5.0%	3.5%
Depreciation and Amortisation	6.0%	4.9%	7.1%	6.7%	7.4%	7.3%	6.7%	6.0%
Other	38.9%	39.6%	50.6%	43.9%	53.4%	42.7%	46.4%	41.7%

**Figure 2 Percentage Share of Airline Operating Costs, by Region of Airline Registration**

(Source: IATA report 2007)



## Social developments

The trend over the last decades has been to do more things in less time. We want to have more free time but we also have more and more tasks to do. In polls done by the National Sleep Foundation ([www.sleepfoundation.org](http://www.sleepfoundation.org)) it has become clear that, over the past 20 years, people have added 158 hours of work and commute time to their annual schedule. Over the last 100 years, sleep has been cut down by at least 20 percent. It seems that sleep is being traded in for career, work and income.

The way people think about sleep is also changing. Nowadays people are taking less time for sleep and putting it on top of their priority list is hardly ever done. It is sometimes seen as a form of weakness or laziness if someone needs more than an average amount of sleep. This is often true in certain company cultures. In other cases it may be impossible to give sleep a high priority; some people have to work two jobs just to get by.

Working hard and long hours should however not be a very big problem. But it seems that we are reaching the end of what the human body can endure. No matter how big the willpower or financial compensation it can never prevent the body from become fatigued and showing the biological and mental effects. After all, the body has in no way evolved as much or as fast as technology and society. Flight has only been around for the last one hundred years, and long-haul civil aviation has only been around for the last couple of decades. Compared to evolution in aviation, human evolution is extremely slow. It seems that we have been pushing our bodies further and further to its limits to keep up with technological innovations.

## Legal

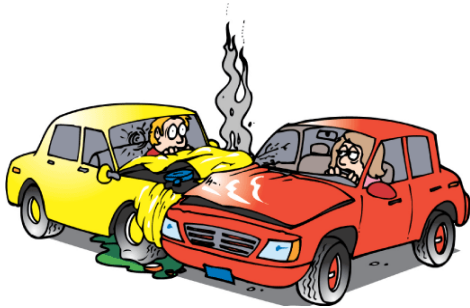
When signing off for duty, most crew members have to drive home. Although a large portion lives within a reasonable distance of the airport, crew is also dispersed in a large area. Some have to drive for 1,5 to 2 hours to get home, depending on the traffic. But even when driving home only takes 15 minutes, it still imposes a significant increase in risk. People have adopted all kinds of creative ways to cope with fatigue while driving.

A trend in the United States is that lawsuits are being filed against employers because they made their employees work too many hours or because they did not receive enough breaks. McDonalds has successfully been sued for the amounts of \$400.000 and \$10.000.000 and a railway company has been sued for as much as \$ 50.000.000. All lawsuits were filed because of (fatal) driving accidents caused by sleepiness or drowsiness.

## Fatigue on the road

Fatigue and road accidents get a considerable amount of scientific attention, currently much more than fatigue in aviation. This is largely because accidents in road traffic occur much faster. Micro sleeps behind the wheel can develop into accidents within seconds. Because driver fatigue is underreported ([www.drowsydriving.org](http://www.drowsydriving.org)) it is difficult to estimate how many people lose their lives as a direct result of fatigue or sleepiness behind the wheel. In the Netherlands around 9000 road fatalities occur each year. Estimations for road accident strongly related to fatigue range from 10-15% (SWOV-rapport R-2003-16) to 40% (Kuiken, et al., 2006). Even using the lowest estimated it means more than hundreds of deaths are related to driver fatigue in the Netherlands alone.

Car manufactures are offering Lane Departure Warning systems that give a chime when a car unintentionally deviates from the current driving lane. The Lane Keeping Support systems can even correct a deviation with automatic steering. Traffic Sign Recognition and Adaptive Cruise Control systems are also available. Fatigue is widely recognised in driving and road studies.





### 1.1.3 *Software – Liveware*

#### **Education**

Because airlines are predominantly profit driven, issues like fatigue usually do not have a very high priority. “Health Service” departments only exist within larger commercial airlines and only the very large airlines spend money on large educational campaigns. These campaigns are mainly focused on medicine, alcohol and drugs. The way information about fatigue is passed on to the employees is usually passive. Information is sometimes available on websites but it has to be actively sought. And, as far as could be determined, fatigue is not (or very limitedly) included in training and education.

#### **Schedule**

Most airlines use some form of ‘crew rostering software’ which can be accessed on the internet. In several informal conversations with cockpit- and cabin crew it appeared that they can create very heavy rosters for themselves. They can (for example) choose a flight from Amsterdam to Sao Paulo on one week and Amsterdam to Tokyo the next. These heavy rosters are often chosen because they offer more time-off than ‘easy’ schedules.

### 1.1.4 *Liveware – Liveware*

#### **Moods**

Fatigue is often associated with changes in someone’s mood. Most of us can relate to feelings of irritability, impatience and being less motivated growing with increased fatigue. These mood changes can have a negative effect on how crew interact. It can block verbal communication between crew members and thus interfere with CRM. It is essential that flight crew members contribute to flight safety with clear and alert communication, both between crew members as well as with ground crew and air traffic control.

#### **Colleagues and responsibility**

As mentioned in the introduction and later in the chapter on the effects of fatigue, the effects of alcohol are similar to those of fatigue. This comparison will get more attention in chapter three. The problem of alcohol is largely debated on internet forums because it is a very sensitive issue. In a strong hierarchical organization like that of an airline it is hard to stand up to more senior colleagues. If your colleague is obviously drunk it should not be very hard to confront him or her, but what if it is less obvious? What if he or she has had too much to drink the night before and you suspect they may still be slightly intoxicated? This question has a place in the training and education of airline pilots. Usually the answer is that the colleague should be persuaded into calling in on a ‘not-fit-to-fly’ basis. The same discussion can be held on fatigue. What do you do when your colleague is constantly yawning or is occasionally nodding off? Since this is a very difficult situation that is likely to result in doing nothing or downplaying the situation it is important to prevent it all together.

### 1.1.5 *Other*

#### **Crew acknowledges fatigue risk**

Caldwell (Caldwell, 2003) talks about research performed by NASA. This research was done together with 1500 flight crew and was on the subject of fatigue. The results of this study show that 74% of the participants think that fatigue is a serious point of concern and that for 61% fatigue is a well known problem they have to deal with on a regular basis. To the question whether they think that fatigue poses a safety hazard, 85% answered that they consider fatigue to impair flight safety.

### Short and long-haul

There seems to be a difference between short-haul and long-haul flights. In a given duty period the number of short-haul flights is much higher than the number of long-haul. In some cases flight crew has to work for 6 consecutive days, performing between one and four flights each day. For long-haul, a duty period usually consists of one flight to the destination (outbound) and within a few days the return flight (inbound). Mainly because of this difference several studies (Bourgeois-Bourgrine, 2003) show that short-haul is perceived as more fatigue inducing than long-haul. When looking through different forums on the internet, this seems to be confirmed by reactions from daily situations. As can be read in this reaction from an anonymous 737 pilot:

*[...]especially if you start your five day duty period (short-haul) with a night flight and your roster shows a double early flight the next three days. By day 5 on the fourth leg you are sure to be nodding off. I have had this duty period for three times this month and yes, next week I have another one [...]*

### Unions

#### New union (Netherlands)

In 2007 a new union called Cabin Pressure (part of the larger FNV union) entered the playing field of negotiations about money, work and rest times. The union is intended for employees working in the cabin. It is very clear about its objectives for the next couple of years and a lot of them are related to fatigue and work pressure.

They pursue a situation in which it is possible to work full-time (until retirement) without a high probability of becoming chronically fatigued or having a burn-out ([www.cabinpressure.nl](http://www.cabinpressure.nl)). They claim that the situation at this moment does not make this possible. People that have problems with fatigue are often persuaded to take a part-time job. For the person in question, this is often not a reasonable option because it also means receiving less income.

During the negotiations in 2007 there have even been protests by cabin crew members. Protests of airline cabin crew have been very rarely seen over the last years. During these last negotiations the union and airline (KLM) agreed that a quick scan of work demands was made. In early 2008, this report concluded that work pressure for cabin crew was very high.

#### Recent actions

In the course of 2008, several cabin and pilot unions have shown an intent to go on strike. Besides an increase of salaries, fatigue was in many cases one of the main points of discussion with the airlines. In the Netherlands, the Dutch airline pilot association organised a strike of Transavia.com pilots in august of 2008. One of the most important aims was to improve night rest facilities at the stop-over locations. This strike was ultimately prohibited by a court ruling.

## 1.2 Why should fatigue be addressed?

The WTR (working time regulation) in collective labour agreements and the law describe (amongst others) the maximum allowed work times and minimal periods of rest. If the rosters that an airline creates are within these boundaries they are considered to be 'legal'. So why should an airline invest time and resources into efforts to reduce fatigue?

### 1.2.1 *Legal rosters offer no guarantee against fatigue*

The boundaries set by the WTR and the law are maximums. These are not 'best practices' but the bare limits of what is allowed. Naturally airlines will pursue these boundaries because their aim is to maximise revenues. When crew is allowed to work long shifts, less crew is needed for the same operation, resulting in fewer costs. These legal limits become operational planning targets but offer no guarantee against human fatigue.

### 1.2.2 *Operating in a dynamic environment, under static regulations*

Most laws were designed many years ago. According to the NTSB, US flight and duty time limits were set in 1938 and 1958. In the light of technological developments and changes in the aviation market this is a long time. New aircraft are developed and new scientific information about human fatigue is discovered. Rules and regulations therefore inevitably lag behind.

Even though collective labour agreements are negotiated about every year they are very rarely reviewed entirely on the basis of current knowledge. These rather static guidelines do not fit very well in such a dynamic environment and may give a false impression on safety.

### 1.2.3 *Airline responsibility and legal consequences*

Airlines have a legal responsibility towards their workers with regard to fatigue. They have to make sure that workers do not have to perform tasks that fatigue them to the point where they can no longer safely perform that task. In the Netherlands this is usually regulated by ARBO/Health Services.

At the end of a (flight) duty period, crew are usually fatigued. Fatigue does not end when duty time ends and is still present when the employee drives home. Sometimes they have to drive for more than an hour in very dense traffic. The larger airlines have at least dozens of workers on the road at any given time, either driving to or from work. This situation should not be underestimated because there is a growing possibility that airlines will be up against employers in lawsuits. Ignorance or lack of awareness about fatigue will no longer hold as an accepted explanation and large amounts of money can be involved. As said before, this is a trend that is already growing larger in the United States. By actively managing fatigue, these kinds of lawsuits can be prevented all together.

### 1.2.4 *Increasing tasks and responsibilities for crew*

The tasks of cockpit and cabin crew are continuously being expanded. Where a pilot's task used to be to fly the airplane from one airport to the other, they are nowadays required to manage the entire flight and confronted with new additional situations such as the threat from terrorism.

New measures to prevent terrorist attacks are also being implemented that impact cabin crew. Besides the tasks of providing service and being involved in flight safety, cabin crew tasks have also been expanded with security related work. Usually there is no (time) compensation for this increase in work. Perhaps a financial compensation is offered but this is not an effective countermeasure for the additional workload or fatigue.

### 1.2.5 *Passenger business and competition*

Together with cargo transportation, passengers are the lifeblood of all airlines. But these passengers are becoming more demanding. The Open Skies agreement for example will enable all low-cost airlines to fly between Europe and the United States. So the passenger's choice of airlines is growing.

One of the differentiating factors between regular (non low-cost) airlines is the *personal service* which is offered. Customers choose an airline because they feel the airline knows and serves them very well. KLM for example invests heavily in the relation with their customers because they feel this is the best way to 'stand out in the crowd'<sup>1</sup>. Moments when the customer meets the airlines are called 'touch points'. Cabin crew are the largest (and longest) touch point that passengers have with an airline. It does not take more than common sense to see that passengers can expect a better service from a crew that is fit and healthy than from an unhappy and fatigued flight crew.

Those customers looking for the cheapest ticket available will most probably choose low-cost airlines. Low-cost airlines are usually known for "low pay – high workload". Passengers can easily translate this into high levels of crew fatigue. As we will later see, there is a strong argument for the relation between fatigue and safety. Passengers are not willing to trade safety for money. So crew fatigue can be a passenger's measure of safety and a differentiating factor between low-cost airlines.

Another differentiating factor is *reliability*. Reliability is usually measured in time deviations from scheduled departing and arrival time. One of the causes of flight delay is when crew calls in sick and a replacement has to be called. He or she usually takes around an hour to get to the aircraft. National and international laws dictate that a flight cannot depart if one or more crewmembers are not onboard. A crew that is not in a general state of fatigue will show less sick leave and this in turn can improve reliability.

### 1.2.6 *Cost of human crew fatigue*

Crew fatigue can (and does) result in unnecessary costs. Unfortunately these costs are mostly indirect, hard to quantify but nevertheless quite obvious. Fatigue in general leads to reduced productivity, low training efficiency, low employee morale, avoiding behaviour, mistakes and more. Direct forms of costs associated with fatigue are avoidable mistakes, showing up (to) late for work and high numbers of sick-leave. Large costs can also arise when pilots call in not-fit-to-fly because of being fatigued. Flight delay or cancellation and accommodating passengers in hotels can be very costly. An increase in fatigue will undoubtedly result in an increase in these kinds of costs. In turn, decreasing crew fatigue will most likely increase airline revenues.

### 1.2.7 *The safety argument*

Profit is the primary goal of any enterprise. Several company components are key to achieving profit. For airlines, a safe operation is crucial. Even a single large accident can put an airline in crisis or even out of business.

People involved in managing an airline never make a conscious decision to trade safety for money. But they continuously make choices that influence the balance between profit and safety. Inevitably some choices, big or small, are made more on the basis of profit than that of safety. Since Murphy's Law is

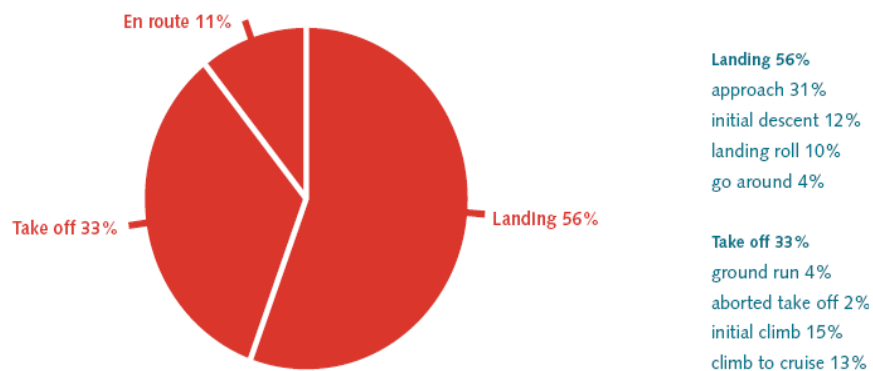
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<sup>1</sup>[www.itcommercie.nl/site.php/121/dossierartikelen/KLM\\_blijft\\_in\\_zware\\_tijden\\_investeren\\_in\\_de\\_klant.html](http://www.itcommercie.nl/site.php/121/dossierartikelen/KLM_blijft_in_zware_tijden_investeren_in_de_klant.html)

actually wrong and “what can go wrong, almost always goes right” the effects of these decisions are not witnessed very often.

Around 70 to 80 percent of all aviation accidents are caused by human factors. (Shappell, et al., 2004). But when looking at accidents in which fatigue (being one of the human factors) is cited as the root cause you would have to conclude that there are only a handful. This does not mean however that fatigue has not contributed to many accidents. Mentioning fatigue as the root cause is something that investigators are not very prone to. Human fatigue is hard to measure and thus hard to prove conclusively. Citing human fatigue as one of the root causes also has significant political effects. Because of this, fatigue is usually mentioned as a contributing (human) factor to an incident or accident.

According to the Dutch ministry of Transport, Public Works and Water Management 11% of accidents occur during flight, 33% at take-off and more than half (56%) occurs during landing. Why is it that most accidents happen during landing? Some can be explained by the fact that landing is the most difficult phase of a flight. The airplane is relatively light, it has to reduce speed and is more susceptible to wind and weather. But landing is also one of the busiest moments in the cockpit. The landing of an aircraft can be preceded by a long-haul flight of sometimes more than 12 hour. Before starting this duty, flight crew could even have been awake from 2 to 12 hours (depending on whether the duty starts at dawn or daybreak). In short-haul many take-offs and landings a day can have the same influence. It is therefore not hard to see that flight crew can be heavily fatigued during landing.



**Figure 3 Accidents and fatalities by phase of flight**

#### **Incidents and accidents**

'Fatigue key to mistakes among pilots' (Alan Levin, 2007) is the title of a USA Today article on crew fatigue. The article mentions that research done by the NTSB shows a high increase risk in pilot mistakes after a long shift or after long periods without proper sleep opportunities. The research used a NASA database to show 750 incidents between 2003 and 2007 (North America) where aviation workers named crew fatigue as a contributing factor. The article also mentions that airline pilot unions see fatigue as one of the most important risks to aviation safety and as a sign of pushing pilots to go beyond their limits.

The database used in this research is part of the NASA 'Aviation Safety Reporting System' or ASRS. This is a database where incidents and accidents can be reported. This database is completely voluntary, confidential and (very important) non punitive. The ASRS collects, analyzes and reacts to the reports with the goal to reduce the chance of aviation accidents. NASA regularly receives reports from flight crew with regard to fatigue. They blame fatigue and loss of sleep for operational errors. These errors include course deviation, mistakes in fuel calculations, landing without clearance or on the incorrect runway, rough landings and difficulty talking to and understanding ATC. These

mistakes are mainly cognitive mistakes and not control errors. In 'Human Factors in the Training of Pilots' Koonce writes about cognitive performance, accidents and fatigue *"...the most common cause of aircraft accidents is human error, the most common cause of the human's error is fatigue"* (Koonce, 2002).

#### **Why don't accidents occur more often?**

Reports that have looked at how prevalent fatigue is among commercial pilots (Bourgeois-Bourgrine, 2003) conclude that *"...self-reported manifestations of fatigue in 60% of LHF pilots and 49% of SHF pilots included reduction in alertness and attention, and a lack of concentration. Signs observed in other crewmembers included an increase in response times and small mistakes (calculation, interpretation). When pilots were tired, all the flying tasks seemed to be more difficult than usual"*. Especially when we hold this information against the backdrop a 400.000 flights arriving and departing from Schiphol alone, we can ask the question why accidents due to fatigue don't occur more often.

Modern airplanes are incredibly reliable. Compared to some decades ago, aircraft reliability has increased tremendously. This reliability is achieved by engineering efforts of major airplane builders such as Boeing and Airbus. These companies have learned valuable lessons on aircraft design and maintenance, although this knowledge has sometimes been learned at a high price. Important knowledge was learned from investigations into accidents, showing vulnerabilities in design and maintenance.

Airplanes have a high level of automation and standardization. Systems such as TCAS prevent collisions and warn for oncoming traffic. Onboard computers have taken over much of the tasks of flying the airplane. With this increasing level over automated flying, the task of the pilot shifts from flying the aircraft themselves towards monitoring computer performance. This situation presents its own unique challenges like the effects of 'boredom fatigue'.

Then there are the procedures that have become international standards because of the 1944 Chicago Convention. These procedures ensure the current high levels of air traffic safety by regulating everything around airports, aircraft handling and ATC procedures. The aviation infrastructure has become very safe.

Finally there is the human factor, the 'glue' that bonds the 'aircraft' and the 'infrastructure'. They operate the aircraft based upon the ICAO international standards. The human factor is the 'flexible' factor in the entire operation. They are the ones that can respond when unexpected situations arise, they can foresee, prevent and correct problems that computers cannot.

But as said before, airlines continuously make trade-offs between safety and profit. This means that this very important human factor is under continuous pressure to perform at optimal levels. Accidents occur when the limits of human flexibility to work in this high-pressure environment are reached. This is why the NTSB, a board that has great expertise in accident investigation, has fatigue on its Most Wanted list.

Finally, the ICAO Safety Management Manual expresses the need not to rely on accidents alone: When safety initiatives rely exclusively on accident data, the limitations of not having many case samples apply. As a result, the wrong conclusions may be drawn or inappropriate corrective action taken.

#### **NTSB: Fatigue on 'Most Wanted' list of critical changes**

Human fatigue is on the list of the NTSB's Most Wanted. This is a list that consists of critical changes needed to reduce aviation accidents. (NTSB, 2008). The NTSB aims to reduce accidents and incidents caused by human fatigue. The first time the Safety Board issued recommendations was in 1989 and human fatigue has remained a top priority ever since and has not been off the Most



Wanted list since 1990. The NTSB has also done several recommendations to the FAA, both on pilot, maintenance and controller fatigue. More information on the standpoint of the NTSB on crew fatigue can be seen on YouTube:



## NTSB: Human Fatigue In Aviation: Part 1/2

<http://www.youtube.com/watch?v=wjyKOUc23U4>

## NTSB: Human Fatigue In Aviation: Part 2/2

[http://www.youtube.com/watch?v=P6\\_gPh-ZOGo](http://www.youtube.com/watch?v=P6_gPh-ZOGo)

### The NASA statement on fatigue

NASA has been involved in research on crew fatigue for many years. The NASA Fatigue Countermeasures Program, funded by the FAA, has been doing research to determine the amount of fatigue and to determine the impact on safety. Countermeasures to minimise the effects of fatigue have also been studied. In a NASA statement on the importance of crew fatigue, the relation between fatigue and safety is described as:

“Throughout the course of this outstanding research program, it has been evident that pilot fatigue is a significant safety issue in aviation. Rather than simply being a mental state that can be willed away or overcome through motivation or discipline, fatigue is rooted in physiological mechanisms related to sleep, sleep loss, and circadian rhythms. These mechanisms are at work in flight crews no less than others who need to remain vigilant despite long duty days, transmeridian travel, and working at night when the body is programmed for sleep. Evidence regarding the existence and extent of fatigue in aviation has been gathered from several different sources and environments, including aviation operations, laboratory studies, high-fidelity simulations, and surveys. **Studies have been consistent in showing that fatigue is an issue with complex, diverse causes and potentially critical consequences.**”

([www.hq.nasa.gov/office/legaff/mann8-3.html](http://www.hq.nasa.gov/office/legaff/mann8-3.html))

### Relation between work and rest times and incidents

As part of an FAA research into the impact of work- and rest times, research has been done on the relation between hours of flight and accidents (Goode, 2003). In this research two sources of data have been compared: standard work patterns of captains and the work patterns of captains that were involved in a considerable accident. The standard work patterns were deduced from data from 10 medium and large sized airlines. The accidents were picked from the NASA ASRS database. The accidents are chosen from the time period between 1978 and 1999. Some of the results from this research are:

20% of Human factor accidents occurred to pilots who had been on duty for 10 or more hours, but only 10% of pilot hours occurred during that time.

5% of Human factor accidents occurred to pilots who had been on duty for 13 or more hours, where only 1% of pilot duty hours occur during that time.

There is a discernible pattern of increased probability of an accident the greater the hours of duty time for pilots. The finding is highly significant.

In the final conclusion of the report it is said that there is no indication of a “discontinuity at a specific duty time” at which the risk of accidents increases significantly. The data shows a constant increase of the risk associated with fatigue, with the increase of duty time.

### Human fatigue in accident models

In the next few paragraphs three models that are used to describe the cause or causes of accidents are presented. These three models are different ways of looking at the same 'reality', but in this order they also represent the development that has taken place over the past decennia. *Each of these models is described on how they explain the relation between fatigue and an incident or accident.*

#### Reasons Swiss cheese and accident causation model

Accidents happen in normal situations where normal people do normal work. People don't make foolish decisions, act irresponsible or make errors on purpose (exceptions set aside of course). Errors take place in situations where people have to meet goals that are very hard to reconcile. For example the combination of optimizing profit, safety and workload.

The phenomenon of 'drifting into failure' (Dekker, 2005) is always a possibility. Small, relatively innocent decisions on all levels of an organization can lead to unforeseen events. The well-known Swiss-cheese model of reason is a model that emphasizes this situation. This model shows different layers that form barriers that prevent an accident from happening. The layers range from senior management (safety policy) to production/operation (operating an aircraft) and operational safety defences (like the TCAS system). Each layer has its own typical deficiencies. Accidents happen when these holes or deficiencies 'align'. One of these layers (or barriers) is called 'preconditions', meaning: why did the operator perform this unsafe act? There could have been a number of different factors which caused the behaviour such as the physical or cognitive state of the individual. Could fatigue have played a role? The holes in this layer are usually referred to as the 'dirty dozen'.

#### The Dirty Dozen:

- Complacency
- Distraction
- Fatigue
- Norms
- Pressure
- Stress
- Insufficient assertiveness
- Insufficient awareness
- Insufficient communication
- Insufficient knowledge
- Insufficient resources
- Insufficient teamwork

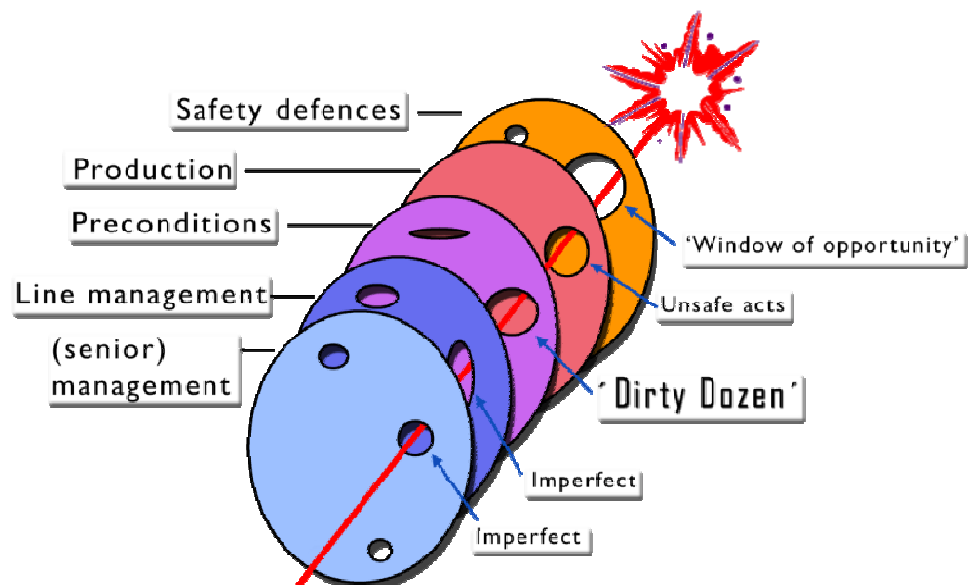


Figure 4 Swiss cheese model

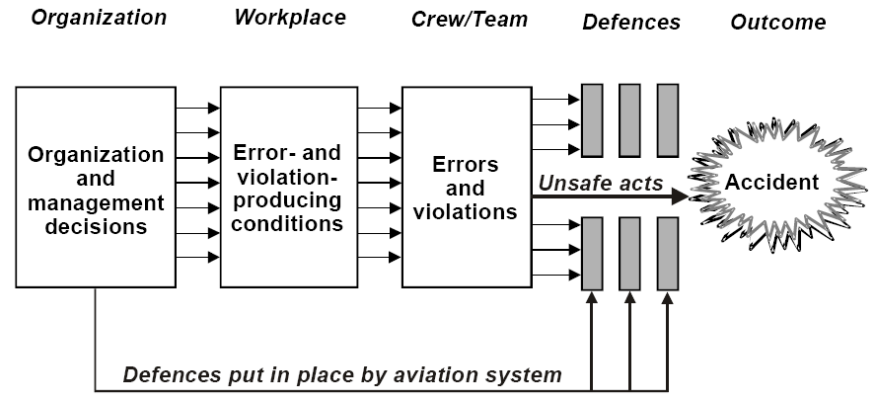


Figure 5 Accident causation model (source: Reason / ICAO Safety Management Module)

### Accident causation model

This model shows how management decisions both create conditions for accidents to happen but also how they can prevent them. This model also shows that crew can make errors or commit violations that result in unsafe acts. Company management has put several defences in place to prevent these unsafe acts from becoming an accident. These barriers can be procedures, checklists, computers systems and so on. The errors and violations are committed in a workplace in which latent and unsafe conditions are present. These latent conditions are the result of decision that were made days, weeks or years before the accident takes place. One of these latent conditions is crew fatigue. Latent conditions themselves are the result of management decisions. In the case of crew fatigue these can be decisions around schedule design and duty times.

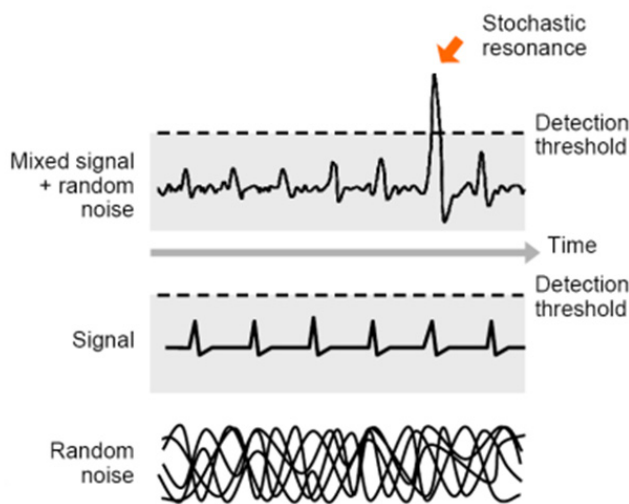


Figure 6 Functional Resonance Accident Model (Source: Hollnagel 2006)

### Functional Resonance Accident Model

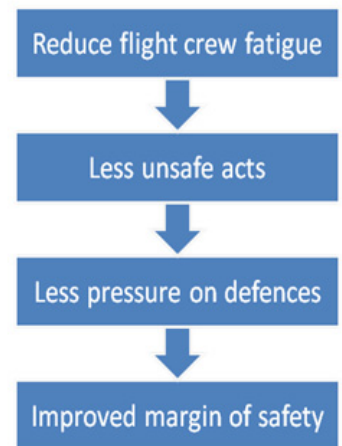
Hollnagel's functional resonance accident model (FRAM) considers the entire system of individual systems (systemic view) when identifying risks or causes of accidents (system failure). Risk can be seen as non-linear combinations of performance variability of individual (sub)systems. System failure is the result of the normal variability of subsystems. One of these subsystems that displays a natural variability is human performance. As Hollnagel describes, one of the steps in reducing the chance of system failure is to identify ways of damping this variability. By reducing fatigue it is possible to 'dampen' human variability.

*When looking at these three models, Reason's model and the Accident Causation Model are the most practical models to use in this report. These models have many similarities. In this report references will be made to 'defences/counter-measures', 'management', 'daily operation/production' and 'crew'. All of which are applicable to both models.*

### Reduce fatigue, increase safety

If we look at the previous accident models we can see that (the effects of) fatigue put pressure on the defences that are built into the aviation system. When looking at the Swiss cheese model, we can see that by closing the 'fatigue' hole in the preconditions layer, we can relieve the pressure that is put on the safety defences. If we use the accident causation model we can see that if management makes decisions that reduce workplace fatigue, there will be less unsafe acts trying to breach the defences.

By reducing the pressure fatigue puts on aviation system defences, the margin of safety increases. A 'window of opportunity' will be less likely to lead to an accident. This report aims to give airlines recommendations to effectively reduce human fatigue.



### The Easyjet example

Easyjet has set an example for addressing fatigue. This low-cost carrier spends a considerable amount of time and resources on dealing with crew fatigue (Stewart, et al., 2006). Being an early adopter, Easyjet is in the process of developing a fatigue management system to get a grip on crew fatigue. The first results are very promising. Working closely with flight crew they have backed away from a 6/3 roster (that is six days of work followed by three days off) and started using a 5/2/5/4 roster. This change has been received favourably by crew that continuously gives feedback for improvements. As a low cost carrier they convinced that this management system contributes to preventing fatigue when operating in a high pressure, high competition market. Easyjet has done such a good job that they were able to present a 'safety case' that stated that their way of managing crew fatigue gives a better protection against fatigue than standard FTL. They were subsequently given the opportunity to work outside these limitations

When we summarize this first chapter we can safely conclude that crew fatigue is an issue with many different aspects. It has technological aspects such as for example aircraft operation, navigating through the aviation infrastructure and scheduling design. Advances in technology make it a very dynamic environment. It also has several managerial aspects like for example changes in national and European policies, rising fuel prices, different responsibilities between employer and employee and changing customer demand. Of course it also has a distinct human aspect.

The results from several research projects and statements from the NTSB and NASA that were presented, point out that crew fatigue poses a risk to aviation safety and that a reduction of crew fatigue is desirable. In the next chapter the research method will be described that was used in order to write recommendations. These recommendations can lead to a decrease in crew fatigue.

## 2 RESEARCH METHOD

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This chapter describes the method by which this research is conducted. Amongst others it formulates the goal, demarcation and research questions.

### 2.1 Goal

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The goal of this research is to formulate one or more technical or policy recommendations. These recommendations should be a contribution to reducing and/or preventing human fatigue of flight crew in civil aviation. The recommendations are to be practical and generically applicable to civil and private airlines. By reducing fatigue, the effect it has on human performance is reduced, thereby improving an airlines margin of safety as well as increasing flight crew wellbeing. Because conflicts about different opinions on Flight and duty Time Limitations or collective labour agreements often exist, the recommendations should also be independent of these national and international rules and regulations to increase the likelihood of acceptance, adoption and implementation.

### 2.2 Demarcation

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This research and the intended recommendations, focus on small, medium and large civil and private airlines and their employees. Employees are those who work on the flight deck (cockpit crew) and those who work within the aircraft cabin (i.e. pursers and flight attendants). No distinction is made between these two groups or about the specific work/tasks they perform. The emphasis is on the typical characteristics of the aviation industry that impact the employee and the Dutch situation. Although they are in some cases referred to, a detailed analysis of FAA-FTL, JAA-FTL or EU-FTL rules and regulations is outside the scope of this research. The reason is that these Flight, Duty and Rest Time Limitations differ between countries. Collective labour agreements are also not included because these differ between airlines.

### 2.3 Problem description

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Several independent studies and organisations view crew fatigue as risk to flight safety. It is difficult to draw decisive conclusions on human fatigue however, one of the reasons for this is that it is difficult to measure 'fatigue levels'. The subject is therefore often sharply debated.

Fatigue has many complex and interacting effect on human performance. Some of these effects are commonly known (slower reaction-time for example) while others like reduced alertness are much more subtle. These effects are also sometimes (unconsciously) masked by company culture and typical human characteristics such as motivation. Certain effects like micro-sleep and attention lapses are particularly dangerous in aviation.

Cabin crew is not only involved in flight safety but they also play an important role in aircraft evacuation. Managing crew fatigue is therefore not only important when it comes to the prevention of accidents, it is also important in the aftermath. Fatigue effects such as slow decision-making and reaction time can be detrimental to the outcome of the accident. Cabin crew are (annually) trained to deal with a large variety of emergency and security situations. During these training days, fatigued crew can be less motivated and have decreased cognitive abilities.

Fatigue is very often linked to flight schedules. These schedules are in turn the translation of company goals. Like all enterprises, airlines are predominantly driven by economical goals, they aim for maximum profit and growth. This can create tensions during negotiations. The schedules flown by flight crew are thus influenced by the outcomes of heavily negotiated agreements. Even the strength of the involved negotiators is part of the equation. As a result different airlines have different labour agreements. The complex issue of crew fatigue finds itself at a cross-road of many different influences and opinions.

## 2.4 Research questions

The main research question is “How can human fatigue amongst flight crew be reduced or prevented?”. To answer this question, it is divided into five sub questions:

- *What are the most important causes of fatigue?*  
If the most important reasons for the onset of fatigue amongst flight crew are identified, this can aid in finding ways to eliminate or mitigate them. Insight into how crew fatigue occurs can also be increased.
- *What are the effects of fatigue on the human system?*  
Fatigue has many different effects on the body and its performance. There are a number of well known aviation incidents in which fatigue has played an important part. Identifying the effects of fatigue (that are relevant for aviation) helps in finding situations that may give room for improving the margin of safety. There is a special interest for the effects that can be measured.
- *What methods are available for measuring or identifying fatigue?*  
Measuring fatigue is complex. The human body (and mind) are very good at temporarily masking fatigue but there are some methods with which fatigue can be measured or identified. The answers to this question can give a practical way to test for fatigue and reduce the ambiguity surrounding fatigue. These methods can be included in the recommendations
- *How is fatigue perceived by different parties that are involved?*  
Fatigue is at the heart of conflicting interests. Commercial, personal and public interests often do not align. An analysis of the actors involved can provide insight into core-values and aid in the formulation of the recommendations increase the chance of them being adopted.
- *What countermeasures for crew fatigue are available?*  
People use a lot of more or less accepted countermeasures for fatigue. When answering the question how airlines can reduce fatigue, these countermeasures may present opportunities or starting points.

## 2.5 Research model

By investigating the main causes and effects of fatigue as well as countermeasures a good picture can be developed about how fatigue effects flight crew (phase A to B). By doing an actor analysis and ranking different methods to measure fatigue (phase B to C) it is possible to write one or more recommendations on how fatigue can effectively be reduced and prevented (phase C to D).

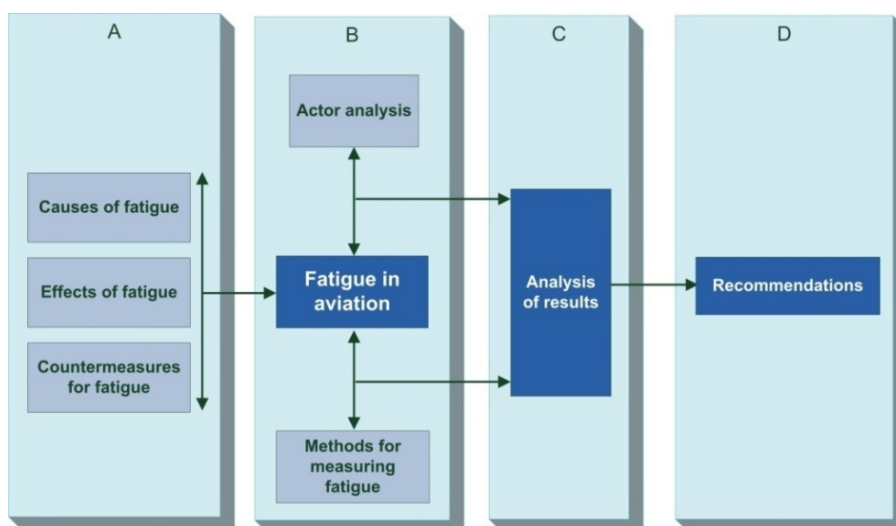


Figure 7 Research model



## 2.6 Strategy

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The strategy is to start off with a literature review about fatigue. The causes, effects and countermeasures of fatigue in an aviation setting are grouped together. This will give insight into crew fatigue in aviation and the current level of knowledge about fatigue. This is then put into the perspective of an actor analysis. The goal of actor analysis is to create an informative 'map' of the goals, perceptions, interests and standpoints of the parties that are stakeholders. Their relations are also investigated. The actor analysis is written based on information gathered from all form of media and interviews.

Because fatigue is often questioned and endlessly debated, it is important to find an objective way to measure or control fatigue. An inventory of methods, tools and products will be made by searching the internet. All possible methods will be ranked by formulating criteria and scoring the methods according to how well they perform on these criteria. This will show which methods are best suited to be used to make fatigue more tangible.

By integrating the characteristics of fatigue with useable measuring methods and the actor analysis, the recommendations for reducing crew fatigue can be formulated.

## 2.7 Research material

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The material needed for this research is retrieved primarily through an investigation of available information and literature (desk research). Additional expert opinions (based on interviews) are also used to gather information.

The next chapter will start with an overview of accident analysis and the place fatigue has had over the years. Next a definition of fatigue will separate it from other phenomena that are often confused. After looking at the many different forms of fatigue, the causes and effects and countermeasures are thoroughly explored. Finally a way to quantify the risk of fatigue will be presented and the way airlines construct crew rosters will be explained in detail.

### 3 CREW FATIGUE

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The rules and regulations under which flight crew works are the result of negotiations. This means that, in the end, the negotiation skills of those who are involved in this process determine the amount of fatigue created by work schedules. And more often than not, work schedules are copied from other traditional schedules. (Folkard, et al., 2003). This is not a preferred situation, it is much better to create work schedules on the basis of scientific knowledge. Dekker writes in “the field guide to understanding Human error” (Dekker, 2006):

*“Fatigue is a huge research area, and one result is that most safety-critical professions are actually regulating work time limitations. These limits, however, are often more the outcome of industrial or political consensus, than they are solidly founded on research data. And duty time limitations, while an enormous step forward in managing fatigue that worlds such as medicine could still learn from, are not always able to deal with the inevitable consequences of operating during unusual periods across time zones...”*

In ‘Fatigue in Aviation’ (Caldwell, 2003) and ‘Stress, workload and fatigue’ (Hancock, et al., 2001) you can read a different approach to fatigue, fitness and flightsafety. Caldwell goes as far as to say that the absence of fatigue is an absolute condition in order to improve flightsafety:

*“Pilot fatigue is an insidious threat throughout aviation, but especially in operations involving sleep loss from circadian disruptions, increased sleep pressure from extended duty, and impaired alertness associated with night work. Aviator fatigue is associated with degradations in response accuracy and in the capacity to integrate information, and narrowing of attention that can lead to forgetting or ignoring important aspects of flight tasks. Fatigued pilots tend to decrease their physical activity, withdraw from social interactions, and lose the ability to effectively divide mental resources among different tasks. As sleepiness levels increase, performance becomes less consistent and vigilance deteriorates. Even the most basic types of psychomotor performance are degraded by sleepiness/fatigue. Thus, it is clear that fatigue is a threat to flight safety; however, it has been difficult to establish the full and exact cost of fatigue in terms of incidents and accidents. “*

One of the major problems of fatigue is that it is such a multi-faced phenomenon. In this chapter we will discuss the causes, effects and known countermeasures to fatigue. But before doing this, it is important to get an understanding of what fatigue actually is by properly defining it. The first part of this chapter gives a short historical overview of accident analysis and fatigue.

#### 3.1 Short historical review of accident analysis and the place of fatigue

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In the field of accident analysis a number of changes have taken place over the last century. Before the nineteen sixties to seventies the root causes of all accidents was thought to be a technical breakdown. Reports of accident investigations almost always resulted in changes of the technical structures, changes in the actual design or in the design process.

After this period, investigators turned their attention to the human operator as the probable cause of accidents. This first change of view on accidents resulted in very large amounts of research on what was to be called the ‘human factor’. The way humans interacted with technology, how they perceived visual and audible signals, stress and health were all the subject of investigations and research. The level of aviation safety that exists today has benefited tremendously from the huge amounts of human factor research. Without it, flying would not be as safe as it is today. Fatigue is part of the umbrella term ‘human factor’.

As a result of increasing aircraft reliability a second change took place at the end of the nineteen seventies. Researchers and investigators started asking the question why people made the mistakes in the first place. Why did they decide on the wrong course of action when

the right one seemed so very obvious? Were they not trained enough? Did the work environment influence the decisions? Did they pursue unachievable goals? This new view now included the entire organisation as a possible cause of accidents. Human error is now seen as a symptom of underlying organizational choices. Pilot error could occur because decisions were based on company goals instead of safety considerations. An example of this is the accident on Tenerife in 1977. The captain of the departing KLM flight did not take enough time to assess the situation (situational awareness) before take-off. The flight was running late (its destination was Las Palmas but it was diverted to Tenerife) and the captain was under a lot of pressure to depart as quickly as possible. The airplane took off and collided with a Pan Am flight resulting in the largest aviation accident in history. The view towards the human component has also improved. The human role is seen as very important because in critical situations, human flexibility and ingenuity can be helpful and decisive to the eventual outcome. Humans are very good at quickly assessing new and unfamiliar situations. Computers are not as adaptive.

True 'new thinking' starts midway through the nineteen nineties. People and the organisation are seen as a whole in the 'systemic accident model' (Hollnagel). This model looks at coincidences, links and 'resonance' between individual units as each unit interacts with other units. The entire organisation is 'more' than the sum of all individual units. Incidents and accidents are now the logical result of a non-perfect system that is operated by non-perfect people that try to reach goals which are sometimes very hard to combine into a single operation.

### 3.2 Definition of human fatigue

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Since fatigue touches on some many different day-to-day aspects of life, finding a fitting definition is not very easy. Someone who is fatigued due to an illness may experience fatigue differently than someone who is overworked or under the effect of jet-lag. Below are some common definitions:

The North American Nursing Diagnosis Association (2003-2004) defines fatigue as:

*"An overwhelming, sustained sense of exhaustion and decreased capacity for physical and mental work."*

A problem with this definition is that the 'sense' can have many different causes that are not mentioned in this definition. Being intoxicated by drugs can also cause a sense of decreased capacity for physical and mental work. Aaronson's (Aaronson, 1999) definition of fatigue is:

*"Fatigue is the awareness of a decreased capacity for physical and/or mental activity due to an imbalance in the availability, utilization, and/or restoration of resources needed to perform activity"*

Although this definition accurately points out that fatigue is an imbalance between the amount of energy available and required there are two problems. First, the imbalance can exist because the job that is required is too heavy, even for a well rested person. Second, it mentions that the person is aware of this imbalance. This is not always the case. There is a variety of ways to mask fatigue, the best known is of course coffee. Coffee may temporarily cut down the feeling of fatigue but it cannot restore the body to a non-fatigued state.

As we can see, fatigue is hard to define. For this research it is important to incorporate the causes, effects and the 'body-state' into a definition. A definition that is well suited is the one by Job and Dalziel (Hancock, et al., 2001):

*"Fatigue refers to the state of an organism's muscles, viscera or central nervous system, in which prior physical activity and/or mental processing, in the absence of sufficient rest, results in insufficient cellular capacity or system wide energy to maintain the original level of activity and/or processing by using normal resources."*

In this definition the causes of fatigue are mentioned as: *prior physical activity and/or mental processing*. The way this is experienced is through a person's *muscles, viscera or central nervous system*. The effects are also included as: *insufficient cellular capacity or system wide energy to maintain the original level of activity and/or processing by using normal resources*.

If we look at human fatigue in general we can see that (even though there are small individual differences) it is a universal, omnipresent and treacherous phenomenon. **Universal** because it affects every person, no matter how much experience they have with fatigue or their level of experience. **Omnipresent** because it affects the physical and mental parts of the human body. **Treacherous** because humans are not very good at assessing personal levels of fatigue. We find it hard to objectively assess how good or bad we perform.

### 3.3 Separating fatigue from related factors

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Fatigue can be confused with a variety of other, often related feelings. There are three main points of confusion that will be discussed here: lack of motivation, boredom and habituation, sleepiness and tiredness.

#### **Lack of motivation, boredom and habituation**

Fatigue can sometimes be confused with a person's lack of motivation, being bored or showing signs of habituation. If we look at the final definition of fatigue from the previous paragraph we can see that these have no physical deterioration, no insufficient capacity. When someone is not motivated this has more to do with not having the right kind of personal goals or work incentives. Boredom can be linked with work that is too simple or work that does not present an interesting challenge. Habituation is due to work repetition. The person has done the same kind of operation for too many times and is becoming complacent. If someone has no influence on the work, this can also lead to habituation.

#### **Sleepiness**

Although sleep and fatigue are different they are also strongly linked. It is therefore important to make a clear distinction between sleepiness and fatigue. When we feel sleepy, it is because our body has been awake for about 14-18 hours. Even after a day of doing little to no work or exercise we can feel sleepy at the end of the day. After a hard day of work, we do not feel sleepy if we have been awake for only 10 hours, but we do feel fatigued. Fatigue can arise after being awake beyond the normal amount of daily wakefulness.

#### **Tiredness**

Tiredness and fatigue are usually treated as the same phenomenon although there is a small distinction. Tiredness has a more temporary nature than fatigue. We can be tired from doing a job during the morning and feel better in the afternoon after having rested a little during lunch. Fatigue has a more profound feeling. Better compared to having a couple of days hard physical (or mental) work. Tiredness goes away after a nice rest, fatigue needs one or more nights of good sleep before feeling 'restored'. In literature acute fatigue and tiredness are sometimes used as synonyms.

### 3.4 Different types of fatigue

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Fatigue can (for practical purposes) be put into different subcategories. These categories relate to the causes and pervasiveness of fatigue. Miller defined the first five types of fatigue ((Miller, 2005) being physical, circadian, acute mental, cumulative mental and chronic fatigue. A sixth type of fatigue is boredom fatigue. Boredom fatigue is becoming a larger issue in modern airplanes. Computers nowadays take over much of the flying. For pilots most of the work is done during take/off and landing. With flight durations easily surpassing the length of a typical eight hour workday, boredom is very common.

### **Physical fatigue**

A person is physically fatigued when the decreased physical capacity is due to overexertion (time duration or relative load) and degrades task performance. Feelings of physical fatigue are common and mostly well known. The level of physical fatigue depends on factors like the type of work that is performed, the overall physical condition, a person's age and gender. Previous periods of minor illness (flu) can deteriorate someone's physical condition making him or her more susceptible to high workload.

### **Circadian fatigue**

When the state of an individual's internal biological rhythm has a degrading effect on task performance, this is called the 'circadian effect'. The changes in the biological rhythm are caused by night work (shift-lag) or rapid changes of time-zones called jet-lag.



### **Acute mental fatigue**

When a person has been awake for more than approximately 16 hours, the mental capacity to perform tasks degrades. When this happens, we speak of acute mental fatigue. Acute mental fatigue can be restored with a good night's sleep of at least 8 hours.

### **Cumulative mental fatigue**

When a person has fragmented, shortened or disturbed sleep for 2 or more periods between major periods of being awake, it results in decreased mental capability and degrades task performance. Cumulative mental fatigue needs more than a single major period of sleep to be restored.

### **Chronic fatigue**

This is a factor when the individual is exposed frequently during at least one month to multiple periods of prolonged wakefulness, excessive work hours, disturbed or shortened major sleep periods, unresolved conflicts, or prolonged frustration and it degrades task performance. An individual must display, concurrently, four or more of the following symptoms: the desire to sleep, apathy, substantial impairment in short-term memory or concentration, muscle pain, multi-joint pain without swelling or redness, headaches (of a new type, pattern or severity), unrefreshing sleep, and post-exertion malaise lasting for more than 23 hours. The symptoms must have persisted or recurred for at least one month. Chronic mental fatigue is not eliminated by any number of sleep periods without removing the cause (source: Miller).

### **Boredom fatigue**

A phenomenon known as 'boredom fatigue' has been shown to decrease alertness by 80% in one hour (Colquhoun, 1976). Boredom fatigue arises when a pilot does not have a 'hands-on' job. In today's aircraft, the task of pilots is shifting away from 'hands-on' towards a monotonous monitoring function, keeping an eye on computer instruments that seldom fail. A risk that is associated with this is that slow changes are far more likely not to be detected than sudden changes. The analogy of the frog in hot water is often used: when a frog is put in cold water, the water can be heated and the frog will die. But if you put the frog in hot water right away, it will jump out immediately.

### 3.5 Causes of crew fatigue

There are very many factors contributing to fatigue. In their report about creating a framework for real-time monitoring of human fatigue (Qiang, et al., 2006) a model is created that visualizes the factors contributing to fatigue. The four main factors contributing to fatigue are: circadian rhythm, sleep, physical and mental condition and work environment and condition. These factors will be described on the basis of a typical civil aviation situation. Appendix 3 shows a 'bow-tie' model of fatigue (representing the causes that lead to fatigue and effects that originate from fatigue) including several modifications and additions made by the author.

#### 3.5.1 *Disruption of the circadian rhythm*

All humans are hardwired with a twenty-four hour biological clock: the circadian rhythm. The circadian rhythms refer to the cyclical changes (like body temperature, blood pressure and hormone levels) that occur over a 24 hour period (Sleep Foundation). In this cycle there is also need for sleep during the night, a need for being awake during the day. The cycle is continuously calibrated with outside cues: zeitgebers. These cues obviously involve light and darkness but we can also think of breakfast, lunch and dinner. In civil aviation these zeitgebers have been in use for many years. Passengers that fly across time-zones are presented with breakfast at sunrise, not when their body is feeling like breakfast. We can even create our own zeitgebers such a reading light material before going to sleep or always taking a walk during lunch. All this information is interacting with the hormonal rhythms dictated by the brain.

A lot of research has been done on the human circadian rhythm. Some of this research focused on the 'default' hormonal human rhythm. This meant putting people in semi darkness for a long period of time and observing their actions. The result was a rhythm of around 25 hours, explaining why it is easier to stay awake for an extra hour than to get up an hour early. It is hypothesized that 25 hour cycle is somehow associated with the lunar cycle of 24 hours and 50 minutes.

Other such research tried to change the 24 hour cycle by changing zeitgebers resulting in 19 hours of activity and 9 hours of sleep. The conclusion of these researches was that the brain has a strong preference for a twenty-four hour cycle. Evolution and the earth's rotation in twenty-four hours may explain this preference. There are two main causes of circadian rhythm disruption: shift lag and jet lag:

##### **1. Shift lag(the human body runs 'out of phase')**

Shift lag is when you have to be awake when you should be sleeping and when you have to sleep at times when you are normally awake. This situation is common among workers that work in shift-rotation schedules in many 24/7 industries. The zeitgebers, the environmental cues, are not synchronized to the internal body cycle creating fatigue and feelings of sleepiness at times when it is not desirable. A generally accepted scheduling practice in creating shift-schedules is to 'rotate forward' by adding a couple of hours to a new schedule. This is done because it is easier to start working later and to continue working longer. When starting at a later time it is possible to sleep more in the morning and when they get home, they are tired enough to fall asleep quickly. The other way around is much harder. Getting up a couple of hours early means cutting sleep short. When getting home, sleepiness is not obvious because it is usually daytime. This can be explained by the tendency for a 25 hour cycle as mentioned earlier.

The speed at which schedules rotate is still under debate. Some argue for fast rotations because the body will not get used to the unnatural work times and it



is easier to go back to relatively normal working hours. Others argue for slow rotations because small adjustments are easier to deal with. Adaptation to working at night time is always difficult because time cues continue to be out of sync.

Research done by (Folkard, et al., 2003) shows that both safety and productivity are reduced at night. The underlying factors include impaired health, disturbed social life, disruptions in sleep, shortened sleep. These factors result in a disrupted circadian rhythm. Folkard also mentions some ways to minimize the overall risk on a shift system by considering the number of consecutive night shifts, the length of the night shifts and the breaks during a night shift. He also stresses that these need to be looked at as a combination. For example, a 12 hour night shift that includes regular breaks may be safer than an 8 hour shift without proper breaks. Comparable are the amount of consecutive night shift and the length of these shifts. Three very long night shifts may be a greater risk than five short night shifts.

An **early report time** is strongly associated with shift-lag and short-haul flights. Report times can be as early as four o'clock in the morning. This means that crew has to get up three o'clock at night. This in turn means that the amount of sleep was short of the eight hours that is needed. If reporting time is at four, this also means going to bed at seven o'clock the previous day (to try to sleep for a full eight hours) and then getting up at three. The biggest problem here is going to bed at seven o'clock. If the circadian rhythm is not adjusted, this is for most people almost impossible (Spencer, 1997).

## **2. Jet lag (environment runs 'out of phase')**

Jet lag occurs when people fly through different time zones within a short period of time. The body is very quickly put into a new time zone with conflicting time cues. The internal body clock is still set to the original time zone so zeitgebers such as sunrise, sunset, breakfast, lunch and dinner come at the wrong moments. One of the problems during the first days is that we tend to wake up times corresponding to the place of departure and not feeling sleepy when the place of arrival is settling for the night. The body needs to adjust to these changes.

The amount the body has to adjust is relative to the time zones that were crossed. General literature often mentions that, as a rule of thumb, the body needs one day for every time zone. But this is just a general rule and often many more days are required. Based several on personal experiences, I would recommend to add at least another day for every 2-3 time zone crossings. This means that the body needs around eight days for crossing six time zones. But this 'adjustment time' also depends on whether the time zones were crossed in a westerly or easterly direction. When flying in a westerly direction the flight crew's day is lengthened and when the flight crew flies in an easterly direction, their day is shortened. A survey among 462 cabin crew showed (Sharma, et al., 2004) showed a slight preference for flying west (61.2%) in stead of east (38.8%). In schedules with shift lag, rotating forward (starting and ending a duty later than the previous duty) seems to be a little more easy than rotating backward. We can compare flying westward with rotating a shift forward and fly eastward with rotation a shift backward.

### *Short-haul and long-haul flights*

Crew that operates on short-haul flights is mostly affected by shift-lag. Standard short-haul schedules usually consist of multiple flights over 5 to 6 days. Sometimes duty periods begin in the afternoon or evening while on other days crew has to wake up at five in the morning. Short-haul crew sometimes experience very rapid changes in shift duration and the time of day when they have to report for duty. Long-haul crew that operates flights without changes in

time-zone (flying north- or southward) may also experience shift-lag. For crew that travels across multiple time-zones, the effect of jet-lag is also present. These are two typical examples of crew pairings that show shift- and jet-lag:

#### **Amsterdam – Johannesburg – Amsterdam**

No time difference during summer, +1 hour during winter

A direct flight from Amsterdam to Johannesburg departs at 10:30 in the morning and arrives at 21:10. Crew usually has to report 1,5 hours prior to departure time: 09:00. On average it takes around one hour to get to the airport and park the car or walk from bus or train station. When we take 1,5 hours to wake up and get dressed, crew has to get up at around 06:30. After a flight of 10 hours and 40 minutes the arrival time is 21:40. Since there is no time difference, crew can go to sleep. This flight does not have serious shift-lag effects.

Crew usually has a few days to spend at the destination.

The return flight is different however. Departure time is 23:30 hours and this means that crew has to report at 22:00 hours. Getting ready for the return flight ('calling') starts at around 20:30 hours. If we look at the previous days, there were no time-zone changes or shift-lag to deal with. This means that circadian rhythm is still 'in sync' with outside zeitgebers such as the day/night cycle. This means that trying to sleep during the day, in preparation of the oncoming night flight, is not very easy. The entire body says it's daytime and there are no signs that sleep is necessary. Departing at 23:30 and a flight duration of 10 hours and 50 minutes means that arrival time is 10:20. Working throughout the night has serious shift-lag effects.

#### **Amsterdam – Chengdu – Amsterdam**

Time difference during summer is +6 hours and during winter +7 hours

Departure time is 20:45 from Amsterdam. This means that crew has to report for duty at around 19:15 and has to depart from home at around 18:15 (realistically this would be earlier when road traffic is high during rush-hour). What could be said for the return flight from Johannesburg to Amsterdam can be said for this reporting time. Trying to get extra sleep during the day will be very hard. After departing at 20:45, flying for 9 hours and 45 minutes and crossing six time-zones, the arrival time at Chengdu is 12:30 local time (06:30 in the morning, Amsterdam time). This flight has shift-lag effects (working through the night) and jet-lag effects (local time is six hours ahead of 'body' time). Another important part of this trip is that the landing phase takes place near the end of the 'circadian low' period.

Crew usually has a couple of days to spend at the destination

Departure time for the return flight is 14:00 local time. After departing and flying for 10 hours and 50 minutes, arrival time at Amsterdam is 18:50 (local time in Amsterdam). The time at the place of departure (Chengdu) is then 00:50, for the last two days the crew has been asleep by this time. But now cockpit crew has to land the aircraft safely and cabin crew has to be prepared to handle any emergency.

Note: Departure and arrival times are examples that were taken from actual timetables found on the internet.

### 3.5.2 Disturbance of sleep patterns

A shortage of sleep is one of the most important causes of a decrease in human function and the increase in fatigue. Alertness and performance get impaired by shortening a typical night rest by just two hours (Caldwell, 2003).

Sleeping is very much like eating, drinking and breathing. It is a vital life function. Feelings of sleepiness and drowsiness are signs that the body has not had enough sleep. The strength of sleepiness can be so strong that, even with our best efforts, at times we cannot resist it. No matter what the environment, whether we are driving a car, flying a plane or doing deskwork, people sometimes fall asleep outside their own control. And at times this even happens without them realizing it ever occurred. These are usually called micro sleeps.

During sleep, the body recovers from physical and mental exertion. In this recovery process changes in the body such as lowering of blood pressure and heart rate and the widening of the blood vessels occur. The digestion process also slows down.

The quality of sleep is determined by different factors. Just closing your eyes for 8 hours is not enough. We all know that the environment in which we sleep can have a great effect on how well we sleep. These are the important factors that influence the quality of sleep:

#### Insufficient, fragmented and disturbed sleep

Insufficient sleep during the previous 24 hours is usually called “*acute sleep loss*” because it happened ‘over night’ instead of being a chronic problem. The average amount of sleep a person needs is between 7½ and 8½ hours in every 24 hour cycle. If less sleep is obtained over a period of several nights we speak of a *sleep deficit*. This deficit is the cumulative number of hours that was missed during the previous days. As a rule of thumb we need one hour of extra sleep for every two hours of sleep deficit.

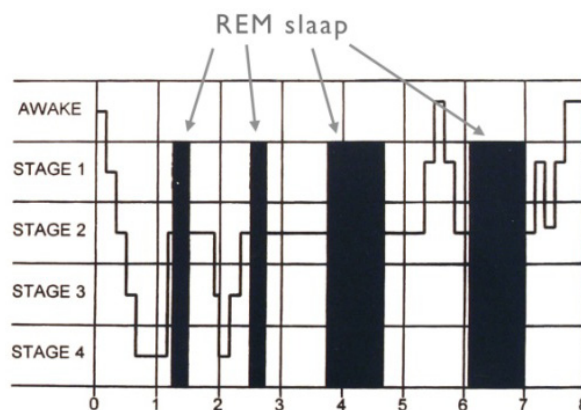


Figure 8 Sleepfases and REM sleep during an 8 hour sleep period (Campbell, et al., 2002)

Fragmented sleep (or rest) occurs when a person is regularly being awakened during the night. This usually happens due to environmental factors like noises (i.e. in hotels), light and temperature. But someone can also be awakened on a regular basis due to family issues (young parents). These awakenings have an effect on the sleeping pattern. As we can see in the representation of a typical 8 hour sleep period there are several cycles and stages that one goes through. During each cycle most of the stages are passed but each cycle last for a different time period. Especially REM sleep is an important part of the sleep process during which improvement and organizing of memory takes place. All the things that have happened during a day get processed during REM sleep. Numerous studies have been conducted on the sleep pattern alone. They all

agree that if you are awakened several times during a night, but in all 8 hours of sleep were still recorded, the recuperation is never as good as when you have slept through the entire night (Campbell, et al., 2002).

### Age

Sleep patterns change with age (Gander, 1993). New born babies sleep around 16 hours a day and young children sleep for up to 14 hours a day. This changes drastically as one becomes older. As soon as we reach childhood the time that we spend sleeping reduces to around 8 or 9 hours. After reaching early adulthood it settles at approximately 7 to 8 hours. This need for sleep does not change very much after that, even for older people. What does change is the sleep pattern. Older people tend to sleep shorter but more often. Sleep at night is no longer one long 'stretch' of 8 hours but is broken up into many parts because they regularly wake up. Sleep experts say that this break-up starts as early as around the age of 40. An effect of this is that older people tend to need naps during the day.

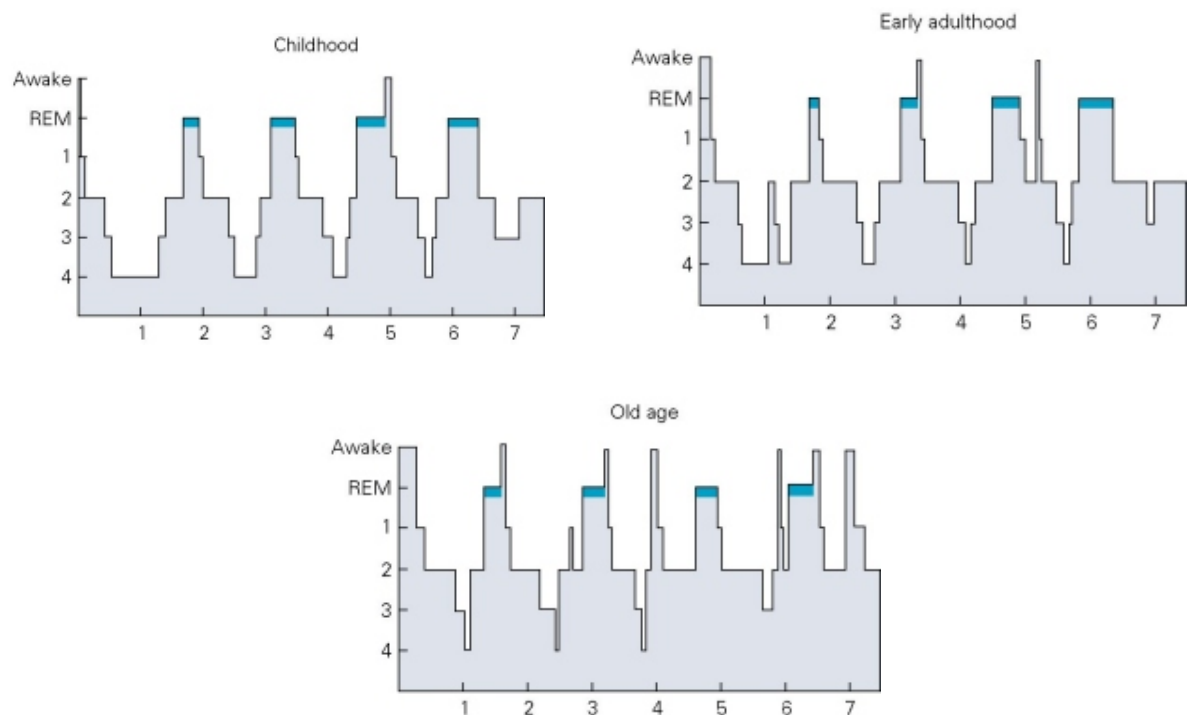


Figure 9 changes in the sleep pattern with the coming of age

### Time since last period of sleep

The time since the last major sleep period is an important contributor to fatigue. When we take an eight hour period as a normal sleeping period it leaves 16 hours a day for activities. When flying a long-haul stretch that departs at the end of the day, and this is not very unusual, it means that the time since the last period of sleep can reach more than 20 hours. Such a long period of wakefulness changes the sleep pattern in the next sleep periods (acute sleep loss).

### Insufficient rest

Rest is never equal to sleep. By resting it is possible to feel a little better but it can never compensate for true sleep. But that doesn't mean that rest is not important. Rest and sleep are linked in the way that rest always has to precede sleep. After ending a duty there has to be a time of relaxation before getting to

sleep. Going straight to bed usually means that falling asleep is difficult. As we noted when defining fatigue in one of the previous paragraphs, rest only alleviates feelings of tiredness after minor activities.

Another period in which rest has to be taken into account is the time just after waking up. This period is called sleep inertia and lasts from a couple of minutes to as much as an hour. In this time body temperature has to rise in order to reach a fully awakened state (Krauchi, et al., 2004). A period of rest after waking up is therefore important.

### 3.5.3 *Deteriorated physical and mental condition*

#### **Medical problems**

There are several medical conditions that are associated with sleep loss and fatigue. Some common conditions that cause sleep loss and sleep fragmentation are 'restless legs' and sleep apnea. 'Restless legs' is a condition where twitches and movement of the legs repeatedly wake up the patient. Sleep apnea is a condition where the person stops breathing for a considerable period of time, wakes up because of a build up of carbon dioxide and continues breathing normally. The danger of these conditions is that they are very hard to notice because the person has no recollection of it happening. But the result is waking up as tired as when going to bed.

#### **Lifestyle**

There are several lifestyle factors that effect fatigue. These lifestyles have the possibility to enhance or reduce a person's capability to deal with fatigue inducing situations. Healthy nutritional habits work both ways. Eating vegetables improves health while eating unhealthy (fast) food and regularly consuming alcohol can reduce general health. Regular exercise improves the overall condition of the body, increasing the ability of dealing with fatigue. Some people work second jobs to add to their income. If these second jobs claim a considerable amount of time and effort they can contribute to fatigue.

#### **Psychological factors:**

Psychological factors can result in mental as well as physical fatigue. Factors include depression, stress, problems in personal relations and mourning.

### 3.5.4 *Unfavourable work environment*

Cockpit and cabin crew work most of their duty hours in a pressurized cabin at high altitude. This unnatural environment means that crew is under the influence of fatigue related effects

#### **Air**

Airplanes try to balance energy efficiently to reduce cost. With respect to the air in the cabin a trade off is made between adequate ventilation, clean air, temperature and humidity. If the ventilation with outside air is reduced and the little outside air is mixed with re-circulated air, this results in higher concentrations of carbon dioxide. Concentrations of other airborne components from the airplane's interior, engines and passengers also rise.

Another trade-off is made between temperature and humidity. Air with a high level of humidity requires more energy to bring to a specific temperature. And since air at very high altitudes has very little humidity to begin with, it is costly to bring humidity and temperature levels to a comfortable level. As a result air inside a pressure cabin is usually dry and temperature is in the lower regions of comfort.

#### **Noise**

Aircraft noise is generated by the engines and passes into the cabin through the airframe and through the air. Noise has two effects of fatigue: continuous noise

leads to mental fatigue and noise can disrupt sleep. According to the American Speech-Language-Hearing Association, noise can reduce task performance, increase fatigue and cause irritability. The inability to hear others or having to listen very carefully and the need to speak loudly leads to fatigue. Tests were done by comparing test results from schools that were near railways and schools that were in a quiet environment. Although there may be additional factors, according to the American Speech-Language-Hearing Association noise induces fatigue and reduces human performance.

#### **Work in a very confined space**

The body of an airplane is a very small space to work in. Even the large wide-body aircraft offer little space for work. Every part of the aircraft is used to transport passengers and cargo. But although they both share the confined space of an airplane, the work conditions for cockpit and cabin crew are somewhat different. Cockpit crew has to remain seated in a fixed position, often for very long periods of time. Even though manual and physically intensive controls have been replaced with modern hydraulic fly-by-wire controls that operate without the need of much force, there are still causes of physical fatigue. Just consider how tiring a long-haul flight for most passengers can be. And they don't have to fly the airline.

For pilots, the workload prior to and during take-off and landing is very high, this is mostly a problem for short-haul crew that fly multiple stretches every day. The type of work done by cabin crew on the other hand is much more labour intensive. On short flights there is often not much time to rest because the service to customers takes up most of the flying time. A recent study done by a Dutch cabin crew union (FNV) shows that the levels of physical work were experienced as high to very high.

#### **Altitude effects**

This is amplified by the altitude effects on physical capacity. At higher altitudes there is less oxygen in the air, this means the heart has to work faster to try to get the needed amount of oxygen. This effort requires a considerable amount of energy as is often experienced by mountaineers.

As we can see, the conditions in which flight crew must work are considerably different from the typical conditions of for example building based offices.

### **3.6 Effects of crew fatigue on the human body**

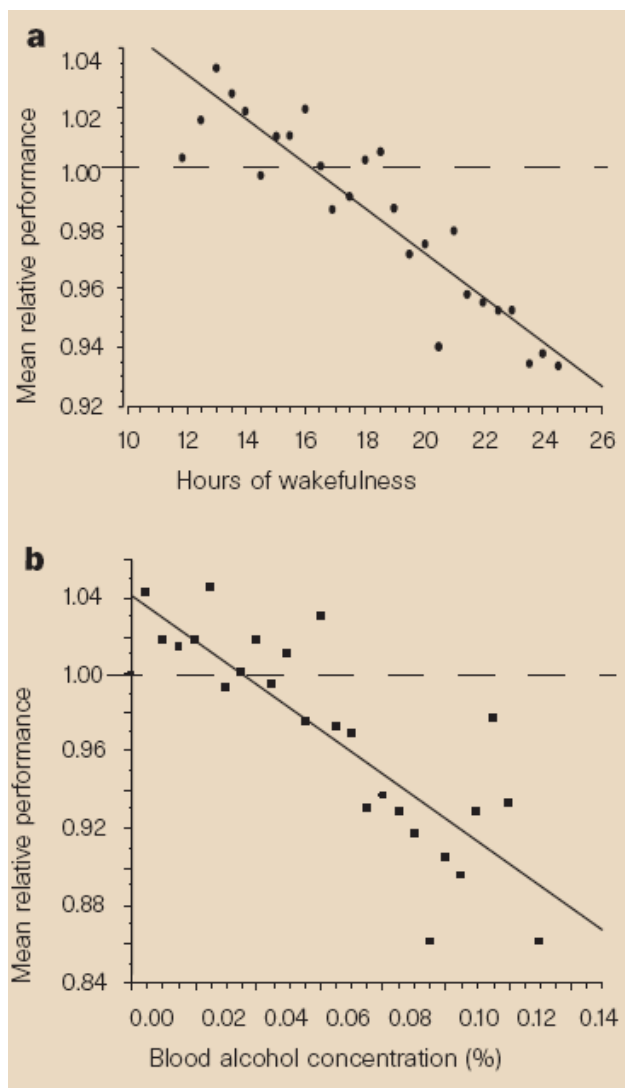
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A hazard is situation that has the potential to cause damage, harm or death. Identifying hazards is (or should be) a continuous process in airline organisations. All the effects of fatigue described in this chapter have the potential to cause damage, and are therefore hazards. Before we look at the effects it is useful to have a look at something that fatigue is often compared to: being under the influence of alcohol.

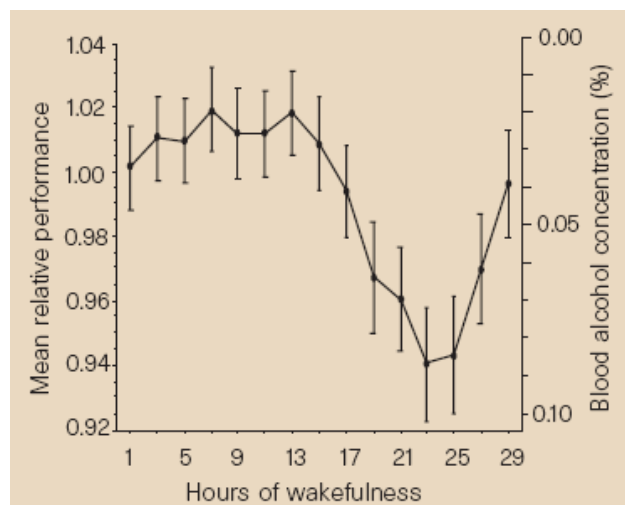
#### **3.6.1 *Comparing fatigue to the effects of alcohol, a practical approach***

Alcohol is a well known, and quantifiable, hazard for all forms of transportation. Different studies (Dawson, et al., 1997), (Williamson, et al., 2000) on the effects of sleep deprivation and alcohol show that the effects of being awake for a prolonged period of time correspond closely to the effects of alcohol. In the study by (Dawson, et al., 1997) forty subjects were separated into two groups. One group (a) was kept awake for 28 hours while the other group (b) consumed very specific amounts of alcohol at 30 minute intervals until their blood alcohol concentration reached a level of 0,10%. Both groups had to do cognitive psychomotor tasks at 30 minute intervals using computer administered tests of hand-eye coordination. The results of this test are shown in Figure 11 and Figure 10.





**Figure 10 Plot of relative performance against time hours of wakefulness and B.A.C.**  
(Dawson, et al., 1997)



**Figure 11 Hours of wakefulness expressed as mean relative performance and blood alcohol concentration.**  
(Dawson, et al., 1997)

Unlike measuring the 'blood alcohol concentration, it is hard to measure fatigue. The result of this is that fatigue does not seem to get the same attention from policymakers as the use of alcohol. Proving that fatigue contributed to an accident is much harder than proving that alcohol was involved. Figure 11 can be helpful in this aspect. This figure links 'hours of wakefulness with the blood alcohol concentration. With this index it is possible to create a norm for prolonged wakefulness in combination with specific tasks. For example, if a driver is not allowed to drive with a blood alcohol level of 0.05%, it should also not be allowed to drive after being awake for more than 18 hours.

Australian research done by (Williamson, et al., 2000) also compares the effects and alcohol with those of fatigue. This test was designed in much the same way as the test before but with an important difference. Two separate groups participated. One group consisted of long-haul professional truck drivers and the other group consisted of people who were otherwise employed. This way the study investigated the possibility that professionals might be better to anticipate and postpone the effects of fatigue on performance. Important conclusions of this very extensive study were:

"This study clearly demonstrated that sleep loss produces notable effects on fatigue and on performance. Performance effects include a range of tests of functions likely to be important for driving such as reaction speed and accuracy, vigilance and hand-eye coordination."

"Using the legal limit for alcohol use when driving as the standard, the results showed that after around 17 to 18 hours of sleep loss, subject's performance on many tests had dropped to that seen at the legal limits for safe driving. While many people remain awake for periods of 16 hours or greater for reasons due to their work, family or social life, these results suggest that it is around this length of wakefulness that fatigue reaches a level significant enough to compromise performance capacity. Any decrements in performance resulting from sleep deprivation may, as a result, compromise safe performance and in turn potentially increase crash risk."

The results also showed that the professional truck drivers were more accurate but slower than the control group. They made a trade-off between time and accuracy. Unfortunately for pilots, time is very short during high levels of workload such as during take-off and landing.

Now that we have seen that the decrease in vigilance and reaction time compare closely to alcohol levels around or in excess of the legal limit, we will look at the effects (Rosekind, et al., 2001) more closely.

### 3.6.2 *Effects on the brain*

#### **Decrease in short term capacity**

As levels of fatigue increase the capacity of the short-term memory also decreases (NASA, 2000), (Neri, et al., 1997). Sometimes up to a point where everything needs to be written down because the short-term memory is practically non-functioning. Short messages and signals are being heard and seen but they do not get processed. This lack of short-term memory can make crew insecure and indecisive.

#### **Decrease in concentration and attention**

A decrease in the attention span and level of concentration is also associated with a rise in fatigue levels (NASA, 2000). The cockpit environment is a place moments that need a high level of concentration are quickly followed by periods that need little concentration. This makes lapses in concentration especially dangerous because a low level of concentration may only become noticeable at critical moments like landing an aircraft or sudden problems.

#### **Decrease in performance**

The performance of the brain decreases with an increase of fatigue. Since the brain is central to most actions that we take, there are several noticeable effects. Just as with alcohol use, both the speed and accuracy of physical and mental tasks decreases (Dawson, 1998). People who are fatigued may show a decrease of 5 to 25 percent compared to a well rested state. This is a result of a trade-off that the body makes. To keep up a high level of accuracy the brain has to decision time.

A decrease in accuracy and timing may lead to several types of mistake like the improper use of onboard computers. Landing on the wrong runway, improper navigation and flying incorrect altitudes are big concerns. The acceptance of lower levels of performance can lead to flight-path deviations. Delays in responses during in-flight emergencies can also lead to potentially dangerous situations (Caldwell, 2003).

#### **Narrowed focus**

Fatigue brings on a narrowed focus. The brain needs all it's capacity to process a single source of information and has little 'attention' for what happens in the rest of the environment. This means that critical audible and visual signal can be missed or misinterpreted.

#### **Changes in voice patterns**

Although not as noticeable as other effects, the human voice changes when the brain becomes fatigued. Research (Shiomi, 2000) has shown that it is possible to detect changes in how words are pronounced as one becomes fatigued. This usually means that the words are spoken in a less articulate manner.

### 3.6.3 *Effects on facial features*

#### **Facial expressions**

Scientific knowledge about the causes and effects of yawning is relatively limited but yawning may be the best known, and most harmless effect of fatigue associated with sleep deprivation. Yawning is an evolutionary process that can be found in all vertebrates, from human to birds, fish and reptiles. Yawning has its biological roots in the brainstem, the 'oldest' part of the brain that is responsible for primary functions like breathing, the sleep/wake cycle, pupil diameter, touch and taste. Some have suggested that the extra amount of air due to yawning increases the level of oxygen and thus the level of attention. Others such as Gallup suggest that yawning has a temperature regulating function in the case of a non-optimal body temperature. Fatigue and sleep deprivation are associated with changes in body temperature.



### **Eye features**

When the body is fatigued due to a lack of sleep, the pressure to get some sleep can become so high that eyelids become 'heavy' and close more often. PERCLOS (Dinges, et al., 1998) is the percentage of eyelid closure over the pupil over a specific time period. It focuses on slow eyelid movements rather than normal blinking of the eye. The slow eyelid movements are associated with tiredness. The percentage of eye closure is considered to be a valid measurement of fatigue. Validation studies are done by the Federal Highway Administration and the National Highway Traffic Safety Administration (Federal Highway Administration, 1998). Another measurement of a characteristic of the eye is AECS which is the average eye closure speed.

The 'eye-gaze' or eye fixation distance and the saccade ratio are also associated with fatigue (Heitmann, et al., 2001). Fatigue is associated with 'staring' instead of 'looking' thus the eye gaze can be a measure of fatigue. The fixation saccade ratio is a measure of how quickly the eye follows passing objects. This eye movement can be observed when a person looks out of the window of a moving train or car.

### **3.6.4 *Effects on the skin***

#### **Body temperature**

When we get fatigued, we usually have a need for warmth. This is because the blood circulation in the skin is reduced in order to make sure that enough blood gets supplied to the organs. The hands, feet and the face are the first body parts that get colder. On the other hand, the core temperature rises. Sleep deprivation results in a non-optimal body temperature regulation.

#### **Skin conductivity**

This effect of fatigue on the human body may well be the least noticeable, but research (Pazderka-Robinson H, 2004) has shown that skin conductivity is higher for people with (chronic) fatigue. It is probable that this change in skin conductivity is the result of internal physiological mechanisms.

### **3.6.5 *Effects on body posture***

When the body becomes fatigued, its ability to maintain a stable position reduces. We feel less stable and lose our footing more often. Most people have had this kind of experience on more than one occasion. Both mental and physical fatigue impacts stability because stability is a combination of our interpretation of what we see and how we react with the muscular system.

### **3.6.6 *Effects on the head***

One of the more noticeable effects is seen in movements of the head. As fatigue sets in, the position of the head changes and tends to tilt more forward. Another typically seen effect is head nodding. The frequency of this head nodding can be a good indicator of fatigue.

### **3.6.7 *Individual differences***

There is still no real consensus about how much (and why) fatigue differs between individuals but some seem to be able to cope better with fatigue than others. In this field, Functional Magnetic Resonance Imaging shows potential for predicting individual differences in fatigue vulnerability (Caldwell, et al., 2004).

### 3.7 Effects of fatigue on overall flight operations

In this chapter the effects of fatigue on several parts of the flight operations process will be discussed. The first part is a short summary of major incidents and accident of the recent past. The selection was based on the accident description. In these cases, fatigue was cited as being a considerable contributing factor to the event. Other effects such as sick leave, cost and unwanted sleep are also discussed in this chapter.

#### 3.7.1 *Examples of incident and accidents where fatigue was involve*

This paragraph sums up several accidents where fatigue was a contributing factor. These cases range from the nineteen seventies until today. Besides examples in the aviation industry other examples are also included.

❖ **2008: Go! Airline flight 1002 overshoot its destination airport at Hawaii**

In this recent incident the aircraft overshoot its destination airport, air traffic controllers were not able to contact the pilots for 25 minutes. The NTSB is investigating the event and is seriously considering the possibility that the pilots were asleep. Both Go! Airlines pilots were subsequently fired. Two reports can be viewed on the internet:

**YouTube:** <http://www.youtube.com/watch?v=PkAROrj2v3U>

**MSNBC:** <http://www.msnbc.msn.com/id/21134540/vp/23307854#23307854>



❖ **2007, Pinnacle Airlines flight 4712 ran off runway (landing) at Cherry Capital Airport**

The official NTSB report of this accident mentions fatigue as one of the two contributing factors. The weather conditions at the airport were deteriorating quickly and the runway had considerable contamination. This meant the pilots had to performing a 'landing distance assessment' but they did not do so. The NTSB report concludes that this poor decision-making reflected the effects of fatigue produced by a long, demanding duty day.

❖ **2007: Runway overrun of Delta Connection flight 6448**

On February 18th 2007 an Embraer landed during snow conditions and overran the end of the runway and collided with the ILS system and airport fences. The NTSB cites as the probably cause: "The National Transportation Safety Board determines that the probable cause of this accident was the failure of the flight crew to execute a missed approach when visual cues for the runway were not distinct and identifiable. Contributing to the accident were (1) the crew's decision to descend to the instrument landing system decision height instead of the localizer (glideslope out) minimum descent altitude; (2) the first officer's long landing on a short contaminated runway and the crew's failure to use reverse thrust and braking to their maximum effectiveness; (3) the captain's fatigue, which affected his ability to effectively plan for and monitor the approach and landing; and (4) Shuttle America's failure to administer an attendance policy that permitted flight crewmembers to call in as fatigued without fear of reprisals".

❖ **2004, Kirksville, Missouri, Corporate Airlines flight 5966**

The aircraft struck several trees on its final approach and crashed short of the airport. Both pilots and 11 passengers were killed. Two passengers received serious injuries.

❖ **2004, Baltimore-Denver, undisclosed airline**

In March of 2004, two commercial pilots of an Airbus A319 fell asleep on a flight between Baltimore and Denver, USA. Both were woken up by calls from ATC.

❖ **2004: Take-off crash of MK Airlines 747**



Because the crew entered incorrect data into the onboard flight computer the aircraft crashed on take-off. The Canadian Transportation Safety Board mentions that crew fatigue was involved in at least two ways. (1) *Crew fatigue likely increased the probability of error during calculation of the take off performance data, and degraded the flight crew's ability to detect this error.* (2) *Crew fatigue, combined with the dark take-off environment, likely contributed to a loss of situational awareness during the take-off roll. Consequently, the crew did not recognize the inadequate take-off performance until the aircraft was beyond the point where the take-off could be safely conducted or safely abandoned.*

❖ **1999: Crash of “Avions de Transport Regional” ATR-42 near Pristana, Kosovo**

After departing from Rome, the aircraft was going to land at Pristina. After flying over the airport, the airplane struck a mountain while turning to return to the airport. The BEA (Bureau Enquêtes – Accidents) mentions several causes for this accident, one of these causes is described as: “teamwork which lacked procedural discipline and vigilance during manoeuvres in a mountainous region with poor visibility”. This low level of vigilance was in turn caused by crew fatigue. 24 People were killed.

❖ **1999: McDonnell Douglas MD-82, Adams Field Airport in Little Rock, Arkansas**



In this flight an American Airlines MD-82 (flight 1420) overran the end of the runway and went over an embankment. After flying from Chicago to Salt Lake City and Dallas, this was the third stretch of that day. At the time of the accident there were rain and thunderstorms. In an investigation of the NTSB the probable cause of this accident was that the crew did not discontinue the approach. Fatigue was cited as one of the three major factors that led to this decision “*Contributing to the accident was the flight crew’s impaired performance resulting from fatigue*”. Continuing a course of action in spite of easily accessible contradicting information, is a common effect of fatigue.(NTSB, 1999).

❖ **1998: Thai Airways Airbus A310 at Surat Thani, Thailand**

Thai airways flight 261 crashed during its third non-precision approach (the ILS was not in service) to the airport of Surat Thani. Weather conditions were poor with little visibility and heavy rainfall. Crew fatigue played a part in this crash that killed 101 passenger and crew. No official report on this crash could be found at this moment.

❖ **1997: Korean Airlines Flight 801**



Before the flight to Guam the captain of this flight had flown Seoul – Australia – Seoul – Hong Kong - Seoul on just a few hours of rest. Besides concluding that “*The captain was fatigued, which degraded his performance and contributed to his failure to properly execute the approach*”, the NTSB report on this accident also mentions that “*CVR evidence indicated that the captain was tired. At the beginning of the approach, the captain made unsolicited comments related to fatigue, stating “eh...really...sleepy.”*”



❖ **1993: Guantanamo bay**

The accident at Guantanamo Bay is probably one of the best known accidents that has been related to fatigue. (NTSB, 1993). The flight crew had been on duty for 18 hours and flown nine legs. According to the NTSB, the probable causes of this accident were *“Impaired judgement, decision making and flying abilities of the captain and flight crew due to the effects of fatigue”*.

❖ **1979: De Havilland Rockland Maine**

In May of 1979 a DeHavilland DHC-6 crashed near the airport of Rockland, Maine killing 17 people onboard. Several errors were made but one of the conclusions of the NTSB was that *“The captain probably suffered from job-related stress which resulted in chronic fatigue”*.

**Examples in other industries:**

❖ **1989: Exxon Valdez, Alaska**

The United States tank ship Exxon Valdez ran aground in Alaska in 1989. Oil being spilled from the ship resulted in a huge environmental catastrophe costing almost 30 million dollars to clean up. The probable cause of this accident included human fatigue (source: [www.nts.gov](http://www.nts.gov)). The sleep-deprived third shipmate was steering the ship without help from his supervisors. He missed warning signals, failed to remain in the shipping channel (marked by navigation buoys) and so ran the ship aground.

❖ **1986: Chernobyl, Russia**



The meltdown of the Chernobyl nuclear reactor was partly the result of actions taken by night-shift personnel. A test was initially scheduled for day-time workers but had to be postponed because of problems with a nearby power plant. The night-shift had to start testing without preparation. The test consisted of shutting down the reactor to see whether the generator still had enough power to cool the installation during the time needed for the diesel back-up engines to start up. The night-shift operators shut down the reactor too soon resulting in a complete meltdown with catastrophic results.

❖ **1979: Three Mile Island Nuclear Reactor, Pennsylvania**

An incident occurred when night-shift personnel did not notice a problem with the reactor's cooling system, thus not taking corrective action. The effects of fatigue contributed to this near melt-down.

### 3.7.2 Sick leave

Crew that experiences high levels of work load and regular sleep disruptions may develop chronic fatigue syndrome. Although this syndrome is by some considered a 'catch-all' term for many little understood disorders, preventing it from occurring can reduce the percentage of sick leave due to fatigue. Exact numbers are very hard to obtain because airlines (as most companies) do not offer these numbers easily. But in a quick scan report made by a large cabin crew union on work pressure, 41% reported calling in sick within the past 6 months, 47% said they had health problems, 88% percent reported flying as the main cause of these health problems.



### 3.7.3 Unwanted sleep during flight

Falling asleep during flight poses a very serious threat to aviation safety. Falling asleep is a clear sign of the human body being too fatigued because it has not had enough time to recuperate by sleeping. There are two distinct forms of sleep, normal sleep and micro sleep.

#### Micro sleep

Fatigue may cause pilots and cabin crew to experience micro sleeps. A micro sleep is a brief period of sleep that lasts for three to five seconds. The danger of micro sleeps is that people who experience them may not always be aware of it. There has been a case in which both pilots experiencing a micro sleep minutes away from landing only to be woken up by the flight engineer who noticed the aircraft veering off course. The crew decided to make a go-around.

#### Significant periods of sleep

There have been numerous cases in which pilots fell asleep during flight. In fact, in some airlines it is one of the tasks of the cabin crew to check the cockpit crew (about every 30 – 45 minutes) if they have not fallen asleep. Cases of cockpit crew falling asleep date back from decades ago until very recent. In the 1950's a DC-7 crew fell asleep, flew over Los Angeles airport (its destination) and then flew out over the Pacific Ocean. When they woke up, there was only just enough fuel left to return to the airport. A more recent case (2004) is that of an Airbus A319 flying too high and too fast while being just 20 minutes from landing. The crew was woken by repeated calls from ATC. The captain admitted he was asleep and reported the case to NASA's Aviation Safety Reporting System. The pilot said that flying three nights in a row caused him to fall asleep. Currently there are two ongoing NTSB investigations on incidents of aircraft overshooting the airport. These incidents are likely to be related to pilots falling asleep.

Note: in some companies 'planned cockpit napping' is used as a counter-measure to reduce fatigue. This is discussed in the next chapter.

### 3.7.4 Costs



Figure 12 Accidental slide deployment

It is very difficult to quantify the cost that is associated with crew fatigue. One can think of the cost due to unnecessary sick-leave. Chronic fatigue is known to lead to weeks or even months of sick-leave. Other costs which are the result of fatigue are those of avoidable mistakes. A common mistake is that of an inadvertent slide deployment. The IATA estimates that these inadvertent slide deployments cost the industry around 20 million dollar each year.

Besides the costs of sick-leave and avoidable mistakes, there are the costs of an accident to which fatigue has contributed. The ICAO safety management manual distinguishes direct and indirect costs. Direct costs are those that are the result of physical damage to aircraft and property at the crash-site, replacing the aircraft and compensation for sustained injuries. Although most of the direct costs can be insured, indirect costs usually cannot. The indirect costs of an accident include: loss of business, damage to reputation, loss of staff productivity, investigation and clean-up costs, damage claims and many more. In the case of an incident (no total loss of an aircraft) the associated costs are due to flight delays or cancellations, alternative transport for passengers, cost of reputation and so on.

Flight cancellation or delay can also be the result of flight crew that report themselves as 'not fit to fly'. Typically, the amount of time available at the destination is not enough to adjust to a new time-zone or to recuperate from very early or late duty times. As with numbers on sick-leave, information on how often this occurs is hard to obtain. Recently (April of 2008) a British Airways pilot declared himself too fatigued to fly and the entire flight was cancelled. All passengers had to be offered a hotel-room.

### 3.7.5 *Degraded situational awareness*

The term 'situational awareness' is used to explain how much aware a person is of his surroundings. The formal definition used by (Endsly, et al., 2000) of situational awareness is: "*the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*". For pilots, having a good situational awareness is very important to safety of flight. Pilots build up this image in their mind by using as much information as possible. They interpret the flying route, the information from the primary flight display, past experiences and information from radio sources. At the Johns Hopkins University (Applied Physics Laboratory) research for the US air force is being done on the relationships between fatigue and situation awareness.

### 3.7.6 *Adoption of simpler but riskier strategies*

People who are fatigue are more inclined to take easy shortcuts to reduce levels of mental effort. Shortcuts are based on past experiences and rely heavily on the absence of new complicating situations. In the case of a (non acute) dangerous or critical situation, people don't work through all the options systematically. Once a strategy is taken, this strategy is often persisted upon. Even when new information that indicates a different strategy is presented.

### 3.7.7 *Variations in performance*

One of the most important effects of human fatigue is the increase in performance variability (Miller, 2005). The effects of fatigue do not increase in a linear fashion. The 'transition phase' consists of levels of high, normal and low performance. Varying levels of performance is a clear sign of fatigue (Caldwell, 2003). The variability means that at one point a person seems fit and able to perform a safety related task when a few moments later the same person may be inadequate to perform the same task. This may give a false sense of security. How long and how often these periods of increased or decreased performance occur is, for now, not possible to detect. Especially with passive monitoring tasks like those often found in cockpit situations, it is hard to notice the performance variations.

### 3.7.8 *Complacency, decreased motivation and risk taking*

According to Caldwell decreased motivation, complacency and an increase in risk taking are often associated with high levels of fatigue. Automation complacency means that pilots (and cabin crew!) rely on the heavily automated systems for controlling the airplane and the high level of safety they have brought. NASA did research in "the relationship between self-efficacy<sup>2</sup> and complacency in pilot automation interaction" (Lawrence, 2002).

The Dutch Air Transport Safety Institute (A. Roelen, NLR) also sees extra risk taking due to fatigue as an important effect and as a possible threat to safety. Approaches that should have been aborted and reattempted are continued in order to avoid delays and 'get home'. A term used in this regard is that pilots have a case of "get-there-itus".

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<sup>2</sup> Self-efficacy is an impression that one is capable of performing in a certain manner or attaining certain goals. It is a belief that one has the capabilities to execute the courses of actions required to manage prospective situations. Unlike efficacy, which is the actual power to produce an effect (in essence, competence), self-efficacy is the mere belief (whether or not this is accurate) that one has the power to produce that effect. (source: wikipedia)

### 3.7.9 Crew coordination and moods

A lack of interest in social interactions and a bad mood or temper can lead to a breakdown of crew interactions. This can pose a safety hazard because a good interaction between crew is important to manage tasks and duties. Crew Resource Management is considered to be a safety critical part of aviation and is very dependent on good, clear and logical interactions between crew.

## 3.8 Countermeasures to the effects of fatigue

Most countermeasures for fatigue are just what they are: countermeasures. They do not prevent fatigue but they prevent or mitigate the effects of fatigue. Countermeasures are band-aids. But this does not imply that they are useless or should be forgotten. As long as fatigue remains an issue, it is important to look at countermeasures and how they can be helpful.

### 3.8.1 Caffeine

Caffeine is the only 'drug' that is allowed in civil aviation. There are two advantages to the use of caffeine. Caffeine is widely available in coffee, tea, and soft drinks and in over the counter medications. Caffeine is very effective for decreasing the feeling of sleepiness. This effect is stronger for people who do not use caffeine in large amount on a regular basis. Although there are ways to strategically use caffeine, relying on the effects of caffeine for a long period of time is not recommended. The body adjusts to the permanent high levels of caffeine and the beneficial effect on sleepiness diminishes.

Caffeine can be a useful countermeasure when used properly. It is important to use caffeine properly. This means avoiding it when one is already alert and awake. Caffeine should only be used when sleepy or 15 minutes before an important period of alertness is expected. Caffeine can also be used just after

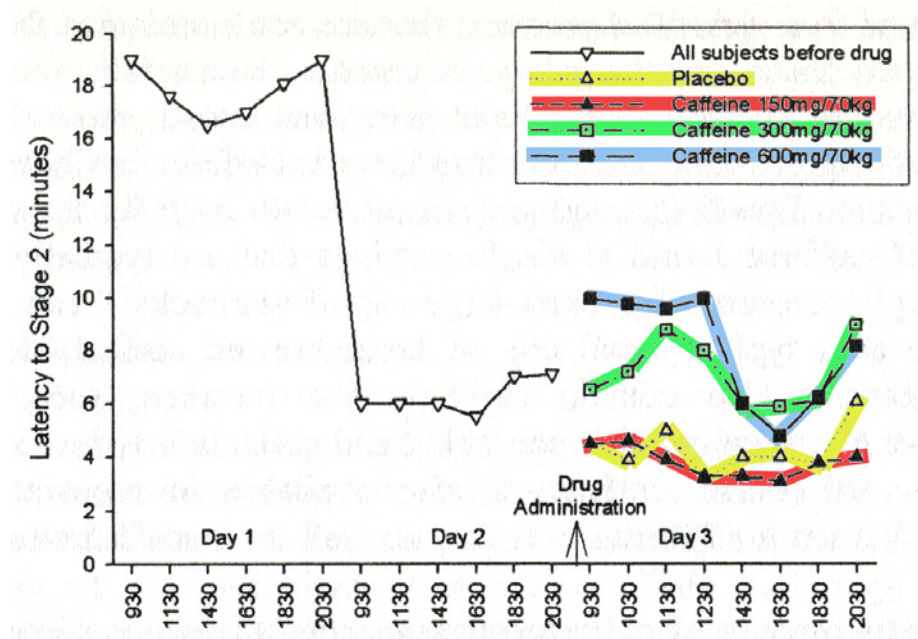
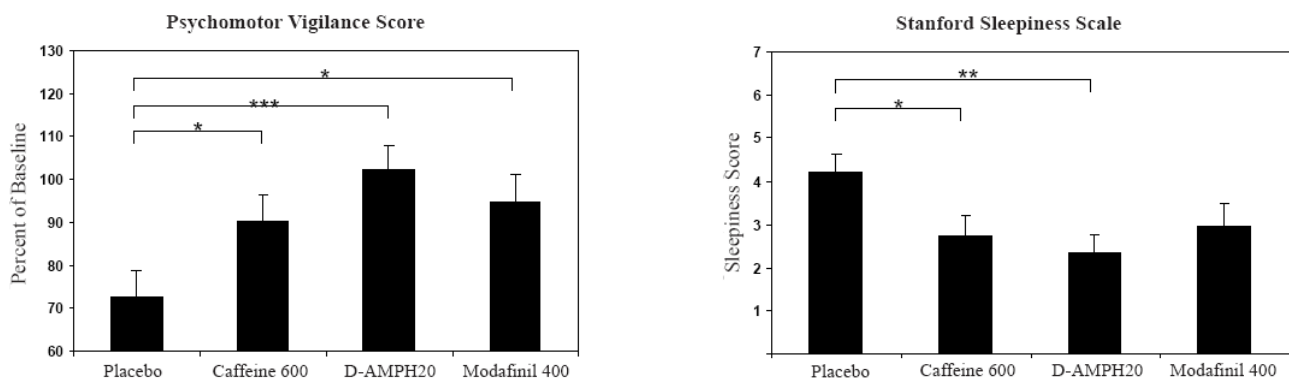


Figure 13 Effects of different levels of caffeine on Alertness

Source: Penetar, D., et al. 1993 Caffeine Reversal of Sleep Deprivation Effects on Alertness and Mood. *Psychopharmacology*, Vol. 112. P.359-365 (Caldwell, 2003)

waking up to reduce the effect of sleep inertia and during the typical 'circadian lows' in late afternoon (15.00 – 17.00) and dawn (03.00 – 05.00). Several studies have shown the effects of caffeine on psychomotor vigilance and alertness. Figure 13 shows the effects of different levels of caffeine after subjects were sleep deprived for two days.

Figure 14 shows the relation between different stimulants and the effect is has on vigilance and sleepiness. Vigilance was measured using psychomotor vigilance tests (PVT) at two hour intervals and sleepiness was measured with the Stanford Sleepiness Scale. In civil aviation however, most stimulants are not allowed because of possible side effects. In the figures above, caffeine (the only allowed stimulant) has almost identical scores as the other stimulants. Thereby confirming its effect.



Mean performance on the palm-based psychomotor vigilance test (PVT) following 49.5 hours of sleep deprivation (expressed as a percentage of performance relative to the baseline day). Higher scores equate to faster response speed. Each of the 3 stimulants produced faster response speed scores on the PVT relative to placebo.

Mean scores on the Stanford Sleepiness Scale following 49.5 hours of sleep deprivation. Scores range from zero to seven. Higher scores equate to greater subjective sleepiness. Relative to placebo, both dextro-amphetamine (D-AMPH) and caffeine were associated with reduced sleepiness scores, whereas sleepiness ratings for modafinil did not differ from placebo.

Figure 14 Effects of different stimulants on vigilance and sleepiness. Source: Killgore, 2006

### 3.8.2 Enough quality sleep

As described in the paragraph about sleep, it is important to obtain enough quality sleep. What constitutes as 'enough' and 'quality' can differ somewhat between individuals. But in general we can say that if we stick to proper sleep periods, fatigue can be mitigated and avoided (Miller, 2005). Normal sleep quality means that these at least these criteria should be met:

- ✓ at least 8 hours of **consecutive** sleep after 16 hours of wakefulness
- ✓ at least 21 hours of sleep in the last three days
- ✓ Obtain the sleep during local night-time

#### Sleep debt

The sleep debt is the amount of hours of sleep that is missed during previous days, that is the amount of hours relative to the (personal) ideal sleep length. If sleep is two hours short for three nights, this means a sleep debt of 6 hours. This debt can be repaid by sleeping extra hours during the following nights. Sleep debt can be repaid at a rate of 2 hours of good quality night sleep for every four hours of debt (Miller, 2005).

### Starting a new duty without sleep debt

A good way to start a new duty period is to have no sleep debt. An easy way to achieve this is to have two nights of unrestricted sleep the before the schedule begins. Unrestricted sleep means an early bed-time and being able to wake up as late as possible. The sleep length should be more than eight hours. Sometimes this strategy is associated with 'pre-sleeping' or adding sleep to your 'sleep account'. Whether this has any effect is still not scientifically proven.

### 3.8.3 *Crew augmentation and planned on-board sleep*



Figure 15 A typical overhead crew rest (OCR) in the Boeing 747

Depending on airline policies, standard cockpit crew consisting of a captain and a first officer is sometimes augmented with additional crew, often an additional first officer. A full augmentation is adding a second captain and a second first officer. How much crew is augmented usually depends on the type of aircraft, duty or flight times and regulations. Typically a first or second officer is added for flights of up to nine hours and a first officer is added for flights between 9 and 12 hours. Flights longer than 12 hours are staffed with four cockpit crew (these are mere indications). When extra crew is added to a flight, crew has the opportunity for planned periods of rest.

Fortunately some airplanes have a sleeping facility for crew. These facilities are different for most aircraft models. Older aircraft usually have rudimentary facilities while the newer aircrafts are fitted with sleeping bunks and in-flight entertainment. Usually referred to as the Overhead Crew Rest. In some models these 'crew rests' are optional, like for example in the MD-11. Airline management can choose whether the space is used as crew sleeping facility, to carry cargo or to accommodate more passengers. Airline management has to make this trade-off. When an aircraft does not have a designated crew rest facility, assigned cabin seats can be shielded off from the passengers with a curtain. The comfort of these crew rest facilities however, is relative low and actually sleeping can be a problem. NASA has taken a large survey on the issue of sleep quantity and quality in onboard crew rests (Rosekind, et al., 2000). The questionnaire consisted of 54 questions that were completed by 1404 crew of three different major US airlines. Almost all crew (91%) reported that they were good or very good 'home sleepers'. But sleeping in on-board crew rest facilities is rated as more difficult. The survey reported that 71 % of crew reported having difficulty with sleeping 'often' or the 'majority of time'.

Planning when cockpit crew gets the opportunity for rest is usually done by the captain. Planning for cabin crew is done by the purser. After take-off and reaching the cruising altitude it is decided who gets to take a rest at what time. Decisions on how this is done are at the crew's discretion but the captain is ultimately responsible for the entire flight. Generally a crew member gets 2 – 3 hours of rest on long-haul flights. The result of another NASA/FAA survey was that crew usually needs around 40 minutes to unwind and fall asleep for on average 2 hours. As we can see in Figure 8 the amount of REM sleep in the first two hours is relatively little. This means that the restorative effect of sleep during the first two hours is also small.

On-board sleep is a very important countermeasure but its effects should not be overestimated. The fact alone that 71% of crew find it hard to get to sleep should be enough to not rely on short (<2-3 hours) periods of on-board sleep.

### 3.8.4 *Planned cockpit Napping*

A 1994 study by NASA and the FAA showed that short periods of planned sleep in the cockpit (commonly referred to as 'cockpit napping') can increase performance and alertness. The study tested two groups of pilots flying the same 9 hour transpacific flight, while one group was allowed to sleep 40



minutes (on average 26 minutes of sleep were obtained). After waking they showed better performance (reaction time) than the group that did not have a short period of sleep. Some airlines have a policy that permits controlled cockpit napping.

### 3.8.5 *Light*

Light has a strong effect on the circadian rhythm, especially daylight. The average bright light bulb emits around 500 lux and a studio lamp emits around 1000 lux but daylight is anywhere from 20.000 (overcast day) to over 100.000 lux on a sunny day. Daylight and the sleep/wake rhythm relate to each other through melatonin. Melatonin is a hormone that is produced in the brain. When the eyes perceive daylight the hormone is not produced but when the level of daylight decreases the brain begins producing this hormone. Since melatonin is such a strong 'sleep drug', having enough light (for example in cockpit or cabin) may lessen the drive for sleep. The production levels of melatonin are also associated with a person's age. As age increases the levels of melatonin are shown to be decreasing. As described in the paragraph on sleep and age, the amount of awakenings during the night increases. It is believed that the decreased levels of melatonin are associated with these regular wake-up periods. The use of melatonin as a 'curing' drug is still very much under debate because of potentially serious side effects. It is often advised not to use this over-the-counter drug on a regular basis or without doctor's supervision.

### 3.8.6 *Exercise*

A study on whether regular exercise can counteract feelings of fatigue was done by the University of Georgia (O'Connor, 2006). The study showed that 90% of sedentary people (=inactive people who lead a 'sitting' life and get little physical exercise) reported having less feelings of fatigue after completing daily regular exercise routines. Other studies show that the effect of regular short moments of physical exercise only have a short lasting effect on fatigue (LeDuc, et al., 1998). Initially there is a positive effect on alertness immediately after the exercise but after 50 minutes this effect wears off. Although exercising during flight is nearly impossible, being active and engaging in regular sporting activities (including the time spend on the destination) is considered beneficial to overall health and helpful when dealing with fatigue inducing situations. A healthy body simply has more resources available.

### 3.8.7 *Medicine*

Because of the potentially serious side effects and possible associated risks, the structural use of sleep promoting medication is not allowed in civil aviation (Rosekind, et al., 2001). In military aviation the United States Army has extensive experience with operational use of alertness improving ('go-pills') medicine like dextroamphetamine, Modafinil and sleep promoting substances ('no-go-pills') such as Zolpidem, Zaleplon and melatonin. Because of the fact that these medicine are not allowed and do not contribute to reducing the causes of inadequate sleep, they will not be discussed further. Readers who are interested in more information can read "Fatigue in Military Aviation: An Overview of U.S. Military-Approved Pharmacological Countermeasures" by John A. Caldwell and J. Lynn Caldwell (Caldwell, et al., 2005).

### 3.8.8 *Education*

Education about fatigue is helpful for gaining insight into backgrounds, causes and effects of fatigue. Recognising moments when fatigue can be expected and when fatigue may become a risk is particularly important.



### 3.9 Quantifying the risk of fatigue

Determining when someone's level of fatigue is critical (and may pose a safety risk) is difficult for both flight crew themselves and management. We have seen that the circadian rhythm, shift-lag, jet-lag, insufficient, fragmented and disturbed sleep are important causes of fatigue. By determining to what extent these causes are present, it is possible to get a good estimate of whether (to much) fatigue is present. For the United States Army Miller developed two kinds of checklists. The factors used in these checklists are mostly based on the SAFTE model (Hursh, et al., 2005). See Appendix 8 for more information on this model.

#### Fatigue checkcard (Figure 16)

This checkcard estimates the probability that fatigue contributed to a mishap. If any factor is a score of 5 or if the sum of the seven factors is 21 or higher, or if the average score is greater than 3, then fatigue may have been a factor in the mishap. The fatigue checkcard is used retrospectively.

#### Hazard Probability – Severity Matrix (Figure 17)

The fatigue checkcard has been modified in such a way that it can be used to identify risks associated with fatigue. The factor of 'human error' has been left out and the scoring has been inverted. A score of 1 is the highest possible risk for a specific factor (priority 1). The scoring rules for assessing the risk associated with fatigue are: If any hazard estimate is a 1 or a 2, then the overall fatigue estimate equals the riskiest hazard estimate. Else, the overall fatigue estimate equals the equally weighted mean of the six estimates. This tool can be used for planning purposes and for personal use.

	Rating
<b>A. Length of Prior Wakefulness (LPW)</b>	
LPW <= 16 hrs	1
16 <= LPW < 19 hrs	3
LPW > 19 hrs	5
<b>B. Amount of Prior Sleep for the Preceding 72 hrs. (APS)</b>	
APS >= 21 hrs	1
18 <= APS < 21 hrs	3
APS < 18 hrs	5
<b>C. Time of Mishap/day (TOD)</b>	
0600 < TOD <= 2200 hrs	1
2200 < TOD <= 0100 hrs	3
0100 < TOD <= 0600 hrs	5
<b>D. Number of Night Shifts in Preceding 30 Days (NNS)</b>	
NNS >= 15	1
8 <= NNS <= 14	3
NNS < 8	5
<b>E. Time Zone Change and Days in Zone</b>	
[Any time change (hours) / Days in zone] < 3	1
Time change of 6 to 12 hours and days in zone > 1	3
Time change of 6 to 12 hours and days in zone <= 1	5
<b>F. Types of Human Errors Associated with Mishap</b>	
Injured; impeded by poor interface design	1
Distraction	2
Poor planning; bad decision	3
Slow reaction time	4
Fell asleep; dozed off	5
<b>G. Estimated Exertion Across the Work Period of Interest</b>	
No exertion at all or extremely light	1
Very light or light	2
Somewhat hard or hard (heavy)	3
Very hard	4
Extremely hard or maximal exertion	5
<b>SUM</b>	

FATIGUE HAZARD	Rating
<b>A. Length of Prior Wakefulness (LPW)</b>	
LPW > 19 hrs	1
16 <= LPW < 19 hrs	3
LPW <= 16 hrs	5
<b>B. Amount of Prior Sleep for the Preceding 72 hrs. (APS)</b>	
APS < 18 hrs	1
18 <= APS < 21 hrs	3
APS >= 21 hrs	5
<b>C. Time of Mishap/day (TOD)</b>	
0100 < TOD <= 0600 hrs	1
2200 < TOD <= 0100 hrs	3
0600 < TOD <= 2200 hrs	5
<b>D. Number of Night Shifts in Preceding 30 Days (NNS)</b>	
NNS < 8	1
8 <= NNS <= 14	3
NNS >= 15	5
<b>E. Time Zone Change and Days in Zone</b>	
Time change of 6 to 12 hours and days in zone <= 1	1
Time change of 6 to 12 hours and days in zone > 1	3
[Any time change (hours) / Days in zone] < 3	5
<b>F. Estimated Exertion Across the Work Period of Interest</b>	
Extremely hard or maximal exertion	1
Very hard exertion	2
Somewhat hard or hard (heavy) exertion	3
Very light or light exertion	4
No exertion at all or extremely light exertion	5
<b>SUM</b>	

Figure 16 Fatigue Checkcard (Miller, 2005)

Figure 17 Fatigue hazards and risk assessment scores (Miller, 2005)

As a rule of thumb, in average people the effects of fatigue are highly probable when any one of these five limits is reached (Miller, 2005):

- The individual has slept less than eight hours in the preceding 24 hours.
- The individual has built up more than eight hours of sleep debt. This is calculated by subtracting actual sleep length from typical sleep length across a preceding period of 72 hours.
- The individual has continuously been awake for more than 17 hours.
- Operations are to occur in the midnight-to-dawn period.
- The individual's body clock is more than three hours out of phase with the local day-night cycle. This happens when the individual crosses at least three time zones at a speed much faster than one time zone per day. This includes shift rotation of more than three hours.

### 3.10 The generic rostering process used by airlines

In order to gain better insight in how crew schedules are made and what factors influence this process, this paragraph describes a generic process that starts with a decision to service a specific destination and ends with assigning individual crew members. The major building blocks of this process are shown in the figure below. In the appendixes a more detailed version of these building blocks can be found. This process is very complex and it is the backbone of the flight operations of an airline (Bazargan, 2004).

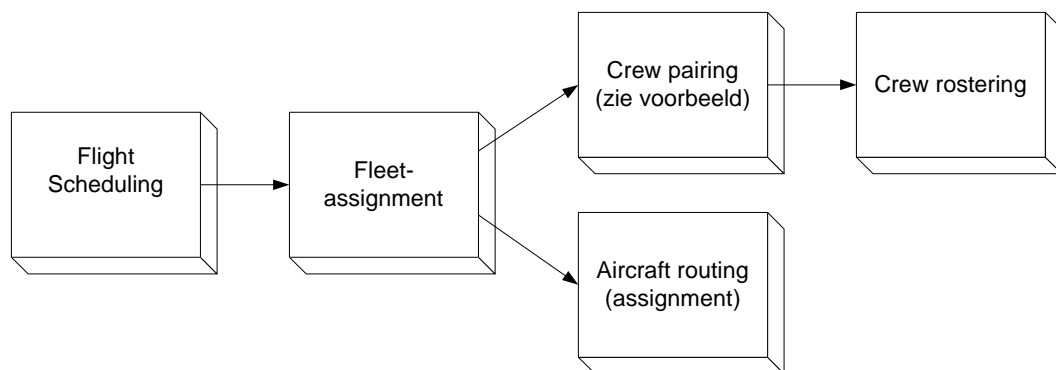


Figure 18 Generic schedulingproces

#### Flight scheduling

Developing the flight roster is the starting point of the entire planning process. The flight schedule is under the influence of many different and often conflicting factors. These factors include expected passenger demand, available capacity, (local) rules and regulations, competition and available crew. The flight schedule is the translation of the company 'mission statement' and the strategic long term decisions. Flight schedules include destinations and departure times.

#### Fleet assignment

The phase of 'fleet assignment' is the process of combining specific aircraft types to the schedules that resulted from the flight scheduling phase. The factors that influence these decisions are aircraft type characteristics like availability, operating cost, flight range, en cost and revenue per set. Fleet assignment is not the same as fleet planning. Fleet planning is the management of the entire fleet of aircraft. This includes buying and selling aircraft to optimise the available fleet.

### Aircraft routing

This is the phase where individual aircraft are coupled with the flights resulting from the fleet assignment. Factors influencing these choices are operational costs, balanced load of available aircraft, maximum availability for maintenance and minimal delay (turn-around-time).

### Crew pairing

Crew pairing takes place at the same time as aircraft routing. Crew pairing is the process of assigning cockpit and cabin crew to the flights that resulted from fleet assignment. This usually means assigning a partial or complete crew 'sets' to several flights over several days or weeks.

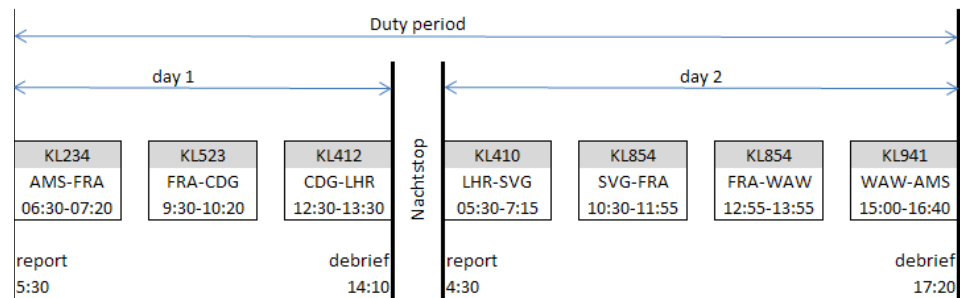


Figure 19 Crew pairing example

### Crew rostering

Just as the aircraft routing phase is the assignment of aircraft to the flight schedule, the crew rostering phase is the assignment of crew to crew pairings. These assignments result in individual crew rosters. It is at this phase that international, national and rules and regulations from labour agreements need to be met. If these rules and regulations are met, crew rosters are considered to be 'legal'. Employees have a considerable amount of freedom in planning destinations in their own rosters. This is usually done using the internet. All the above phases are completed using specialised automation software. A large company that provides this kind of software is Jeppesen's product 'Carmen'. Carmen comes in many flavours like: Carmen

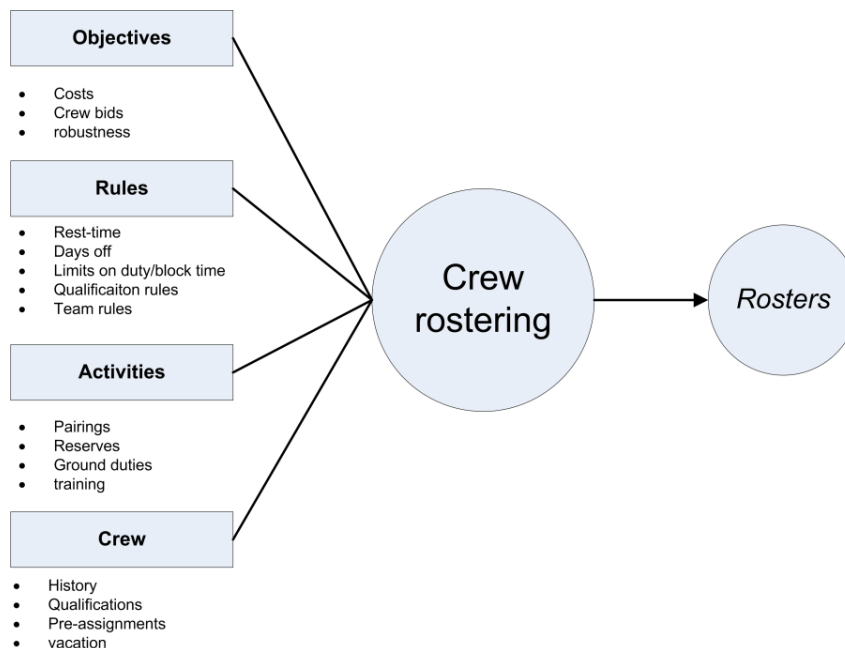


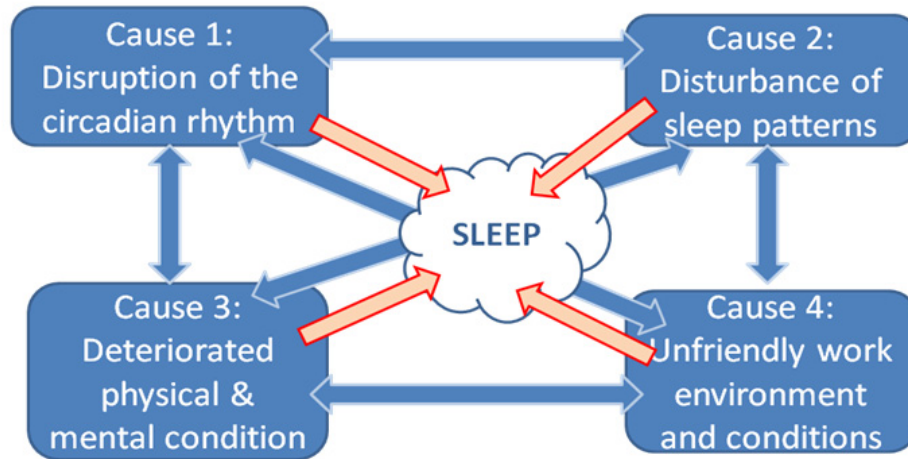
Figure 20 Factors influencing a crew roster (Bazargan, 2004)

Manpower, Carmen  
Crewparing, Carmen  
rostering, preferential  
bidding, bidlines, Carmen  
Crew Tracking, Carmen  
Crew Control, Carmen Tail  
Assignment, Carmen Fleet  
Control, Carmen Passenger  
recovery, Carmen  
Integrated Operations  
Control en Carmen Rave.

When we look at this entire process, it provides several moments for introducing fatigue reducing efforts. At the very start of the process, the development of flight schedules, we could think of adjusting (local) departure times to departure times that take human fatigue into account.

### 3.11 Summing up the characteristics of crew fatigue

Although fatigue is a difficult to grasp phenomenon, it is possible to get a grip on it by looking at causes and effects. If we look at the different causes we can not only conclude that they are all related to each other but they all impact the amount and quality of sleep.



Once fatigue (in one of its many forms) is prevalent, it causes a wide range of effects. Initially it impacts the human body in many different ways. Some of the effects have a distinct relation to performance, like the decrease of short-term memory and reaction time, while others such as changes in skin temperature have less impact. As a result of these changes in human performance, flight operations may also be influenced in a number of ways. The tendency to adopt simpler or riskier strategies (also known as pilot 'get-there-itus'), a degraded situational awareness and an increase in mistakes and sick leave are just some examples of how fatigue may impact daily flight operations.

Countermeasures are defences that are put in place to mitigate the amount of fatigue build-up or the effects it has on the human body. Countermeasures would not be needed if fatigue did not build up in the first place but they can also provide valuable additional information. In this case it confirms that sleep is at the heart of the problem. Sleep is probably the most effective 'countermeasure' available.

This chapter also provided us with a good way to assess the risk levels associated with crew fatigue. Combined with the fact that we have a detailed picture of what crew fatigue is and what kind of impact it can have, we turn to the subject of measuring crew fatigue in the next chapter. We will look at different methods and products that try to measure either the cause or effect of fatigue. Measuring crew fatigue will aid in reducing and objectifying the vagueness which often accompanies human fatigue.

## 4 METHODS FOR MEASURING HUMAN FATIGUE

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Measuring fatigue, for example in the same way that we measure the blood alcohol level, could help rationalise adjustments in current duty times. It may also assist in changing (company) policies for work and rest times to optimize human performance. Unfortunately measuring fatigue is nowhere near as easy as measuring blood alcohol levels. There is no golden standard, no threshold where we can say that any one person is 'too fatigued' for work. Possible problems can be that fatigue is 'disguised' by temporarily increasing motivation and using stimulants such as coffee. Even in the light of these apparent difficulties, there are different ways to assess the amount of fatigue in a person. In the following paragraphs the most important, most promising and best established methods will be discussed.

There are generally three ways of measuring or predicting fatigue: subjective scales (questionnaires to be filled in by the subject), physical measurements and predictive models. Some of these methods focus on the causes of fatigue while others measure the effects. A more detailed explanation of these methods can be found in Appendix 1 and Appendix 2. For practical purposes the methods will be grouped by whether they focus on cause or effect.

### 4.1 Methods with a focus on the causes of fatigue

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In this chapter a number of measuring methods will be described. These include physical methods, usually a device attached to the body and models used to predict levels of fatigue and performance. These methods focus on causes of fatigue like the amount of sleep, the length of wakefulness and time of day. The first three are so called activity watches, the final two are sleep tests.

#### 4.1.1 *Physical methods*

When looking at previous sleep patterns, it is possible to determine how much or how little sleep debt is present. Recording and monitoring sleep and activity patterns can be done using a kind of watch.

- **The Sleep Watch** from *PrecisionControlDesign, Florida USA*  
The Sleep Watch can record periods of activity and sleep. It can also record environmental information such as temperature and available light. This information can be downloaded from the watch to be used for further analysis.
- **The Sleeptracker** from *Sleeptronix, Georgia, USA*  
The sleep tracker monitors the period of sleep. It records the different phases that are present in a sleep period and determines the ideal moment to wake up. This way the moment of sleep inertia can be shortened.
- **The ActiGraph GT1M** from *LLC, Pensacola, USA*  
This activity tracker records and saves accelerations. The product comes with extensive software to analyse the data. Data can be downloaded to desktop computers or servers.

There are also two well known methods for testing how much sleep debt is present in a person at the current moment. Sleep debt is a major cause of on-the-job fatigue. Both methods are so called nap studies and are often used in sleep centres to diagnose sleep problems. These tests often require the person to visit the sleep centre for several hours.

- **Mean (or Multiple) Sleep Latency Test**

This test measures how quickly a person falls asleep during daytime. The test is done several times at fixed time intervals and takes place in a dark, quiet and comfortable room. The more sleep debt is present, the more quickly a person falls asleep

- **Maintenance of Wakefulness Test**

This test is conducted in almost the same manner as the mean sleep latency test. The difference is that in this test the subject has to remain quite and still but has to try to stay awake. The dark and comfortable room makes sleeping very desirable.

#### 4.1.2 *Predictive models for fatigue and performance*

When the body comes under the influence of a changing environment or when the body is forced to become desynchronized with its environment, the (biological) rhythms of the human body change. By using models for the human body these changes can be predicted and 'translated' into numerical fatigue or performance indications. This predictability has been shown by different models. Around these models, software packages are designed that simulate the human body experiencing the effects of shift- and jetlag and feed this information into the model. These models are based on (and validated with) human averages, sleep studies and performance and vigilance tests in operational settings.

- **FAST** by the Nova Scientific Corporation (American)

FAST (Fatigue Avoidance Scheduling Tool) is a tool which is designed around the SAFTE (sleep, activity, fatigue and task-effectiveness) model (see Appendix 8) and initially developed for the US Air Force. This software tool can be used to manually or automated enter duty schedules, periods of sleep and time zone changes. The model then determines the expected probable levels of human performance. This tool can also be used retrospectively to investigate situations around incidents. The FAST tool is commercially available.

- **FAID** from Interdynamics (Australian)

The FAID software tool determines a score for the amount of expected fatigue at a specific moment. The fatigue score is based on the length of each work period, the time of day at which work occurs, work in the prior seven days and the biological limitations of sleep and recovery. These scores are compared with predetermined risk levels. These risk levels are task specific and can be determined (by the user) using dedicated software (Hazard). By comparing expected fatigue and risk levels the tool estimates green, yellow and red conditions. Air Maestro™, a scheduling/planning tool, offers an integrated version FAID. Easyjet used FAID to change work/rest schedules.

- **SAFE** from QinetiQ (British)

As with the above models, predictions of alertness by SAFE (System for Aircrew Fatigue Evaluation) are done by combining influences of time since last sleep and the circadian rhythm (time of day) of natural moments of high and low performance. The SAFE Alertness Model is tailored to flight crew. The environment in which flight crew works (and the rules and regulations that schedules are constructed by), are very specific to that industry. QinetiQ was contracted by the CAA-UK to develop the system and the UK civil aviation administration now uses SAFE to assess flight schedules without the need to contact experts at every occasion. Air New Zealand is also using the software in their flight scheduling.



## 4.2 Methods with a focus on effects of fatigue

### 4.2.1 *Subjective assessments*

Subjective scales come in a great variety of forms. Usually these are in the form of a questionnaire. These self-rating scales have the advantage that they assess the way the person actually feels, not how they should be feeling (according to a model). This makes them a valuable tool for getting personal information. A common drawback of questionnaires in general is that they can give the respondent the opportunity to give incorrect answers. The results are then a skewed representation of the actual situation. Since there is so much at stake, people tend to give slightly better scores than they would under normal circumstances. We can think about a company culture in which there is an (informal) taboo on 'burn-outs' and fatigue. Other drawbacks are that the available answer may not always provide the right kind of answers for all people.

These are often used subjective scales to assess personal fatigue. Examples and a detailed description of these scales can be found in Appendix 1.

- **Checklist Individual Strength (CIS)**
- **De Dutch Fatigue Scale (DFS)**
- **Dutch Exertion Fatigue Scale (DEFS)**
- **Situational Fatigue Scale (SFS)**
- **The Stanford Sleepiness Scale (SSS)**
- **The Epworth Sleepiness Scale (ESS)**
- **The Samn-Perelli Fatigue Scale (SPFS)**

### 4.2.2 *Physical methods*

When we look at the effects of fatigue as described in the previous chapter, we see that a lot of the effects are physical. This is the reason that most methods for measuring fatigue are aimed at reliably measuring these physical effects. Most research has been done in measuring eye movements and reaction time. Here we will look at the different options for physical measurements.

#### **Posturographic tests**

As most of us know, when we become fatigued we tend to be less stable on our feet. We feel light headed and regularly feel the desire to sit down. By measuring the reaction to changes in the surface beneath our feet it is possible to get a measurement of how fatigued we are. Posture can be measured by:

- *Tetrax Posturography System*, Tel Aviv University, Israel Air Force

#### **Eye measurements**

Eye closure is a very strong effect of fatigue. When the drive for sleep becomes stronger we tend to close our eyes for longer periods of time, even if we are not sleepy. Many methods look at how often and how long we close our eyes and convert this information into a degree of fatigue.

Examples of products measuring this effect are:

- *FaceLAB* from Seeing Machines, Asia, Europe and North America
- *Optalert* from Sleep Diagnostics, Australia
- *AntiSleep 2.0* from Smart Eye, Sweden
- *Copilot* from Carnegie Mellon University, Pennsylvania, USA

### Reaction time

When fatigue sets in and we need to keep accuracy to a high level, we spend more time on decisions, need more convincing to change the course of action and respond more slowly to external stimuli. Some methods have been developed to measure this lowered reaction time. Often these methods are in the form of a button which has to be pushed at certain intervals or when a light comes on or a buzzer is heard.

Examples of products measuring this effect are:

- *Fatigue Monitor* from ARRB, Australia
- *Fatigue Warning System*: Muirhead/Remote Control Technologies, Australia

### Changes in voice

Although this method is still the subject of research it is a promising way of measuring fatigue. By comparing voice samples from a non-fatigued state with a current sample it is would be possible to detect fatigue. Advantages of this kind of measurement are that it is non- intrusive, does not require any action from the subject and it can detect fatigue real-time. The idea behind measuring changes in voice is that these changes indicate a change in brain activity.

Examples of products measuring this effect:

- *SiCECA* from Electronic Navigation Research Institute, Tokyo Japan (voice)

### Skin conductivity

A recent study (Pazderka-Robinson, 2004) suggests that differences in skin temperature and in electro dermal activity provide a way to measure fatigue. The study showed that the skin of people who are fatigued conduct electricity much less than people who are not fatigued. Skin temperature was also higher.

Examples of products measuring this effect:

- *DVTCS* from Neurocom, Russia

### Multiple effects

The methods below combine multiple forms of detection to get a complete. More information about these methods can be found in the appendixes.

Examples of products measuring multiple effects:

- *Tiredness and Fatigue Warning System* from Total Control Pty. Ltd
- *AWAKE* from the European commission (road use)

## 4.3 Comparing subjective assessments

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Because there are many different fatigue scales available it is useful to know which of these scales fits the aviation sector best. To make this distinction, different fatigue scales are ranked in a multi-criteria analysis. In Appendix 4 a weighted multi-criteria analysis can be found that uses a fictitious example to illustrate how this rating mechanism works.

In the table below, the main criteria, sub-criteria and associated weights as well as the possible ratings can be found. Appendix 1 contains full descriptions of all the ratings that were made for each of the seven fatigue scales.

## **1 Research and applicability**

**weight: 7**

How much has the scale been used in other research and how well is the scale designed to fit the characteristics of human fatigue in aviation.

### **1.1 Research**

**weight: 6**

How much research has been done with this scale? Research in an aviation setting is desirable.

- 0 None
- + Little
- ++ Average
- +++ Much
- ++++ Very much

### **1.2 Applicable to aviation**

**weight: 8**

How well is the scale applicable to the aviation sector? How well do the questions fit characteristics of human fatigue in aviation?

- 0 Very poor
- + Poor
- ++ Acceptable
- +++ good
- ++++ Very good

## **2 Practicality in use**

**weight: 9**

How practical is this scale in using it in an operational setting? Does it require a lot of input from the user or not?

### **2.1 Time spend on method**

**weight: 9**

How quickly can the subject take the questionnaire? When a questionnaire needs to be taken regularly it is important that it does not take too long. The less choice that someone has to make and the less reading that has to be done, the quicker it will be.

- 0 Longer than 20 minutes
- + Around 10 minutes
- ++ Around 5 minutes
- +++ Around 2 minutes
- ++++ Less than 2 minutes

### **2.2 Clarity of questions**

**weight: 8**

Are the questions easy or hard to understand?

- 0 Very unclear
- + unclear
- ++ Average
- +++ good
- ++++ Very good

## **3 Detection**

**weight: 8**

It is desirable to know what a questionnaire measures. Does it measure fatigue 'in general' or does it make distinctions between different forms of fatigue?

### **3.1 Physical fatigue**

**weight: 7**

Does it distinguish physical fatigue from other forms of fatigue? Are there questions that refer specifically to physical fatigue?

- 0 No
- ++ Yes, but limited
- +++ Yes, to some extent
- ++++ Yes, very specific

### 3.2 *Mental fatigue* **weight: 9**

Does it distinguish mental fatigue from other forms of fatigue?  
Are there questions that refer specifically to physical fatigue?  
Mental fatigue is often associated with sleepiness.

- 0 *No*
- ++ *Yes, but limited*
- +++ *Yes, to some extent*
- ++++ *Yes, very specific*

## **4 Validity and reliability** **weight: 7**

Scientific standards such as validity, reliability, generalizability, sensitivity and specificity are important when doing measurements.

### 4.1 *Validity* **weight: 7**

How well is the scale validated for measuring fatigue? How much literature can be readily found on the scale?

- 0 *None*
- + *Little*
- ++ *Some*
- +++ *Much*
- ++++ *Very much*

### 4.2 *Reliability* **weight: 8**

How reliable is the scale? Is the scale 'resistant' to different subjective interpretations? Does it use for example refer to common everyday situations for comparisons or does it leave a lot open to interpretation.

- 0 *Unreliable*
- + *Little reliable*
- ++ *Reliable*
- +++ *Very reliable*
- ++++ *Extremely reliable*

## **Results**

The scoring is a 'best effort' attempt based on the information that is available at this time and logical reasoning. How well a scale scored on specific criteria can be read in the full descriptions in the appendixes. After scoring all scales on all sub-criteria the scores are added and they are finally ranked. The results of the scoring process are:

Rank	Product	Score
1	The Stanford Sleepiness Scale	55
2	The Samn-Perelli Fatigue Scale	52
3	Checklist Individual Strength	47
4	The Epworth Sleepiness Scale	44
5	Situational Fatigue Scale	41
6	Dutch Exertion Fatigue Scale	24
7	Dutch Fatigue Scale	20

*All scores and descriptions can be found in the appendixes*

Criteria			Weight (0 – 10)	Normalized weight	Checklist Individual Strength	Dutch Fatigue Scale	Dutch Exertion Fatigue Scale	Situational Fatigue Scale	The Stanford Sleepiness Scale	The Epworth Sleepiness Scale	The Samn-Perelli Fatigue Scale
1	7	0,23									
1.1	6	0,43	+++	+	+	+	0	+++	++++	+++	
1.2	8	0,57	++	++	++	++	++	++	++	++	+++
					0,10	0,05	0,05	0,04	0,10	0,14	0,14
2	9	0,29									
2.1	9	0,53	+	++	++	+	++++	++	++++	+++	+++
2.2	8	0,47	++	++	++	++++	+++	++	+++	++	+++
					0,06	0,09	0,09	0,15	0,24	0,09	0,24
3	8	0,26									
3.1	7	0,44	++	0	++	+++	++	++	++	++	++
3.2	9	0,56	++++	0	0	+++	++	++	++	++	++
					0,18	0,00	0,03	0,15	0,08	0,08	0,08
4	7	0,23									
4.1	7	0,47	+++	++	++	++	+++	+++	+++	++	++
4.2	8	0,53	+++	++	++	++	+++	+++	+++	++	++
					0,14	0,07	0,07	0,07	0,14	0,14	0,07
TOTAL SCORE:			0,4676	0,2032	0,2371	0,4133	0,5454	0,4355	0,5163		

From this weighted multi-criteria analysis we can conclude that there are only minor differences between the first five scales. We can also look at a subset of the main criteria. Of particular interest would be how practical a scale is for use in an operational setting. If we ignore the other criteria, this would result in:

Rank	Product	Score
1	The Stanford Sleepiness Scale	81
2	The Samn-Perelli Fatigue Scale	81
3	Situational Fatigue Scale	52
4	The Epworth Sleepiness Scale	30
5	Dutch Exertion Fatigue Scale	30
6	Dutch Fatigue Scale	30
7	Checklist Individual Strength	19

The previously best scoring scales (Stanford Sleepiness and Samn-Perelli) also score very high on practicality. They stand out far beyond the other scales on clarity of the questions and how fast they can be performed. Because they are so quick and easy, it is possible to make multiple use of these scales in for example a specific duty period. Repeated testing could provide information on the progression of fatigue. Besides scoring best in this analysis, the additional facts that the Stanford Sleepiness Scale is well established and regularly used in validation processes makes this the preferred scale with regard to crew fatigue.

## 4.4 Comparing products for physical measurements

In this paragraph the physical tools and products as described in the previous paragraphs are also compared to each other by use of a weighted multi-criteria analysis. No matter what kind of product it is and whether it measures causes or effect, the best suitable product needs to be found. Some of the products and systems in the previous paragraphs were designed for automotive application but when comparing these products, for instance on 'practicality in use', this is done with an aviation setting in mind.

As was the case with the comparison of the subjective scales, a full description of the scores for each product can be found in the appendixes. The scoring is a 'best effort' attempt based on the information that is available at this time together with logical reasoning. The criteria used in the analyses are:

### **1 Development stage weight: 6**

**In what stage of development of this product/method? Methods for measuring fatigue are still very much under development, therefore most products will likely be in a development stage.**

#### **1.1 How long has the product been (commercially) available? weight: 6**

The longer a product has been commercially available the more initial problems will have been solved. Longer is better.

- 0      *Less than one year*
- +      *Between one and two years*
- ++     *Between two and three years*
- +++    *Between three and five years*
- ++++   *Longer than five years*

#### **1.2 Can the product be ready for an initial project within a few years? weight: 7**

Does it need modifications, user education or a team of specialists?

- 0      *Longer than five years*
- +      *Within five years*
- ++     *Within four years*
- +++    *Within three years*
- ++++   *Within two years*

#### **1.3 Is the product currently in use in other (aviation) companies? weight: 9**

If a product has proven to be success in other parts of aviation this would be very beneficial.

- 0      *No evidence*
- +      *Little evidence*
- ++     *A few ( pilot) projects*
- +++    *Yes, but in other industries*
- ++++   *Yes, in other airlines*

**1.4 How easily can it be introduced on a 'medium' scale?**

**weight: 8**

If a product needs a considerable amount of work and time to be installed or deployed it cannot be easily introduced on a medium scale.

- 0 Impossible
- + A lot of effort needed
- ++ Some effort needed
- +++ Relatively easy
- ++++ Very easy

**2 Practicality in use**

**weight: 8**

**How practical is this product for use in an operational setting? Does it require a lot of input from the user or not? Does the user have to wear certain gear?**

**2.1 General acceptance?**

**weight: 6**

Will people accept the method of measuring fatigue? Some measurements may require a considerable amount of time and energy or they are time consuming and impractical.

- 0 Completely Unacceptable
- + Mostly unacceptable
- ++ Acceptable
- +++ Very acceptable
- ++++ Highly acceptable

**2.2 Resistance to manipulation?**

**weight: 5**

Can the product be manipulated, for example by not cooperating or displaying behaviour that makes the measurement inaccurate? Since this behaviour is not expected this criteria has relatively little weight.

- 0 Very poor
- + Poor
- ++ Acceptable
- +++ good
- ++++ Very good

**2.3 Resistance to destruction**

**weight: 7**

What is the durability of the product or method? If a product has fine mechanics or very sensitive electrodes it may not be very suitable.

- 0 Very poor
- + Poor
- ++ Acceptable
- +++ good
- ++++ Very good

**2.4 Level of physical invasiveness**

**weight: 7**

Does the product need to be 'attached' to a person's body for a long period of time or does it interfere with normal work procedures? The less invasive, the better.

- 0 Very high
- + High
- ++ Average
- +++ Low
- ++++ Very low



**2.5 Ease and flexibility of use in cockpit /cabin situations** **weight: 9**

Large systems are impossible to fit in a cockpit. Usage must be easy and flexible.

- 0 Very poor
- + Poor
- ++ Acceptable
- +++ good
- ++++ Very good

**3 Product performance** **weight: 6**

How does the product work and how is fatigue measured or predicted?

**3.1 Can it detect fatigue real-time?** **weight: 8**

Does the product require ex post analysis by experts or does it detect in real-time.

- 0 No (only after data analysis)
- +++ Yes, but with a (slight) delay
- ++++ Yes

**3.2 Can it predict the onset of fatigue?** **weight: 9**

Can the product warn in advance, giving time to prevent high levels of fatigue?

- 0 No
- +++ To a certain extend
- ++++ Very good

**3.3 What is the level of automation?** **weight: 7**

Is it a stand-alone product or does it need an additional laptop or other processing devices? Does it need a lot of user input? High levels of automation are preferred.

- 0 Very low
- + Low
- ++ Average
- +++ High
- ++++ Very high

**3.4 How much information can be stored for later analysis?** **weight: 7**

If a product can store multiple days of data this can aid in reviewing and comparing different people and situations.

- 0 Non
- ++ Some
- ++++ At least several days

**4 Feed-back** **weight: 7**

What forms of feed-back/information does the system give? If a system gives useful information about the state of (expected) fatigue, this can be very helpful and may even prevent dangerous situations

**4.1 How often can the system be queried for levels of fatigue?** **weight: 7**

Does the person need to look through lots of data or is it a simple task of pushing a button? Can it be queried at any time or only sometimes?

- 0 no
- + Only days after analysis
- ++ Directly after a test
- +++ Sometimes
- ++++ Continuously

**4.2 Is the user informed through visible or audible alarms? weight: 8**

For example coloured lights, alarms or vibrations when fatigue levels exceed a certain threshold.

- 0 No
- ++ Yes, but non-intrusively
- +++ Very clearly

**4.3 How quickly is the information available for management? weight: 4**

Does management have an indication of fatigue states of crew in multiple aircraft in operation? Since the detection of fatigue alone is difficult, this is seen as a very desirable development that is initially not crucial.

- 0 Very slow
- + within weeks
- ++ within a couple days
- +++ within a day
- ++++ Real-time fatigue levels

**5 Factors influencing good measurements weight: 6**

How good is the product 'protected' against external influences?

**5.1 Lighting of the cabin/cockpit? weight: 8**

Inside airplanes it can be very dark at night or brightly lit during the day.

- 0 Badly influenced
- + Considerable influence
- ++ Some influence may be present
- +++ Very little influence
- ++++ uninfluenced

**5.2 Sounds in the cabin/cockpit? weight: 7**

Do sounds in the cockpit influence the measurements?

- 0 Badly influenced
- + Considerable influence
- ++ Some influence may be present
- +++ Very little influence
- ++++ uninfluenced

**5.3 Obstructions to good measurements(i.e. spectacles, clothing) weight: 8**

A person may be wearing spectacles, sunglasses or special clothing.

- 0 Badly influenced
- + Considerable influence
- ++ Some influence may be present
- +++ Very little influence
- ++++ uninfluenced

---

## **6      Validity and reliability** **weight: 8**

How good are the measurements and are they dependable?

### **6.1      *Is the product/method objectively validated?*** **weight: 7**

What is the amount of scientific information on validation?

- 0          None*
- +          Little*
- ++        Some*
- +++       Much*
- ++++      Very much*

### **6.2      *Reliability*** **weight: 8**

How reliable is the product? Has it been tested and trialled or is it in use in other forms of transportation?

- 0          Unreliable*
- +          Little reliable*
- ++        Reliable*
- +++       Very reliable*
- ++++      Extremely reliable*

---

## **7      Cost estimation** **weight: 9**

The expected price range of product is an important criterion. Cost should be kept within reasonable limits.

### **7.1      *Small scale implementation/modification costs?*** **weight: 7**

- 0          Very high*
- +          High*
- ++        Average*
- +++       Low*
- ++++      Very low*

### **7.2      *Running costs*** **weight: 8**

What are the expected costs for use and maintenance of the product?

- 0          Very high*
- +          High*
- ++        Average*
- +++       Low*
- ++++      Very low*

### **Scoring and results**

Each of the products was scored on these twenty-five criteria, the results of this scoring process and a description behind each individual rating can be found in the appendixes. The scoring was done on a 'best effort' base using the information that was available to the writer at that time and logical reasoning. These are the results of ranking the total scores of all products:

Rank	Product	Score	Method
1	ActiGraph GT1M	61	<b>Activity watch</b>
2	SleepTracker Watch	59	<b>Activity watch</b>
3	DVTCP	59	skin conductibility
4	Tiredness and fatigue Warning System	57	<b>Activity watch</b>
5	Copilot	57	Eye measurement
6	SiCECA	54	Voice
7	The Sleep Watch	52	<b>Activity watch</b>
8	FaceLAB 4.5	50	Eye measurement
9	AWAKE	50	Multiple sources
10	Optalert	47	Eye measurement
11	Smart Eye ANTISLEEP 2.0	46	Eye measurement
12	MSLT and MWT	44	Sleep test
13	Fatigue Warning System Muirhead	41	reaction time
14	ARRB Fatigue Monitor	39	reaction time
15	Tetrax Posturography System	34	Posturographic

One of the things we can conclude is that the overall ratings of the different products do not differ very much. The best scoring products are all very close. What does stand out is the preference for 'activity watches'. Two of the best three products are activity registering watches and thus focus on the *cause* of fatigue. We can also use a *sub-set* of the main criteria for further analysis. Since cost is always an issue we could look at products that give 'the most bang for the buck'. In other words, what products score best when we look at the cost, development stage and validity and reliability criteria. The result of this sub/set analysis is that there is an even stronger preference for activity watches. In both of the rankings the ActiGraph GT1M scores best, this will be the preferred product. The table on the next page is the entire table with all the scores for each product

Rank	Product	Score	Method
1	ActiGraph GT1M	75	<b>Activity watch</b>
2	SleepTracker Watch	66	<b>Activity watch</b>
3	The Sleep Watch	57	<b>Activity watch</b>
4	MSLT and MWT	55	Sleep test
5	DVTCP	49	skin conductibility
6	Copilot	47	Eye measurement
7	Tiredness and fatigue Warning System	46	<b>Activity watch</b>
8	FaceLAB 4.5	44	Eye measurement
9	Optalert	39	Eye measurement
10	Fatigue Warning System Muirhead	38	reaction time
11	Tetrax Posturography System	38	Posturographic
12	SiCECA	37	Voice
13	ARRB Fatigue Monitor	36	reaction time
14	Smart Eye ANTISLEEP 2.0	33	Eye measurement
15	AWAKE	28	Multiple sources

Criteria																	
Weight (0 – 10)																	
Normalized weight			Tetraz Posturography System	FaceLAB 4.5	Optalert	Smart Eye ANTISLEEP 2.0	Copilot	DVTCP	ARRB Fatigue Monitor	Fatigue Warning System Muirhead	AWAKE	SICECA	The Sleep Watch	SleepTracker Watch	ActiGraph GTIM	Tiredness and fatigue Warning System (TCG industrial)	MSLT and MVT
1	6	0,12															
1.1	6	0,20	++++	++++	++++	++++	++++	++++	++++	+++	+++	+++	++++	++++	++++	+++	++++
1.2	7	0,23	++++	++++	+++	++++	++++	++++	++	+++	+	+	++++	++++	++++	++++	++++
1.3	9	0,30	++	+++	++	+++	+	+++	++	+++	+	++	++++	+	+++	+++	++++
1.4	8	0,27	+	+	+	+	++	++	++	++	+	++	+++	++++	++++	++++	+++
			0,07	0,08	0,05	0,08	0,07	0,08	0,05	0,06	0,02	0,04	0,11	0,09	0,11	0,10	0,11
2	8	0,16															
2.1	6	0,18	++	+++	+	+++	+++	++	+	+	+++	++	+++	++++	+++	++	++
2.2	5	0,15	++	+++	+	+++	+++	++	+	+	+++	++++	++	++	+++	++	++
2.3	7	0,21	++	++	+	++	++++	+++	++++	++++	++	+++	+++	+++	+++	++	++
2.4	7	0,21	++	++++	+	++++	++++	+++	+	+	+++	++++	+++	+++	++	++	+
2.5	9	0,26	0	++	0	++	++	+++	++	++	+++	++++	++++	++++	+++	+++	++
			0,04	0,09	0,01	0,09	0,11	0,08	0,05	0,05	0,09	0,13	0,11	0,12	0,09	0,06	0,04
3	6	0,12															
3.1	8	0,26	++	++++	++++	++++	++++	++++	++	++	++++	+++	0	0	0	++++	0
3.2	9	0,29	0	++	+++	++	++++	++++	++	++	+++	++++	0	0	0	+++	0
3.3	7	0,23	++	+++	+++	+++	+++	++++	++	++	+++	++++	++++	+++	+++	+++	+
3.4	7	0,23	++++	++++	++++	++++	+	0	0	0	++	++	++++	++++	++++	+	++++
			0,04	0,08	0,10	0,08	0,08	0,09	0,03	0,03	0,07	0,09	0,05	0,04	0,04	0,07	0,03
4	7	0,14															
4.1	7	0,37	0	+++	++++	+++	++++	++++	0	0	++++	+++	+	0	+	++++	++
4.2	8	0,42	++	++	+++	++	++	+++	++	++++	++++	++	0	++	0	++++	++
4.3	4	0,21	+++	++	++	++	++	0	++++	0	++	++	++	++	++	0	++
			0,04	0,06	0,10	0,06	0,08	0,09	0,05	0,06	0,12	0,06	0,01	0,03	0,01	0,11	0,04
5	6	0,12															
5.1	8	0,35	++	+++	+++	+++	+++	++++	++	++	++++	++++	+++	++++	++++	++++	+++
5.2	7	0,30	++	++++	++++	++++	++++	++++	++++	++++	++++	++	++++	++++	++++	++++	+++
5.3	8	0,35	+++	++	+++	++	++	+++	++++	++++	+++	++++	+++	+++	++++	++++	+++
			0,05	0,07	0,09	0,07	0,07	0,10	0,09	0,09	0,10	0,09	0,09	0,10	0,12	0,12	0,07
6	8	0,16															
6.1	7	0,47	+++	+++	+++	++	+++	+	++	++	+++	++	++	++	+++	+	++
6.2	8	0,53	++	+++	+++	++	++	+++	++	++	+++	++	+++	+++	+++	++	++
			0,07	0,10	0,10	0,05	0,07	0,06	0,05	0,05	0,10	0,05	0,07	0,07	0,10	0,03	0,05
7	9	0,18															
7.1	7	0,47	+	0	0	0	++	++	+	+	0	++	++	++++	++++	++	+++
7.2	8	0,53	++	++	++	++	+++	+++	+++	+++	+	+++	+++	+++	+++	+++	+++
			0,04	0,03	0,03	0,03	0,08	0,08	0,07	0,07	0,01	0,08	0,08	0,14	0,14	0,08	0,10
TOTAL SCORE:			0,3373	0,5045	0,4690	0,4565	0,5650	0,5883	0,3867	0,4081	0,5042	0,5360	0,5243	0,5932	0,6067	0,5739	0,4364

Figure 21 the entire table of scores for each product

## 5 ACTOR ANALYSIS

The issue of crew fatigue is positioned between different actors. This means that multiple parties are (at least partial) stakeholders. For some stakeholders it is important that fatigue does not cause an increase in small, medium or big incidents and accidents. For other stakeholders it may be a more personal problem. Crew fatigue also has a different priority for each actor, they have different goals, resources, opportunities, power and so on. Therefore an actor-analysis is an important tool to get a good 'inside' view of these actors, their dependencies, relations and interactions. It will assist in judging possible recommendations for their chance of success, especially with regard to the core-values of the actors. The actor analysis is made on a 'macro' scale with an emphasis on the Dutch situation. On a meso/micro scale it is up to the airlines what parts of their organization get involved with managing crew fatigue.

### 5.1 Setting the scene

Aviation has always been very much internationally orientated. The International Civil Aviation Organization (ICAO), which is an agency of the United Nations, has been on the forefront of international coordination and regulation of air travel and transport. Countries that have signed the Chicago Convention adopt the ICAO standards into national law. ICAO standards define a basic level of flightsafety. For the nations that have signed the Chicago Convention the policies, rules and regulations are rarely an exclusive national matter.

At this moment, rules and regulations within the European Union are also being harmonized. The founding of EASA in July of 2002, which is to take over the tasks of JAA, was an important step in this harmonization process. The mission of EASA is to promote the highest possible standards for safety and environmental protection in civil aviation. Their main tasks are rulemaking, inspection and aircraft, engine and part certification. The approval of maintenance and aircraft/design companies, the authorization of non-EU airline operators and data collection, analysis and research are also part of the EASA tasks.

Because the Netherlands is an ICAO member, Dutch law, rules and regulations about aviation safety are a 90% translation of ICAO standards, European law and EASA/JAA standards (Waterstaat, 2005). Specific Dutch law for civil aviation is limited to ultra-lights, experimental and military aircraft. The Dutch policy for flightsafety is directed at influencing international regulations by being represented in as much committees as possible. This has become the most important way of putting Dutch safety subjects and ideas on the international agenda.

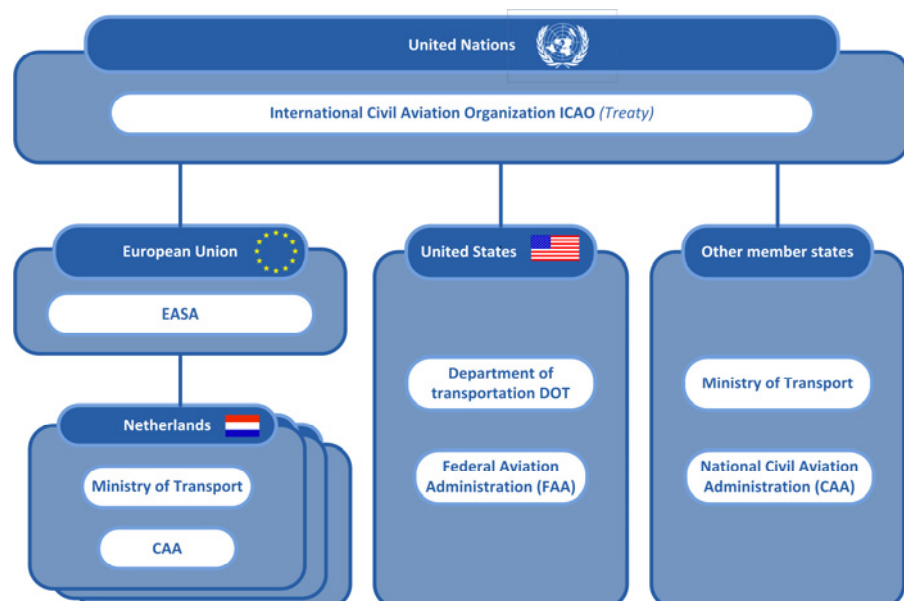


Figure 22 Political map of aviation



## 5.2 Scan of actors

In this chapter a scan of possible actors around this issue of crew fatigue is made. Most actors are also stakeholders which mean that they have a direct interest in resolving, controlling or minimizing crew fatigue. Actors may also be able to take action and influence processes and decisions. Some actors are not stakeholders but they can take actions on the issue. The scan is done with a Dutch framework in mind but, in the initial scan, international actors are also considered. For each actor a description is made. During the process of writing the actor analysis it proved difficult to get into contact with actors. The most probable reason for this was that the issues of work pressure and crew fatigue are currently highly debated. Another typical characteristic of actors in a network is that they are closed in nature (Heuvelhof, et al., 2007), they are not inclined to give openness on their true position and ideas. This seems especially true in this case. Nonetheless the actor descriptions of this quick scan provide ample insight.

### 5.2.1 *International regulatory authorities*

#### **ICAO**

The International Civil Aviation Organisation (ICAO) was established to implement the regulative policies that were defined during the Chicago Convention of 1944. The goals of this convention are to improve safety and economic regulation. To achieve these goals, the Convention is supported by 18 annexes that contain the Standards and Recommended Practices (SARPs). These annexes are written on subjects ranging from aeronautical charts, airworthiness of aircraft, aerodromes and accident investigations. Annex 6 (operation of aircraft) is the most relevant annex for crew fatigue.

To achieve safe development of civil aviation, ICAO has six strategic objectives that it works on today. They are safety, security, environmental protection, efficiency, continuity and rule of law.

Each member state has the obligation to comply with ICAO standards. The ICAO Standards and Recommended Practices are translated into national law by each member state. On a regular basis national aviation authorities are audited by ICAO to check this compliance. In general, member nations have to ensure capable and licensed flight crew, that all airplanes comply with the ICAO airworthiness directives (certification) and the quality of flight operations by airlines (operating license).

#### **EASA**

EASA is set to take over all functions of the Joint Aviation Authorities (JAA) by the end of 2008. EASA, the European equivalent to the American FAA, is the creator of safety and environmental rules at a European level. Its member states are Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Germany, Greece, Finland, France, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, The Netherlands and the United Kingdom. Goals of EASA are to develop and maintain a high and uniform level of safety for European civil aviation, to promote European safety standards worldwide and to assist European member states with complying to ICAO obligations. Although the EASA works closely with ICAO it is not a member of ICAO itself.

Especially Subpart Q of the EU-OPS (operations), the Flight Time Limitations (EU-FTL), has a big influence on how airlines compose their Flight Duty Periods. EU-FTL is heavily debated, national and European pilot unions (ECA) as well as independent agencies are convinced that the imposed European standards for flight time limitation are too low and reduce safety. The United Kingdom has even chosen not to 'downgrade' to EU-FTL but to keep current practices in place. The chance that other nations may choose to 'downgrade' is a serious issue.

### 5.2.2 *(Dutch) national regulatory authorities*

#### **Dutch Ministry of Social Affairs and Employment**

This ministry (Ministerie Sociale Zaken en Werkgelegenheid) is responsible for the laws regarding national work- and rest times (arbeidstijdenwet). In 2007 this law has been made less restrictive to increase the competition capabilities of Dutch companies. This ministry has the possibility to change, impose and enforce new or adjusted work- and rest times. It is not likely that these will change within the next couple of years.

#### **Dutch Ministry of Transport, Public Works and Water Management**

One of the goals of the ministry of Transport (Ministerie Verkeer en Waterstaat) is to increase the safety of all air transport. The ministry is divided into several divisions, one of these is the Division Aviation. The ICAO Standards and Recommended Practices are the basis of all national safety policies. They are augmented with European and national rules and regulation. Supervision of these policies is done by the Civil Aviation Authorities (Inspectie Verkeer en Waterstaat). Human fatigue and its effects on safety are mentioned as a safety concern in the “Beleidsagenda Luchtvaartveiligheid 2005 - 2010”.

#### **Dutch Transport and Water Management Inspectorate (CAA-NL)**

##### **(Inspectie Verkeer en Waterstaat)**

On behalf of the Ministry of Social Affairs and Employment, this inspectorate supervises whether the aviation industry follows laws regarding labour, in this case specifically the ‘arbeidstijdenwet’ and the ‘arbeidstijdenbesluit’.

On behalf of the ministry of Transport, Public Works and Water Management the inspectorate supervises the aviation industry on their responsibility to follow (safety) standards set out by this ministry. These tasks include admissions to the aviation market and performing self-initiated inspections. Annual reports on the aviation industry are made to assist policy developments by the ministry of transport. Within the inspectorate, the NLA (Nederlandse Luchtvaart Autoriteit) is responsible for implementation of policies and the DLA (Handhavingsdienst Luchtvaart) is responsible for enforcement of policies.

#### **FAA**

Although the FAA is the US national civil aviation authority it is internationally very influential. Smaller national aviation authorities of other countries often follow FAA guidelines. The Federal Aviation Administration is part of the American Ministry of Transport and responsible for safety of aviation. Flight Time Limitations and Rest Requirements are regulated in the Federal Aviation Regulations (FAR) and enforced by the FAA itself.

### 5.2.3 *Civil aviation industry*

#### **Airline management (operators)**

Managing an airline is very much like managing any other commercial enterprise. The goal is to maximise profit and growth within a safe operation and within the boundaries of applicable rules and regulations. For airline management this means they aim to operate aircraft safely and efficiently to transport as much people and cargo as possible. Profit and safety are core-values of any airline, while safety in itself is a necessary condition for profit.

Airline management is in a constant state of balancing different goals. Decisions are being made between financial interests, safety, employee satisfaction, customer satisfaction, available resources, future plans, punctuality, reliability and many other factors. All these decisions are trade-offs. Safety can conflict with punctuality and customer and employee satisfaction do not always align. Airline management may see crew fatigue as a trade-off between safety, employee satisfaction and optimisation of human resources. Appendix 6 gives a more detailed overview of a generic scheduling process and the many trade-offs that have to be made during this process.

Within airlines there is a large focus on crew optimisation. Coming only second to fuel costs, the cost for crew is large part of overall operational cost. The high costs for fuel increases the strain on crew every day. For crew planning, the collective labour agreements and the law are the absolute boundaries. But in the ever growing process of reducing cost, these limits can easily become the norm.

#### **Work councils (ondernemingsraad)**

These councils consist of members that work in the sector/company. Work councils have certain rights within the decision-making process, they are a form of democracy. Workers take part in managing a business by getting involved within the work council. Their importance however is being weakened in the latest 'arbeidstijdenwet' and 'arbeidstijdenbesluit' (Ginkel, et al., 2007).

#### **Aircraft manufacturers**

The manufacturers of aircraft such as Boeing and Airbus produce the aircraft that are operated by humans. Their main goal is to sell as much aircraft. The way the aircraft is designed may have a significant impact on the levels of fatigue experienced by flight crew. Environmental factors like noise, light and vibration play an important role.

### **5.2.4 Professional (unions of) employees and airlines**

#### **Airline Pilot Unions**

Pilot unions are important because of their represent the many different interests of cockpit crew on work conditions and salaries. Opinions and decisions are made in a democratic manner. The largest pilot union is North American ALPA while the largest Dutch union for pilots is VNV-DALPA. The European Cockpit Association (ECA) is a body that represents cockpit crew at a European level and the International Federation of Air Line Pilots' Associations (IFALPA) represents pilots internationally.

#### **Cabin crew unions**

Cabin crew unions are important because of their represent the many different interests of cabin crew on work conditions and salaries. Decisions are made in a democratic manner. The largest Dutch unions are VNC and FNV "Cabin Pressure". Smaller unions are CNV and UNC.

#### **Association of European Airlines**

Besides pilot and cabin crew, the airlines are also represented by a single association: AEA. Thirty-five of the largest airlines are member of the AEA and has represented them over the past 50 years. The AEA works together with the European Union and other stakeholders to ensure sustainable growth.

### 5.2.5 *Interests of non-organized groups*

#### **Passengers**

Airlines transport people and luggage from A to B and charge a fee for this product. People buying this product have the right to a safe flight. They have the right to board a safe and well maintained aircraft but they also have the right to assume that this aircraft is operated by safe, certified and fit aircrew.

#### **Civilians**

People that live in the proximity of an airport, or in the neighbourhood of approach and departure routes, have same rights as passengers aboard airplanes. Both passenger and people on the ground run the risk of being involved in an airplane crash. In the Netherlands this risk is commonly known as 'group risk' and 'external safety' which are often part of safety studies.

### 5.2.6 *Investigative agencies and boards*

#### **NTSB**

The National Transportation Safety Board (NTSB) is an independent agency responsible for the investigation of accidents involving all forms of transport, including aviation accidents, and the promotion of safe transportation by developing safety recommendations. The organisations reports to US Congress and is internationally recognised as a centre of expertise for crew fatigue.

#### **De Onderzoeksraad voor de Veiligheid**

The 'Onderzoeksraad voor de veiligheid' is an independent Dutch agency that investigates high profile accidents and possible consequences of accidents and disasters. It is the Dutch equivalent to the American NTSB.

### 5.2.7 *Research, training and knowledge institutions*

#### **NASA**

NASA is an agency of the United States government. Besides its space program is it responsible for civil and military aviation research. NASA has done extensive research on the effects of crew fatigue, beginning as early as the 1980's. Research started with the 'NASA Ames Fatigue/Jet Lag Program' that determined the extent of fatigue, sleep loss and circadian disruptions in flight operations as well as the impact of fatigue on flight crew performance and countermeasures for fatigue. Today this group is called the Fatigue Countermeasures Group. In a statement on pilot fatigue made in 1999, NASA considers pilot fatigue to be a significant safety issue in aviation. This statement also included that fatigue is not *simply being a mental state that can be willed away or overcome through motivation or discipline, fatigue is rooted in physiological mechanisms related to sleep, sleep loss, and circadian rhythms. These mechanisms are at work in flight crews no less than others who need to remain vigilant despite long duty days, transmeridien travel, and working at night when the body is programmed for sleep.*

### Dutch National Aerospace Laboratory NLR

The NLR is an independent not-for-profit laboratory for aviation and space research. Among others, the NLR provides support for government policies, works together with airlines on research projects and assist the Dutch military. As a result of the 1993 crash of a Boeing 747 into a suburb of Amsterdam, the Dutch Civil Aviation Authority (of the Dutch ministry of Transport) initiated the design of a causal model to give insight into how the many factors (ATC, airport, airline management) play a part in the overall risk of accidents. The NLR took part in this process. In-flight crew alertness is a factor that is used in this causal model and is modelled as shown in Figure 23.

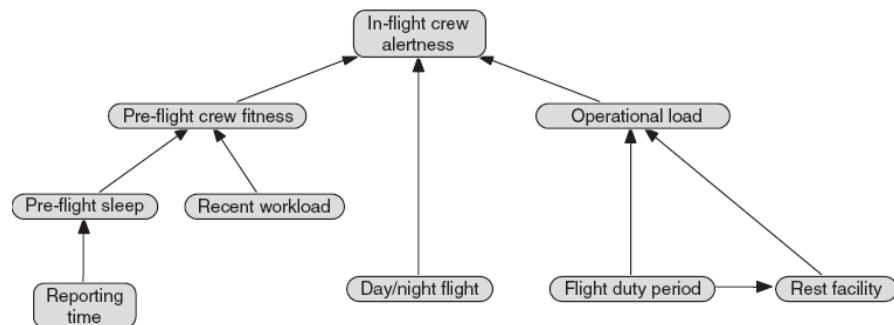


Figure 23 Flight Crew Alertness Model. Source: (Roelen, et al., 2003)

*With respect to this report, an interview was held with A.L.C. Roelen of the Dutch NLR Air Transport Safety Institute. The information gathered from that interview has been used on several occasions throughout this report. During this interview several notions about crew fatigue were discussed. Most of these ideas coincided with the knowledge presented by other institutions like NASA. Of particular interest for future situations is the fact that ‘very light jets’ are becoming more widely spread. These very light jets are single pilot aircraft that are capable of flight at the speeds and altitudes used by commercial airlines. Together with fatigue this can potentially cause dangerous situations. With regard to the most important cause of fatigue, scheduling practices are considered paramount and ‘get-there-itus’ is possible the riskiest effect of fatigue.*

### Universities

Universities can deliver knowledge and they can perform unbiased research. In the Netherlands, the Safety Science Group of the Delft University of Technology is involved with the development of the causal model that was mentioned above.

*With respect to this report, an interview was held with J.A.A.M. Stoop of the faculty of Aerospace Engineering at the University of Delft. The information gathered from that interview has been used on several occasions in this report. The issue of crew fatigue is a large but often unacknowledged problem. The selection process for pilots is even aimed at selecting people who can mask the effects of fatigue well. As for the causes of crew fatigue several were mentioned. These include a person’s age (the older one gets, the longer the recovery process), the rosters, cabin environment and flight schedule disruption. The actual and formal duty times may also vary strongly, contributing to fatigue. Concentration, judgement, vigilance and tunnel vision are mentioned as the most important effects. Methods for measuring fatigue are important for estimation the size of the problem.*

### **Flight Safety Foundation**

The Flight safety Foundation is an impartial organization that is driven by members ranging from regulatory to aircraft maintenance organisations. The goals are to share information and to achieve the common goal of improving and maintaining flight safety.

## **5.2.8 Other**

### **ECAC**

The European Civil Aviation Conference is the oldest (established in 1955) intergovernmental organisation for civil aviation. ECAC has a close relationship with ICAO, European government and other non-governmental agencies. The goal of ECAC is to promote a safe and efficient European environment for aviation. Member states show a lot of interest for the conferences organised by ECAC but the decisions and recommendations of ECAC are not binding.

### **Insurance companies**

When serious accidents happen there are at least two kind of insurance companies that are involved. First there are the insurance companies that insure airlines for loss of aircraft and associated costs. These insurance companies may have policies regarding flight crew. Second there are insurance companies for the passengers. In the case of an accident they may hold the airline accountable.

### **Travel industry (Leisure and business)**

Today's travel industry cannot exist without air transportation. In 2006 the Turkish Airline Onur Air had a temporary ban imposed by the Dutch Civil Aviation Authority for flying in Dutch airspace. Lack of maintenance and unsafe operations were the main reasons for this ban. This ban had a serious effect on the travel industry between the Netherlands and Turkey. If this kind of situation were to happen because crew did not comply with aviation rules (for example flying outside Flight Time Limitations) this could also have serious consequences for the travel industry. People may choose not to fly with airlines that 'have a name' for utilizing crew past the limits.

### **Different forms of media**

Media are very keen on reporting problems with security and safety. In the past several television programs have 'gone undercover' to investigate situations that (in their view) were out of line. In the case of crew fatigue Ryanair (the largest budget airline of Europe) has received negative publication. In a documentary made by Channel 4 the airline was accused of security lapses, flying dirty aircraft and making cabin crew and pilots work excessively long hours. The basis for these allegations was an investigation of two reporters that spend five (!) months secretly filming not only the flights of Ryanair but also training sessions. Ryanair denied all allegations and said it operated the airline to the highest European safety standards.



### 5.2.9 Constellations

From the quick scan of actors, several constellations can be distinguished. A constellation is a group of actors that are bound to each other at a high level of aggregation. Constellations are also sometimes referred to as networks. Every actor has his own network but when viewed in its entirety, the networks form a 'network of networks'. The two constellations here are the European and International constellation. Constellations are useful for building a basic mental picture. Lines and arrows are used to show the most relevant relations (not every single relation is shown). The dotted lines represent influential relations whereas the solid lines are used to indicate more formal relations.

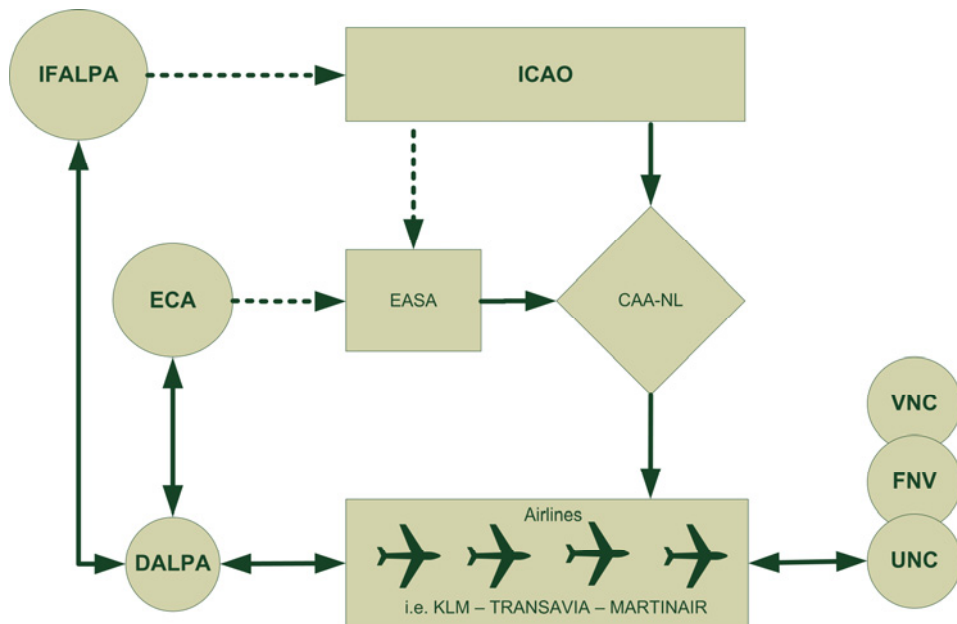


Figure 24 European constellation of regulatory bodies, pilot unions and airlines (Dutch situation)

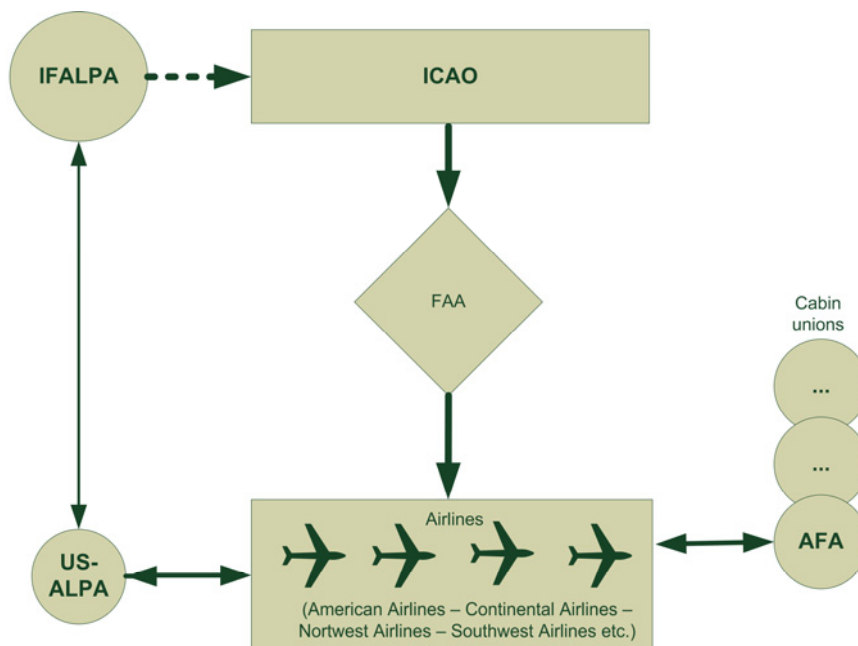


Figure 25 International constellation of regulatory bodies, pilot unions and airlines (US situation)

## 5.3 Selection of relevant actors

Because not all the actors mentioned above can (nor should) be included in the process leading towards the recommendations it is important to make a selection. For this selection process four considerations are mentioned by (Bruijn, et al., 2002). In fact this selection process is one of the design principles that leads towards an open decision making process. Based on the following considerations the relevant actors will be selected.

### 5.3.1 Selection criteria

#### 1. Consider actors that have the power to block processes and developments

These actors can block or slow down the entire process. When these actors are included this power can be mitigated. However, if the chance that such an actor will indeed use their blocking power is very high (usually because their core-values are not recognized or because they have little or no interest) and if this blocking power is very strong, not including this actor can be considered.

#### 2. Consider actors that have power of production

These are actors that essentially are needed to implement the recommendations and use the solutions in day to day situations. Different actors usually possess different resources (knowledge, money, human capital) which are needed for development and implementation.

#### 3. Consider actors that have an interest in the solutions but that have no power to block or that cannot contribute to the process or solutions

These can be actors who are affected by the negative sides of the current problem, those that have an interest in the possible solutions and those that have both.

#### 4. Consider including actors due to moral considerations

Actors that are chosen because of moral considerations are usually those that are (negatively) affected by the solutions. By including them it is possible to create an understanding for the problem and effectively compensate them.

#### Additional criteria: Consider Dutch national situation

Because this study focuses on the Dutch situation, national actors are preferred to those of other countries. Because the Dutch constellation is very much equivalent to that of other (European) countries, the final recommendations are aimed to be suitable for every country.

#### Additional criteria: Consider actors with the strongest ties

To be successful at reducing crew fatigue, actors that hold close ties with the issue of crew fatigue are usually those that have the best opportunities to successfully reduce fatigue are essential for good results.

Based on these considerations a selection of relevant actors has to be made. The most important selection criterion is whether an actor's core-values are in some way affected by crew fatigue. Because in the end it all comes down to how these core-values are taken into consideration in the recommendations. If an actor's core-values are not properly met, there is an increased risk that they will use some form of blocking power to frustrate the process of fatigue reduction.

### 5.3.2 *Selected actors*

Based on the selection criteria, these four actors are considered to be crucial for successfully reducing crew fatigue: Airline management, pilot unions, cabin crew unions and aviation safety research institutes.

The relative small amount of selected actors is due to the fact that these actors are so closely related to crew fatigue and also because they have the best opportunities and resources to effectively combat it. Other actors only have an indirect involvement or they have little blocking power. Because the reduction will take place within the boundaries of rules and regulation, regulatory actors for example have little influence.

This selection can also be easily translated to any other countries that have signed the Chicago Convention. All countries have comparable constellations. To get a better understanding of each selected actor and agent, paragraph 5.4 will give an in-depth analysis.

#### **1. Airline management (in the Netherlands: all major airlines)**

Airline management has both blocking power and production power. They can block the entire process in several ways. They can, for example, call on the legality of the rosters and claim that no further investigation is mandatory. On the other hand airline management also has production power in the form of staffing, knowledge and budget.

#### **2. Pilot unions (in the Netherlands: VNV)**

Most unions have different forms of blocking power. These include protests, strikes and 'working by the book'. These are generally very rarely used. Even protests are very scarce. The largest Dutch pilot union cooperates constructively with the different national airlines. Naturally the pilots also have 'production power' as they can provide the relevant information from daily operational situations.

#### **3. Cabin crew unions (in the Netherlands: VNC, FNV, UNC)**

That which can be said about pilot unions also holds for cabin crew unions. Both have almost the same blocking and production powers. When looking at recent developments, the willingness to protest seems to be bigger in cabin crew unions.

#### **4. Aviation Safety and Research institutes (in the Netherlands: NLR-ATSI)**

Because airlines and unions are experts-by-experience, it is necessary to include expert that have in-depth knowledge. These experts can assist with knowledge about human fatigue, scheduling, risk and safety. By including experts in the process, it ensures an independent view on possible problems and conflicts. Other examples are the DLR (Germany), IFSA (France) the Flight Safety Foundation and NASA (both international). These institutes have a great scientific interest in data and solutions regarding crew fatigue.

## 5.4 Detailed analysis of the selected actors

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In this paragraph the selected actors are described in more detail. The actors are described on their interests, standpoints, causes and influences. This is complemented with a swot-analysis that looks at strengths, weaknesses, opportunities and threats.

<b>Interests</b>	– What advantage/benefit does the actor have in reducing crew fatigue?
<b>Standpoint</b>	– What is the position of an actor on crew fatigue?
<b>Causes</b>	– What does the actor consider to be the causes of crew fatigue?
<b>Influence</b>	– What influence does the actor have on crew fatigue?

The SWOT analysis for the actors is integrated into the next paragraphs. For each actor the **strengths** and **weaknesses** are determined by looking at the internal situation, the **opportunities** and **threats** are determined by looking at external developments and events and that may have an impact on the actor. After that, the relations between the actors are described in terms of formality, dynamics, intensity and dependencies.

As mentioned before, during the process of writing about these actors it proved difficult to schedule talks and interviews with these actors about crew fatigue, especially with unions and airline management. This is probably caused by the fact that this subject is under intense debate in the Netherlands (and probably in most other countries too). Information was gathered reading publicly available documents and relevant literature.

#### 5.4.1 *Airline management: the commercial view*

*This analysis of the actor 'airline management' is a generic analysis and not specific to any airline. This means that the expressed views will match some airlines better than others. This information can be found in literature (Caldwell, 2003) and on the internet. Crew fatigue has been a subject during many collective labour agreement negotiations. Information on how airlines deal with fatigue can be found in publicly available reports on these kinds of negotiations*

##### **Interests**

Airlines are run like any other business, they sell a product (transport people around the world) and maximise profits (i.e. ticket revenues minus fixed and variable costs). An improvement of fatigue levels is sure to be followed by a reduction in numbers of short- and long term sick leave and burn-out cases. A healthy workforce thus leads to an (indirect) cost reduction.

Airlines sometimes have a bad reputation when it comes to work times and work pressure. Especially 'cargo' and low-cost airlines are renowned in for this. Reducing crew fatigue can improve a negative company image. Not only can company image among pilots and cabin crew improve but public opinion can also improve once the information reaches the flying public. An improved company image can, in turn, lead to extra revenues.

Improving safety is a common goal between all large airlines. Safety is fundamental to the existence of an airline. Just one large incident can bring down an entire airline. Although the relation between safety and fatigue will continue to be under (political) debate and remain a field of research for a long time, the safety arguments that were made in the first chapter are more than enough reason for any airline to put fatigue on the top of their list of interests.

##### **Standpoint**

The general position on crew fatigue is fundamentally influenced by the fact that airlines are a profit driven business. If the cost of reducing crew fatigue is too high, the chance of a risk being addressed is small. Although most airlines look at crew fatigue as an important consideration, there are some common reactions to proposals for crew fatigue reduction. Some examples of these reactions are:

- The amount of accidents as a clear and direct result of crew fatigue is too low to justify any changes in current operations.
- Benefits do not outweigh the costs.
- Our survey on 'work satisfaction' shows that employees are satisfied. So there is no reason to change anything.
- Crew utilization needs to be maximized within the limits set by the collective labour agreement or the law to achieve optimal profits. (Banfe, 1992).
- There is no proven relation between fatigue and safety for our airline.

These reactions or statements can give the impression that airline managements have a 'low sense of urgency' when it comes to fatigue. This seems especially true for smaller airlines with low budgets that operate in a high competition environment. The reasons behind most of these arguments are commercial and strategic in nature. They are aimed at mitigating the importance of crew fatigue, in this way extra costs are avoided. Airlines don't want to spend money on issues that do not result a direct and obvious increase in profit. Because cost reduction as a result of reduced crew fatigue is perhaps indirect, efforts should cost as little as possible.

Large national airlines (flag carriers) have a very tight and complex operation; they are affected by production agreements, rules and regulations, security and political constraints. Any (proposed) changes in daily operations should be the result of a sound and mutually accepted process because it requires significant resources and planning. Whatever process or method that is used to reduce fatigue, the chance of 'false positives' should be extremely small. Until a specific product to measure fatigue is 100% reliable, airlines are not inclined to make large decisions. Smaller airlines may be more flexible.

Airlines also have another very important 'hard constraint' on any change in operations: safety must never be compromised. Next to profit, safety is fundamental to the existence of an airline. Any changes made to improve crew fatigue should not result in a risk increase in another part of operation. Again, any changes should be the results of a thorough process.

CORE-VALUES: profitable growth, continued operations and safety

#### Causes

Because changes in operations are sometimes very difficult, there is a tendency to focus on countermeasures and crew behaviour. Countermeasures receive relatively high attention (educational campaigns) because this is a lot easier to realize than changes in operation. Crew fatigue is often explained as normal part of working in (commercial) aviation. As long as schedules are legal, fatigue is caused by unused or failing countermeasures, off-duty crew behaviour like having a second job, family issues (children, marriage, and loss of family members) and leisure time activities (Orlady, et al., 1999).

#### Influence

Airlines have considerable influence on decisions that surround the issue of crew fatigue. The resources needed for operational changes (human, financial) are often available.

		Reducing crew fatigue	
		Beneficial	Detrimental
Airline Management	Internal	<b>Strengths</b> <ul style="list-style-type: none"> <li>• Knowledge of safety processes</li> <li>• In depth knowledge of the scheduling process</li> <li>• Available resources to realize changes</li> <li>• Improve company image</li> </ul>	<b>Weaknesses</b> <ul style="list-style-type: none"> <li>• Safety is always a trade-off with profit (Banfe, 1992).</li> <li>• Higher costs for safety management.</li> <li>• Sense of urgency remains low until accidents happen</li> </ul>
	External	<b>Opportunities</b> <ul style="list-style-type: none"> <li>• increased public awareness of crew fatigue -&gt; research funds may become available</li> </ul>	<b>Threats</b> <ul style="list-style-type: none"> <li>• Private activities may have an influence on fatigue levels</li> <li>• Competing low-cost airlines</li> </ul>

## 5.4.2 Pilot unions

*This analysis of the actor 'pilot unions' is also a generic analysis and not specific for any particular pilot union. The expressed views will therefore match some unions better than others but overall the views hold true for most pilot unions.*

### Interests

Although the goal of a union is slightly different than that of the members (unions strive for as many union-members as possible by representing member interests), in this case both will be treated as equal. The goal of pilot unions is to protect and improve pilot interests. Reducing fatigue is one of these interests. Generally, airline pilot associations aim for fatigue levels that are comparable to other professions. Protecting work load levels and reducing the chance of accidents and incidents are two other goals.

Pilots flying corporate en executive jets share this interest. A survey conducted by NASA (Rosekind, et al., 2000) resulted in 1488 corporate flight crew responding to 107 questions each. Remarkably there were 55 responses from flight crew over the age of 60. Corporate pilots do not have a mandatory retirement age and they are often not represented in unions. Many US corporate aviation departments also set their own flight- and duty time limitations because the FAR's do not provide strict rules or don't apply. The results from this survey show that for 61% fatigue is a common occurrence and 75% describes it as a moderate or serious concern. 85% identifies fatigue as a moderate or serious safety issue, mainly during approach and landing. Three-quarters of the respondents admitted to nodding off during flight while only 39% reported making arrangements for a pilot nap in the cockpit! These number show that fatigue is a significant issue in corporate flight operations.

### Standpoints

US-ALPA is the worlds largest pilot union and represents around 60.000 (US and Canadian) pilots in the United States and Canada. In a press release of April 6, 2008 US-ALPA's chairman Captain Don Wykoff commends the NTSB for continuing to raise awareness to pilot fatigue as a major safety concern. He also stresses the need for the aviation industry to do research and respond to fatigue. US-ALPA emphasises that not only changes in the outdated flight- and duty time limitations are needed but that changes in corporate culture are just as important. Pilots need to be able to decline flights due to fatigue without the chance of being punished or blamed otherwise.

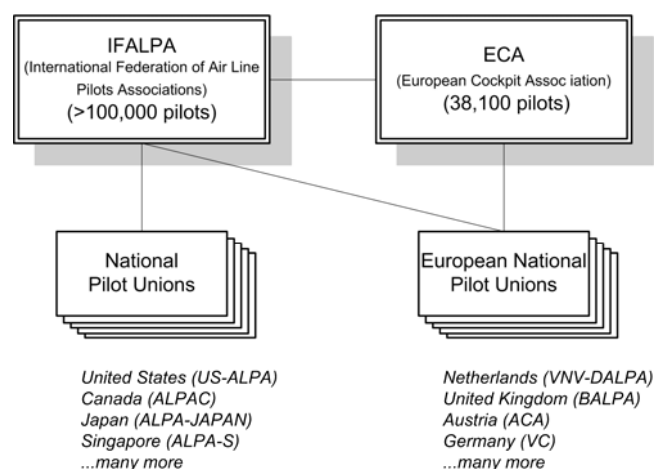


Figure 26 National and international Pilot Unions and associations



### Causes

Long-haul pilots associate fatigue with lack of sleep and the effects of changes of the circadian rhythm due to time-zone changes and night duties. Short-haul pilots relate fatigue to very early or very late reporting times, time pressure, commercial pressure and multi-sector days. Corporate and executive pilots point to mainly the same causes of fatigue (Caldwell, 2003).

### Influence

Most pilot associations are members of the International Federation of Airline Pilots' Associations (IFALPA) and the European Cockpit Association (ECA). Individual unions, such as the Dutch Airline Pilot Association, can influence International organisations like ICAO and IATA through their memberships of IFALPA and/or ECA. Strong, intelligent negotiations, lobbying and actions (strikes) are their main sources of influence.

CORE-VALUES: Representation of member interest, improve safety

		Reducing crew fatigue	
		Beneficial	Detrimental
Pilot unions	Internal	<p>Strengths</p> <ul style="list-style-type: none"><li>• Knowledge of members</li><li>• Active member involvement</li><li>• Member commitment</li><li>• Power of production</li><li>• Profit is not the main goal</li><li>• High sense of urgency</li></ul>	<p>Weaknesses</p> <ul style="list-style-type: none"><li>• National pilot unions sometimes represents pilots of different airlines, this could lead to conflicts of interest.</li><li>• Large number of members may slow down responsiveness if internal consensus is missing</li><li>• May be too dependable on airlines.</li></ul>
	External	<p>Opportunities</p> <ul style="list-style-type: none"><li>• National pilot unions are represented by international associations</li><li>• Improved public awareness</li></ul>	<p>Threats</p> <ul style="list-style-type: none"><li>• Increased competition</li><li>• Slow economic growth</li><li>• Low-wage countries</li></ul>

### 5.4.3 Cabin crew unions

Most of the elements mentioned in the description about pilot unions also apply to cabin crew unions. Both pilots and cabin crew work in practically the same environment and undergo almost identical work- and duty times. The most important difference is the type of work that they have to perform. While pilot have a mostly a sedentary occupation that requires short periods of high cognitive workload, cabin crew has to perform physical labour over many hours.

### Interests

The goal of cabin crew unions is to look after individual and collective interests (work conditions) of all union members. One of these interests is to protect cabin crew members against high levels of fatigue and work pressure. But as a union, one of the goals is to achieve a high number of memberships. Being successful at reducing crew fatigue can increase the number of memberships. But in this case, union interests are put equal to the member (cabin crew) interest.

### Standpoint

Fatigue due to physical labour (passenger service) and long duty periods are large contributors to overall fatigue. A general standpoint of cabin unions is that cabin crew can work a full-time employment without a high chance of health problems.

CORE-VALUE: Representation of individual and collective member interests: protect against high levels of work pressure and guarantee a balance between on- and off duty periods.

### Causes

As mentioned in previous chapters, a 'Quick Scan on work pressure' within one of largest Dutch airline revealed that duty time and sleep was a main cause of fatigue. (FNV / Cabin Pressure, 2007, 2008). Work- and rest times, days off and physical exertion are also involved.

### Influence

National cabin crew unions are not unified in European or international associations. Because of this, their influence remains 'local'. Besides the use of media, they have little formal means to address issues internationally. Through negotiations with airline management cabin crew unions can influence the contents of collective labour agreements and related work- and rest-time regulations. The number of cabin crew members determines the negotiating strength of individual unions.

		Reducing crew fatigue	
		Beneficial	Detrimental
Cabin crew union(s)	Internal	<b>Strengths</b> <ul style="list-style-type: none"><li>• Strong support of members</li><li>• Willingness to take action</li><li>• Rising number of members</li></ul>	<b>Weaknesses</b> <ul style="list-style-type: none"><li>• The different unions for cabin crew do not always agree. This can have implications during negotiations and when accepting airline proposals.</li></ul>
	External	<b>Opportunities</b> <ul style="list-style-type: none"><li>• Recently conducted independent survey on workload</li><li>• Increased public awareness</li></ul>	<b>Threats</b> <ul style="list-style-type: none"><li>• Increased competition</li><li>• Slow economic growth</li><li>• Low-wage countries</li><li>• Perception of line-of-work</li></ul>

#### 5.4.4 Aviation Safety Research institutes

##### Interests

The aim of most institutes is to support stakeholders in aviation with information and knowledge about best practices with regard to air transport safety. They have in-depth knowledge of all aspects of aviation operation. Aviation safety institutes can also increase their own knowledge about crew fatigue when they are involved in a hands-on process. Most institutes have the objective to share new knowledge.

### Standpoint

Among other topics, the standpoint on crew fatigue was discussed in an interview with A. Roelen of the Dutch Air Transport Safety Institute (NLR-ATSI). Fatigue has the potential to create dangerous situations or even incidents and accidents. During moments when tasks that need to be performed do not match the level of alertness, fatigue can be a detrimental factor. Cargo and small operators are most at risk because they predominantly operate at night (cargo) and on an irregular basis (small operators). One of the important effects of fatigue is that pilots develop a case of “get-there-itus”. They are eager to get home and get some rest, taking unnecessary risks in order to avoid delays.

### Causes

In the same interview the causes of crew fatigue were discussed. Scheduling practises were mentioned as the most important causes of fatigue. Especially short-term changes (as a result of disturbances in normal operation) increase the likelihood that fatigue is a contributor to accidents.

### Influence

The safety institutes can have a significant influence on the process to reduce fatigue. They can assist when looking for solutions or when proposed changes need to be chosen. Their independent status can help solve or prevent conflicts.

## 5.5 Relations between actors: the network

Airline management and unions are strongly interdependent. The unifying factor between them is flight crew. On the one hand a crewmember is an employee of an airline while on the other hand the crew members’ interests are being represented by a union. This ultimately leads to a situation where both airline and unions have no other option than to co-exist. This co-existence is a continuous situation of bargaining, supplying (and withholding) information and negotiating on labour agreements.

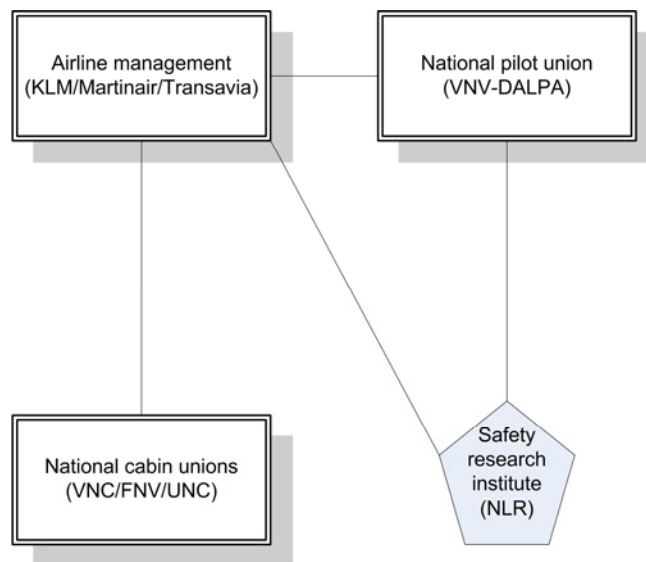


Figure 27 Actor relations

It is important to look closely at the relationships between these different actors. Especially the relation between airline management and unions is important because it can give insight into how the actors will respond to certain changes and why they make certain decisions. To what extent these relations can be made clear depends very much on the openness of the actors. The focus is again on the Dutch situation.

## Unions and airline management

Legally, every Dutch company with more than 50 employees is required to have a work council (Wet op de Ondernemingsraad WOR). Cockpit and cabin crew are both represented in the work council and (group)commissions. Figure 28 shows the typical formal relations between an airline operator and unions. It also shows how labour agreements emerge and how its daily implementation is monitored. Airline management and crew unions negotiate on the collective labour agreements. These negotiations take place in the months prior to the expiration of the current agreement. Typical subjects on which the two disagree are wages, work conditions and on/off duty periods. During these negotiations the relation can become very tense. Sometimes unions decide to use methods like a work strike to enforce their opinion. These actions can result in a breakthrough but may also worsen the situation. Strikes can be very costly for airlines, a 29-day strike of United Airlines pilots in 1985 resulted in enormous costs for hiring and recruiting new pilots and due to lost revenues (some estimate it around 1 billion USD). As recent as 2008, the British ALPA considered a possible strike over the issue of British Airways new European airline. This airline will be using non-BA pilots and paying them basic salaries. In the summer of 2008 Lufthansa pilots were on strike for better wages and better work conditions. The result was that around 1600 flights had to be cancelled (source: RTL nieuws).

Airlines can decide whether to include a specific union into labour agreement negotiations or whether to essentially ignore it. Besides this, unions also have to depend on airlines to put the negotiated results into practice. If an airline chooses to ignore a union or their agreements, there is a chance that union members will switch to another union or cancel their membership. In the long run, a good relation with (relevant) airline management is very important for unions. On the other hand, airlines need good relationship with unions because

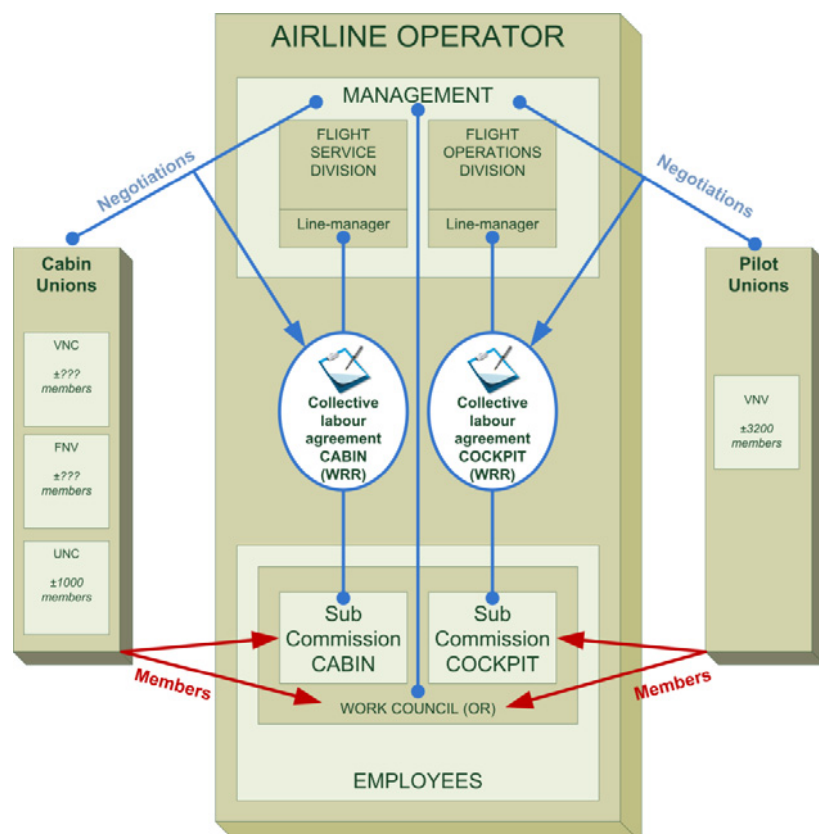


Figure 28 Relation between airline management and unions

(generally speaking) unions express the opinions of flight crew and are in the position to mobilise large groups for strikes and protest. These can potentially involve great costs in the form of missed revenue. Protests can also damage company image.

#### **Airlines and Safety Research Institutes**

Airlines and research institutes rarely have a formal relationship, but they are still dependent on each other. Cooperation is important because of an every changing environment, changing rules and new technologies. When airlines have to comply with new regulations or when they want to know the effect of new technology, they can rely on the expertise and knowledge of these institutes.

Research institutes on the other hand, also rely on the cooperation of airlines. Most modern airplanes record many different flight parameters such as flight path, flight level, speed, configuration, pilot input and so on. New models and ideas can be validated with this historical data. Airlines can also provide the resources for field studies. In the Netherlands KLM has cooperated with an extensive study on pilot alertness (Simons, R., Valk, P.).

From this detailed analysis of actors involved with crew fatigue we can conclude that the issue mainly resides with airline management and flight crew (represented by unions). National and international rules are relevant but they only provide very basic and often debateable standards. To really tackle this issue a healthy cooperation between airline management and their employees is of prime importance. Both depend on each other.

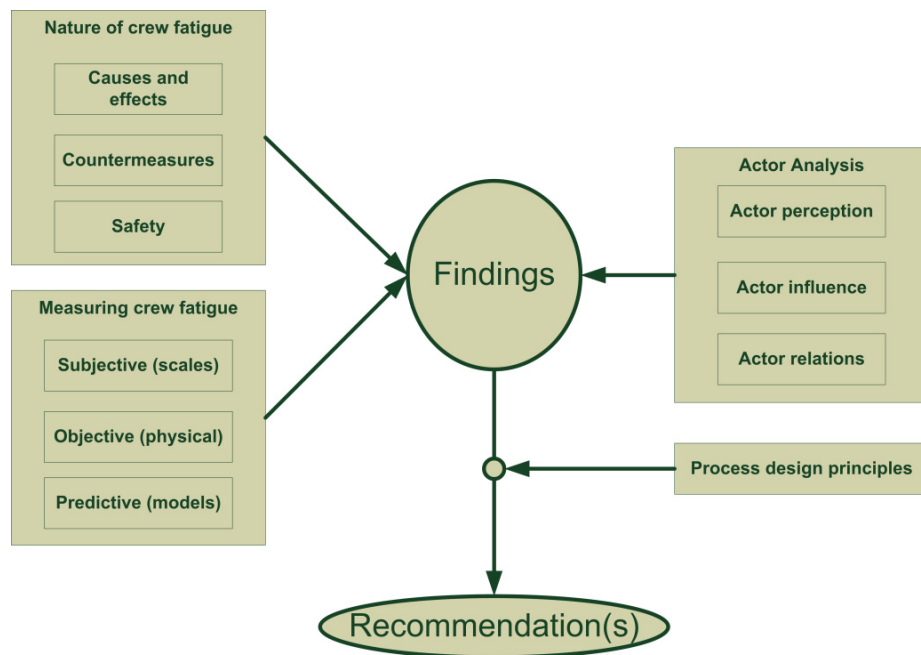
#### **Pilot unions and Safety Research Institutes**

Safety institutes can also assist pilot unions with studies into many different areas of flightsafety. In the past the Dutch Pilot union has often been represented in studies together with the NLR. Both are highly knowledgeable professional organisations.

## 6 FINDINGS AND RECOMMENDATIONS

There is no doubt that air travel will continue to require a high level of flexibility of flight crew to adjust to the typical characteristics of aviation. Until airplanes are fully automated and do not require any person for safe flight, unusual work-times and time-zone changes will continue to be part of work in this industry. But this does not mean that improvements are not possible.

The goal of this research was to formulate universal recommendations that can contribute to reducing crew fatigue. In this chapter several findings about the nature of crew fatigue, measuring fatigue and the relevant actors are presented. Together these findings form the context into which the recommendations are placed. Several conclusions of the previous chapters will be put into practice within the recommendations (for example the use of the best performing subjective scale or incorporating an actor's core-values).



### 6.1 Findings

For each of the three main parts of this research (nature of crew fatigue, measuring fatigue and the analysis of actors) the findings are presented in this paragraph. These findings will be used within, or as a context for, the recommendations.

#### 6.1.1 *Cooperation and understanding needs improvement*

The actor analysis gave us an insight in the relations between involved actors. When we look at the relation between unions and airline management and their respective core-values we can see that they, in essence, are not very different. In fact, there may be more similarities than differences. The main difference is that airline's are profit driven while unions are driven by member (crew) interest. Crew interest is a good balance between work and wage. Unfortunately these differences usually receive most of the attention.

Airlines management and flight crew have to realise they require each other to secure a strong and profitable airline in the future. Without making profit, airlines go out of business and employees will lose their jobs. And without a well rested and fit flight crew is difficult to guarantee operational continuity and the high levels of service and reliability needed in the high competition market.

Airline management and unions in essence have the same goal: a strong and healthy airline. Both need to put efforts into achieving or preserving this. As said before, a single fatigue related incident can have very large consequences for everyone involved in the airline. Reconciling opinions, thought and ideas between airline management and flight crew and reducing uncertainty about each others responsibilities are the main points of the first and second recommendation.

### *6.1.2 Sleep is essential for prevention and recovery*

As we have seen in the section on causes of fatigue, there are many different causes of crew fatigue. Work environment, age, mental state, lifestyle, workload and many more factors increase the likelihood of fatigue. But all of these factors also exist in industries other than aviation. What makes aviation different to other lines of work is that people who operate flights on a regular basis, consistently have to deal with shift-lag, jet-lag and very long duty periods (actual working hours may be even be longer than formal working hours). To increase the complexity of the issue, crew experiences different levels shift- and jetlag on an irregular basis during the entire year.

As we have seen in the paragraph on the subject sleep, regulating sleep quality and protecting basic amounts of sleep is the only way to prevent and 'repair' fatigue (Caldwell, 2003). Not meeting these requirements lie at the heart of the issue of crew fatigue. If crew were to have regular periods of quality sleep, this would reduce fatigue to more 'normal' levels. Sleep problems are caused by inadequate, fragmented or disturbed sleep, not having enough rest prior to sleep, disruptions of the internal circadian rhythm due to shift-lag, jet-lag and the very long duty periods. Sleep planning needs to receive the same amount of attention as work planning. This concept is the focus of the third and fourth recommendation.

### *6.1.3 Measuring fatigue: combine several different methods*

The fifth and final recommendations are on the subject of reducing current levels of crew fatigue. As we have seen in the chapter on methods for measuring or determining fatigue, there are three distinct categories: subjective measurements (scales/questionnaires), physical measurements (products measuring the causes or effects of fatigue) and predictive models (modelling the human body). Results from the multi criteria analysis show that the Stanford Sleepiness Scale, the Samn-Perelli Fatigue Scale and the Situational Fatigue Scale are best for use in a questionnaire or report form on crew fatigue. Actigraphs (in different forms and functions) are most helpful in measuring (the causes of) fatigue in an operational setting. A benefit of using products that focus on the causes of fatigue is that it provides a way of preventing fatigue altogether, proactive instead of reactive. When we look at the predictive models for performance and fatigue, only FAST and FAID are commercially available and both can be integrated into existing planning software. Although FAID includes the possibility of adding user-defined risk levels, the user interface of FAST is easier and more intuitive. Outputs from FAST are also easier to interpret and more intuitive. Otherwise there is little difference between the two programs.

From the actor analysis we learned that airline management is (rightfully so) not inclined to base any decision on a product that is not 100% reliable. Achieving such a level of reliability and sensitivity for measuring fatigue with any single product is, for now, not possible. Technological advances need to be made. Waiting for these developments however, is not an option. Therefore the final recommendation (the fatigue reduction cycle) combines data from as many different sources as possible into one single process. This process provides a solid case for making well-advised changes.



## 6.2 Recommendations

In this paragraph recommendations for reducing crew fatigue will be made. The first two (policy orientated) recommendations are important prerequisites for the success of the other four recommendations. The next two recommendations are focussed on improving sleep while the other two are aimed at actually reducing or preventing fatigue in present flight operations. Most recommendations are not meant to be 'stand-alone'. All have mutual aspects and the can best be seen as a complete package. To put the recommendations in their proper perspective, they are described using the various stages of the Accident Causation Model as presented in the first chapter. Where applicable, each recommendation will be discussed in terms of '**airline management**' (*organization*), '**daily operations**' (*workplace*) and '**flight crew**' (*crew/team*).

### 6.2.1 *Take the 'sting' out of crew fatigue, clarify it in your organisation*

Conflict often prevents clear thinking and stands in the way of progress. When fatigue is an issue that can be openly talked about in a supportive company culture and when employer and employee responsibilities are visible, there is a solid foundation for a successful approach to solving crew fatigue.

#### **Recommendation 1: Establish an open culture on fatigue**

Fatigue is often a subject that is avoided because it may be emotionally charged and be the source of endless debates and discussions. Company culture can withhold someone to talk about the fatigue they experience, and thus withhold important data or evidence. In the 2007 Delta Connection accident (where fatigue was a contributing factor), the captain stated that he did not 'call in to-fatigued-to-fly' because of the fear that the company would terminate his employment. To change this, an open culture on fatigue should be established

##### *Airline management*

It is imperative that an open company culture on fatigue is present or established. Two important conditions must be met to achieve this: (1) company management should be on the forefront of **open discussions** on fatigue and (2) these discussions and associated actions should be **non-punitive**. Even though non work related employee behaviour (during and outside working hours) can have a profound effect on fatigue, this is not a reason for management to take disciplinary actions if this subject arises during open discussions.

##### *Flight crew*

As a response to employer commitment, flight crew is expected to act equally responsible. Matters regarding fatigue should be discussed openly and, on every relevant occasion, reporting fatigue to management should be done. This 'equation' sums up the relation between employer and employee:

$$\begin{array}{l} \text{Employer commitment} \\ \text{Fatigue program visibility} + \\ \hline \text{Employee awareness and motivation} \end{array}$$

#### **Recommendation 2: Establish and/or clarify responsibilities**

It is very important to establish or clarify responsibilities of employer and employee regarding factors that cause fatigue. Responsibilities about these factors should be put in writing and communicated throughout the company.

Well balanced responsibilities between employer and employee are necessary condition form compliance.

#### *Airline management responsibilities*

*Sleep:* Airline management has to provide for good sleeping opportunities and a good sleeping environment. This means that crew should be able to sleep at appropriate times (preferable at night) for at least 8 hours while having enough time to rest before sleeping (at least 3 hours) and before the start of a new duty period. The sleeping environment should be quiet, dark, comfortable and cool. Interruptions and paperwork should be avoided or kept to an absolute minimum.

*Identification:* Airline management should actively search for and acknowledge situations where high levels of fatigue pose a risk to safety or employee wellbeing.

*Mitigation:* Airline management should actively seek changes in operation that reduce fatigue.

*Education:* Management has the responsibility that schedulers and flight crew receive proper education on fatigue. Good scheduling practices need well informed, educated and trained people. For example, schedulers need to be aware of general variations of performance during the day (circadian rhythm) and the effects of shift-work and time-zone changes. Flight crew (new and existing) should also be educated on all issues surrounding human fatigue. They should be educated on the nature of fatigue, what the warning signs are, what the effects on their behaviour can be and how they can (temporarily) counteract these effects.

#### *Flight crew*

*Sleep:* Flight crew should use the opportunities for sleep as much as possible and avoid activities that have a negative effect on sleep. Consuming alcohol, caffeine and nicotine should be avoided or kept to a minimum. Social activities must not take priority over resting and sleeping.

*Identification:* Flight crew should report problems and situations where fatigue is involved. Not only personal experiences should be addressed but colleagues should be encouraged to actively report. Flight crew should cooperate with and contribute to systems, processes and methods designed to reduce fatigue

*Mitigation:* Flight crew should manage individual factors that affect fatigue negatively. Both in their personal life and on-the-job.

*Education:* Flight crew has the responsibility to actively pursue knowledge about fatigue. This knowledge should be put into practice, both on- and off-duty.

### **6.2.2 *Promote and facilitate sleeping***

Throughout this report the importance of sleep as a way to prevent and restore fatigue was stressed many times. But aviation is a difficult place to achieve quality sleep. With the help of these next two recommendations, and the backing of the previous two, sleep can be improved *without major changes to current operations or high costs*.

#### **Recommendation 3: Establish a program for health and lifestyle factors**

Sleep disorders are important contributors to fatigue and in aviation. Sleep disorders are relatively common (Caldwell, 2003). Caldwell classifies the sleep disorders in four categories of which 'dysomnias' is the most important. Dysomnias are problems with falling asleep and maintaining sleep (insomnia), having excessive daytime sleepiness (hypersomnia) and experiencing unwanted events during sleep (parasomnia) such as sleep apnoea.

#### *Airline management*

A special, easy entry program for sleep disorders should be initiated by airline management. For large airlines this can be done by their Health Services department, smaller airlines can make use of specialised sleep clinics (like the U.S. National Sleep Foundation or the 'Waak-Slaap centrum' in Amsterdam). The program could consist of an educational and monitoring component. Educating flight crew on sleep problems (and the accompanying lifestyle changes) raises awareness and motivation. Monitoring could be done by randomly selecting individual flight crew to (voluntarily) take part in a non-punitive sleep quality assessment. Ideally the airline should make time available for attending these sessions.

#### *Flight crew*

When a person finds that fatigue or sleep is becoming a problem, he or she should actively seek professional help through the airline and not wait for the problem to get bigger. An open and non-punitive culture on fatigue and a sense of responsibility should make this an easy step.

### **Recommendation 4: Provide generic sleep schedules together with the work schedule**

Based on scientific knowledge about sleep, airlines should be able to provide flight crew with 'recommended sleep schedules'. These are schedules that assist crew in getting adequate sleep. Especially inexperienced crew would benefit from such guidance. Sleep schedules are essentially countermeasures that lessen the impact or intensity of fatigue. Research, training and knowledge institutions such as the NLR or specialised sleep clinics can provide the necessary expertise on sleep.

#### *Airline management*

A sleep schedule would have to be made in such a way that it provides optimal preparation to and recovery from a duty period. A simple rule of thumb would be: before embarking on a westbound flight, a sleep schedule should recommend adding a couple of hours to every day for at least two or three days. By going to bed at a later time, the body is prepared for the upcoming time difference. Before returning (flying eastbound) the sleep schedule should make sleep recommendations that prepare the body to return to the original time zone. If this is not possible, the ideal moments for sleep should be advised. A sleep schedule is useful for both short-haul (the early reporting time issue) and long-haul (time differences). There are at least two ways in which 'single' sleep schedule can be expanded: design *connecting* and/or *personalized* schedules.

A **connecting sleep schedule** is one schedule that is designed for multiple flights. In the case of long-haul flights a connection schedule takes previous and expected time zones changes into account. For short-haul rosters, a connection sleep schedule is almost always necessary because short-haul rosters include multiple flights over multiple (mostly connecting) days.

Initially these sleeping schedules can be generic but as experience grows, airlines could decide to implement a number of different sleep **profiles**. At first, crew would be able to choose a profile based on their personal experience. People who prefer to stay up late would choose an 'owl'-profile and people who like to get up early could choose a 'lark'-profile. The ultimate situation would be to design **personalized sleep** schedules which is tailored for each individual. Feedback from daily operations is essential for designing sleep profiles and individual sleep schedules. After an initial design project most of this process (maintenance) could be done

automatically. These sleep schedules should be published together with work rosters.

As described before, in multi-crew cockpit situations pilots usually have the possibility to make use of crew bunks. Pilots decide among each other “who sleeps when and how long”. Always at the captains’ discretion, this process is sometimes influenced by his authority and interpersonal relationships. This sleep schedule can be integrated in the overall sleep schedule. This on-duty sleep schedule should be designed with the typical time-task demands in a cockpit setting.

Appendix 9 shows an example of how task effectiveness can vary using different sleep strategies. In this example a typical 48-hour return flight from Amsterdam to Hong Kong is used to illustrate these differences. The flight was entered into the FAST tool and three different sleep strategies were used: (1) immediately adjust to local time (2) partially adjust to local time and (3) stay on ‘base time’. All three examples resulted in different levels of task effectiveness during landing on the return flight. In this case, partially adjusting to the time-zone changes resulted in best performance at the end of the duty.

#### *Flight crew*

When sleep schedules are presented to flight crew as a preventive- or countermeasure to fatigue, these should be followed as much as possible. In the process of fine-tuning these sleep schedules, feedback from flight crew is essential. Feedback should be encouraged as much as possible to improve the usability of the sleep schedules.

*Of special concern are legal responsibilities. Sleep schedules should be presented as guidelines and not as obligatory. In the end individuals will have to decide what works best for them (and provide give feedback).*

### **6.2.3 Take action: measure, change and fine-tune schedules**

#### **Recommendation 5: Introduce a non-punitive anonymous Fatigue Report Form**

In most safety management systems (SMS), a well established way of retrieving data from daily operations is through report forms. In civil aviation there are many such forms like an Air Safety Report (ASR) and the In-Flight Report (IFR). A report form for fatigue could be added. To add just another one to the hundreds of acronyms and abbreviations, let’s call it an FRF (Fatigue Report Form). **In Appendix 10 an example of such a form can be found.** *This form uses the Stanford Sleepiness Scale and the Samn-Perelli Fatigue scale.*

#### *Airline management*

It is important to emphasise that filing a Fatigue Report Form will have no consequences for current and future job situations and that all information will be treated confidentially and be considered non-punitive. Giving feedback on how the reported situation will be investigated will improve flight crew involvement in the overall fatigue program.

#### *Flight crew*

In order to get as much data as possible from daily operations, all flight crew should be encouraged to file a Fatigue Report Form whenever they think is necessary. A sample report form is provided below:

## Recommendation 6: Implement the Fatigue Reduction Cycle



This final recommendation is the most effective but it also requires significant efforts from airline management, unions and flight crew. It is a combined effort of all the actors identified in the actor analysis to identify and resolve flights that result in high levels of fatigue.

The Fatigue Reduction Cycle (FRC) is a *process template* that can be used to reduce the total amount of perceived fatigue in daily operations. Its goal is to make well informed adjustment to duty periods with the combined support of airline management and cockpit- and cabin crew unions. *It is complementary to and not a substitute for all applicable Duty and Flight Time Regulations, it functions within these boundaries.* Before using this template the initiator (preferable airline management) should invite cockpit and cabin unions to decide upon process rules or protocols.

Also, they should agree on a goal that is to be reached with this process: how much fatigue should be reduced in what period of time. Or in the case of the Fatigue Reduction Cycle: how many cycles should be performed in what period of time. In each unique situation, specific rules and goals should be agreed upon.

Because inadequate sleep is the most important cause of fatigue, the main focus of the FRC is on scheduling practices. Sleep periods are highly dictated by schedules. The FRC is designed on the basic principles of problem solution and modified to fit specific challengers that are associated with crew fatigue. These challenges are often due to (perceived) conflicting interests between airline management and unions/crew. To minimize the chance that these different interests result in debilitating conflicts, it is important that (1) **airline management takes the initiative** to reduce fatigue, (2) that **all actors commit to the process** (=FRC) and (3) that they **do not have to commit to the results**. When actors do not have to commit to end results, taking part in the process becomes an easy step.

The FRC was designed with the four design principles (Bruijn, et al., 2002) of a process in mind. When implementing the FRC, these design principles should also be used as guidelines when actors decide on specific process rules. This is why they are presented here:

### 1. Preserve openness

Airline management should have an open view and not take decisions without consensus of other actors. Management and unions should both create and agree upon the 'rules of the game'. During this process of creating rules it is important to keep a *focus on the process itself and not the content*. Focussing on current problems, ideas for specific solutions and causes should be avoided because this will most likely cause debilitating conflicts.

### 2. Protect core values

Both management and unions have so called 'core values'. These core values are the essence of an organisation. They define what an organisation stands for, the beliefs it has and its identity. These core values should be respected and must not be compromised by process rules. For example, this means that airline management should not be forced into implementing small changes that have high costs. The process rules should also not result in a situation where unions have to agree with changes that they know will not be supported by their members (flight crew).

An important part of the process is the availability of exit-rules. There are two kinds of exit rules to be made: (1) an exit-rule for abandoning the entire process and (2) an exit-rule for abandoning a specific 'cycle' of the fatigue reduction cycle. This last exit rule is included in the FRC template. While the focus on the process, using an exit option is less desirable. When a process is successful, exit rules may no longer be necessary.

### 3. Guarantee continuation

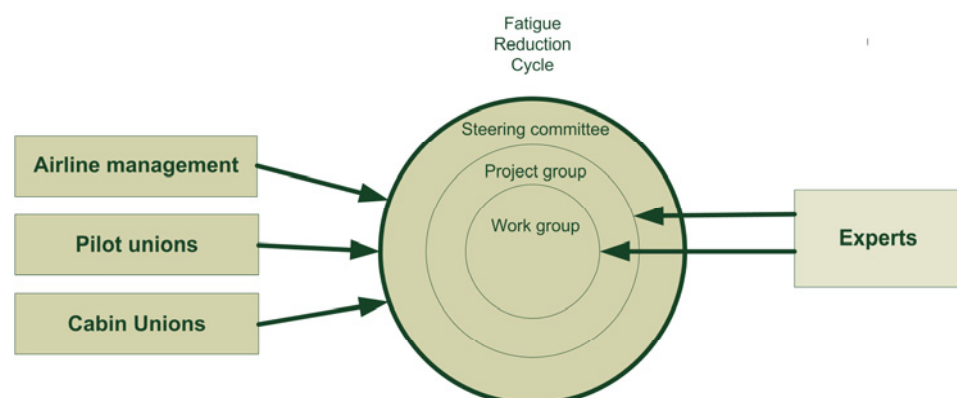
Continuation of the process must also be guaranteed. To achieve this, it is important that the exit choice is less favourable than continuing the process and that cooperative behaviour is stimulated. The FRC achieves this by putting the actual moment of success (reducing fatigue) near the end of a cycle.

Airline management can also secure the continuation of the process by using people that have enough 'organisational power' to implement decisions without having regularly having to consult their superiors. De Bruijn et al. mention the use of different layers in the process to avoid conflicts and secure continuation. The structure consists of three layers:

<b>Steering committee</b>	The steering committee consists of (high profile) airline, cockpit and cabin union representatives. This committee takes decisions the rules/protocols that are used in the FRC template.
<b>Project group</b>	The project group also consists of representatives of airline management, cockpit and cabin unions. This group should be educated on crew fatigue and include external experts on fatigue models and fatigue measuring methods. It is the project group that carries out fatigue reduction cycle. The project group can be turned into a permanent structure if the results are positive.
<b>Work groups</b>	Work groups perform the daily tasks of managing equipment, retrieving data from daily operations or perform the actual measurements. The workgroups should preferably consist of cockpit and cabin crew. Communication and trust between flight crew can be an advantage when it comes to acceptance and tolerance. Work groups should be educated on how to perform measurements.

### 4. Safeguard content

The use of experts ensures that, during the process, the focus is on the content and this focus is not lost because of conflicts. It must also be prevented that experts get involved in the interests of other parties. To have the best access to expert knowledge, a local institute is preferred.



### Different phases of the Fatigue Reduction Cycle

The Fatigue Reduction Cycle is divided into several phases. What follows is a detailed description of the different phases of the fatigue reducing cycle after which an example cycle is included.

GET STARTED	A. Identify suspect	Where is fatigue encountered?
	B. Prioritize suspect	How large is the problem?
MEASURE	C. Determine fatigue moments	When and why is it encountered?
	D. Validate and compare	Compare with other schedules and scientific fatigue models
SOLVE	E. Find solutions	How can this fatigue be reduced?
	F. Decide on solutions	All parties/experts should agree
APPLY	G. Implement	Apply solution
LEARN	H. Evaluate	Learn, document and educate

#### PHASE A: Identify suspects

The first phase in reducing fatigue is identifying a crew pairing (this can be a single or group of flights) that seems to result in a relatively high level of fatigue. At this moment such a crew pairing is only a 'suspect'. Finding suspects can be done in a number of ways, but information should be retrieved from actual daily operations. This is important because it is only in everyday situations that fatigue is encountered by flight crew, not by people behind desks.

Airlines that register when pilots (or cabin crew) call in 'not-fit-to-fly' can use this data to search for crew pairings that have an increased number of not-fit-to-fly calls. Another way to collect information about fatigue 'suspects' is to use in-flight reports. Most large airlines use IFR's that enable crew to report situations before, during and after flight to company management. Using IFR's to report fatigue situations should be encouraged by management. It is also possible to introduce the standardised 'fatigue report form' as proposed in recommendation 5. The information that is received should be managed by a workgroup. The project group should analyse the data for suspects. The processes and rules on the identification of suspects should include decisions on important aspects such as:

- The amount of fatigue reports during a specific period
- How many different people reported the fatigue
- Was the overall reported cause of the fatigue work related
- Has it been addressed previously

Because the process of identifying suspects does not guarantee that every suspect is automatically included, using **random schedules** to evaluate levels of fatigue is highly recommended. Informal information (word of mouth) can also be used to identify suspects.



## PHASE B: Prioritize suspects

Once a suspect is identified it is important to prioritise the suspect in relation to other suspects. Multiple suspects can flow simultaneously through the cycle but some require more attention than others. This initial prioritization avoids overloading by small or insignificant suspects and so helps to keep the cost down. To prioritise a suspect's urgency the **fatigue hazard probability** matrix (Miller, 2005) can be used. This checkcard, described in a previous chapter, results in a risk score. The information that is used to fill in the check card should come from published schedules. Potentially combined with other organisational reasons, this risk score can prioritise a suspect effectively.

Another possible measure of priority can be obtained by looking for evidence of fatigue related incidents through browsing incident reports, complaints, flight data and so on.



Figure 29 the Fatigue Reduction Cycle (source: author)

### **PHASE C: Determine moments of high levels of fatigue**

The chapter on methods for measuring human fatigue describes a number of ways to do this: physical methods focusing on the causes and effects of fatigue and subjective assessments focusing on personal experience of the effect. The use of both physical and subjective assessments should give a good indication of fatigue levels.

At this point a workgroup should deploy a standardised method for measurement which takes place during several weeks or months (this frequency depends on the process rules). The method should start with informing crew beforehand about the study. Individual crew members would be allowed to decline participating to the measurement. If the captain of the flight declines, the entire crew should be excluded. To get as much data as possible it is advised to include both cockpit and cabin crew.

Prior to the duty period the crew should be briefed to inform them of what can be expected. To take measurements it is recommended to use both a questionnaire and a physical measurement. Following the multi-criteria analysis of subjective assessment methods, the Situational Fatigue Scale and the Stanford Sleepiness Scale are the preferred methods for crew to self-assess fatigue. In order to get a good view of the development of fatigue levels it is necessary to have crew rate the level of fatigue regularly and at previously defined important moments. These moments should be chosen carefully and in order not to increase workload, each rating should only take a few moments (this was one of the main selection criteria). The ranking of physical measurements shows a preference for watch-like activity meters (actigraphs). Especially the 'ActiGraph GT1M' has good software capabilities for reviewing sleep and activity levels. Crew should wear an actigraph for the entire duty period. During the briefing, crew is instructed (in person) on how to use the actigraphs.

By combining formal duty schedule information, the information supplied by the flight crew (questionnaire) and the information on activity gathered by the activity watches, the varying levels of fatigue can be determined. When analysing the data gathered from the activity watches it is advisable to use the knowledge of experts. The answers to these questions can help understand specific fatigue moments during a duty period:

- How much sleep has been had in the last sleep period?
- How long ago was this sleep period? <sup>3</sup>
- Has the sleep been continuous or disturbed?
- How many night duties preceded the moment?
- How long was the actual or previous duty period?
- How many time-zones were crossed?
- What time zones were crossed in the previous duty period?
- Was there a preceding early or late reporting time?

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<sup>3</sup> The 'time since awake' is affected by and prolonged due to: jet lag, shift lag, early awakenings because of environment, time needed for hotel checkout, travel time to airport and delays in flight because of weather, mechanical problems or changing time slots.

Besides these questions, special attention should be paid to the combination of fatigue levels and required task performance. For pilots, the combination of high levels of fatigue during moments of high workload (take-off and landing) is of particular importance.

#### **PHASE D: Validate and compare**

When specific moments with high levels of fatigue are found, they should be compared/validated with existing models for fatigue. This is done by inputting the duty schedules and activity/sleep data (gathered from the activity watch) into a software tool. Of the three described tools, FAST is a good choice and it is easily available

This comparison is an important step in 'objectifying' the results. Potential conflicts between management and unions can be prevented when two sources (subjective and objective) show the same result. The results from the predictive fatigue model should also match to reasonable levels.

*This phase is of particular importance to reach agreement on high fatigue moments. Rightfully, airline management is not inclined to make changes based on mediocre evidence. But here we have three sources that, if they 'agree' make a very strong case: subjective measurements, objective measurements and a validated predictive model for fatigue and performance!*

In the case that the data does not match, experts on fatigue should be called into the process to examine the data. Particularly when subjective data from the questionnaires indicates a problem and it is not backed by measurements from the activity watch or the predictive fatigue model.

To get the best 'value' from the finding it is useful to compare the situation with other schedules. For example, it is likely that equal results can be found in flights to neighbouring cities or in flights that have comparable characteristics (flight duration, time-zone changes and so on). Potential solutions could be implemented into these additional crew pairings. This could save significant costs.

#### **PHASE E: Find solutions**

The project group now has enough information available to start looking for solutions. Experts can be asked to join the group in the process of finding one or more solutions. Factors to consider when looking for solutions are:

- time of day
- amount of sleep obtained
- hours of wakefulness
- durations of rest periods
- number of consecutive night duties
- and so on...

There are several categories of solutions which can be proposed, in order of effectiveness these are:

**Elimination:** cancel a specific flight (most effective but least realistic)

**Substitution:** substitute a flight for another (i.e. one long-haul into two short-haul)

**Modification:** make changes in a schedule (i.e. change departure time or add crew)

**Education:** inform and prepare crew on this specific problem, take no further action

In the case of multiple flights over multiple days (mostly short-haul) changes in crew pairings are most obvious. By adding or removing certain flights at certain moments, improvements can be made. This kind of change usually does not need a change in the main flight schedule but only in a specific crew pairing or personal roster.

In the case of long-haul operations changing the moment of a flight does require a change in the flight schedule. These kind of solutions can have far reaching effects and should only be done carefully and (of course) in consensus with all involved actors.

Additionally, experts on aviation, safety and fatigue (like the Dutch NLR) can be asked to assist in finding practical solutions and to assess the operational and flight technical consequences of a particular change or solution.

Note: Solutions should not exceed governing rules and regulations on flight-and duty time limitations! Crew rosters should remain 'legal'.

#### **PHASE F: Decide on a solution**

The solutions should be checked with the FAST model to estimate the results. By checking the effects of each possible solution with the fatigue models, one or more solutions will probably have the greatest effect on performance. The project group now has to make a decision on which solution to implement. This decision has to be made together with the steering committee. The airline management representatives of the project group may have to consult the scheduling department on the possibilities of changing crew pairings or the flight schedule. Union representatives may have to consult with their members to get approval. If a decision cannot be reached, experts (NLR) can be called in to give their opinion. It is also possible to implement a solution as a pilot project.

From the start of the process the actors were not committed to the end results but only to the process. Therefore, if an actor cannot agree to a certain solution because his or her core-values are not met (or for any other reason no decision can be reached) this phase offers an exit option. All actors must 'agree to disagree' and return Phase A and start with a new suspect.

*Perhaps an obvious statement, but using the exit option should be prevented as much as possible. If every cycle results in taking the exit option, the fatigue reduction cycle will lose momentum. If one actor repeatedly opts for the exit option, this may result in losing his/her credibility.*

#### **PHASE G: Implement solution**

Implementing the chosen solution can be done on a large scale implementation or in the form a temporary pilot project. Large airlines may prefer a pilot project while smaller and corporate airlines may be able to introduce a solution directly. Pilot projects can also be chosen if the expected results show some variability.

#### **PHASE H: Evaluate**

Evaluation should be done with a standardised method. At a minimum, several flight crews will have to take the same questionnaire as in phase D. Preferably the entire method used in Phase D should be used again to evaluate the results. By comparing these results with the results from Phase D, an evaluation can be made of the results from implementing the chosen solution. Additional indicators can be sleep quantity, sleep quality, performance, errors and incidents.

## Example of one cycle in the Fatigue Reduction Cycle

This is a fictitious and simplified example for reducing fatigue by performing a cycle of the FRC. The example does represent a real-world situation. The described solutions are also examples. Let's go through the phases of a single cycle:

Fatigue Report Form	
This form can be issued to inform management of a situation in which you experienced a level of fatigue that you considered highly uncomfortable or a particular risk to safety. This form is non-punitive and can be submitted anonymously. IT IS ADVISED TO USE THIS FORM AT THE MOMENT FATIGUE IS EXPERIENCED.	
<b>Report the occurrence</b>	
Date	
Approx. time	
Flight number	
How many hours had you been awake?	
How many hours of sleep did you have in the preceding 72 hours?	
How many time zones did you cross (cumulative hours) in the preceding 24 hours?	
How many days were you in the new time zone?	
<b>Self assess the fatigue level</b>	
Please describe what level of fatigue you experienced (Samn-Perelli fatigue scale)	<input type="radio"/> Fully alert, wide awake. <input type="radio"/> Very lively, responsive, but not at peak. <input type="radio"/> Okay, somewhat fresh. <input type="radio"/> A little tired, less than fresh. <input type="radio"/> Moderately tired, let down. <input type="radio"/> Extremely tired, very difficult to concentrate. <input type="radio"/> Completely exhausted, unable to function effectively.
Please describe what level of sleepiness you experienced (Stanford Sleepiness Scale)	<input type="radio"/> Feeling active, vital, alert, or wide awake <input type="radio"/> Functioning at high levels, but not at peak; able to concentrate <input type="radio"/> Awake, but nervous, responsive but not fully alert <input type="radio"/> Somewhat foggy, let down <input type="radio"/> Foggy; losing interest in remaining awake; slowed down <input type="radio"/> Sleepy, woozy, fighting sleep; prefer to lie down <input type="radio"/> No longer fighting sleep; sleep onset soon; having dream-like thoughts <input type="radio"/> I fell asleep
Please describe your fatigue in the past 24 hours in as much detail as possible.	
<b>Safety</b>	
Please describe whether you think your fatigue could have been a risk to flight safety	
Please describe what you think were the causes of your fatigue:	

The workgroup has collected data from various sources (i.e. in-flight reports, fatigue report forms and word of mouth) and by analysing this data the project group notices that the crew pairing Amsterdam-Toronto-Amsterdam has a high number of crew feeling fatigued. They label this as a suspect. The crew pairing looks like this:

### Day 1: flight Amsterdam to Toronto (Flying time: 8 hours, 5 minutes, time zone: +6)

Report for duty: 18:20

End of duty: 02:25

### Day 4: flight Toronto to Amsterdam (Flying time: 7 hours, 10 minutes, time zone: +6)

Report for duty: 04:20 (22.20 Toronto time)

End of duty: 11:30 (05.30 Toronto time)

When the project group prioritises this suspect looking at arrival times is a good start since these are moments of flight when most incidents occur. Performance demands on pilots are highest. Scoring Millers Matrix for the time of arrival at Toronto Airport we would get:

FATIGUE HAZARD	Rating
<b>A. Length of Prior Wakefulness (LPW)</b>	
16<= LPW < 19 hrs (assuming a wake-up time of 08:00 means 18 hours of prior wakefulness, waking up at 07:00 would even result in LPW>19hrs)	3
<b>B. Amount of Prior Sleep for the Preceding 72 hrs. (APS)</b>	
18 <= APS < 21 hrs (Assuming no sleep loss in the previous night and a normal bed-time of 23.00 than an arrival at 02:25 would result in 3 hours sleep loss. Three nights of eight hours minus three equals 21 hours)	3
<b>C. Time of mishap/day (TOD)</b>	
0100 <TOD <= 0600 hrs (Arrival is at 02:25)	1
<b>D. Number of Night Shifts in Preceding 30 Days (NNS)</b>	
NNS < 8 (unknown)	5
<b>E. Time Zone Change and Days in Zone</b>	
Time change of 6 to 12 hours and days in zone <=1	1
<b>F. Estimated Exertion Across the Work Period of Interest</b>	
Somewhat hard or hard (heavy) exertion (Average estimation)	3

Following the scoring rules (if any rating is 1 it should be considered a fatigue risk) the group concludes that, based on the flight to Toronto alone, this suspect should receiver further examination.



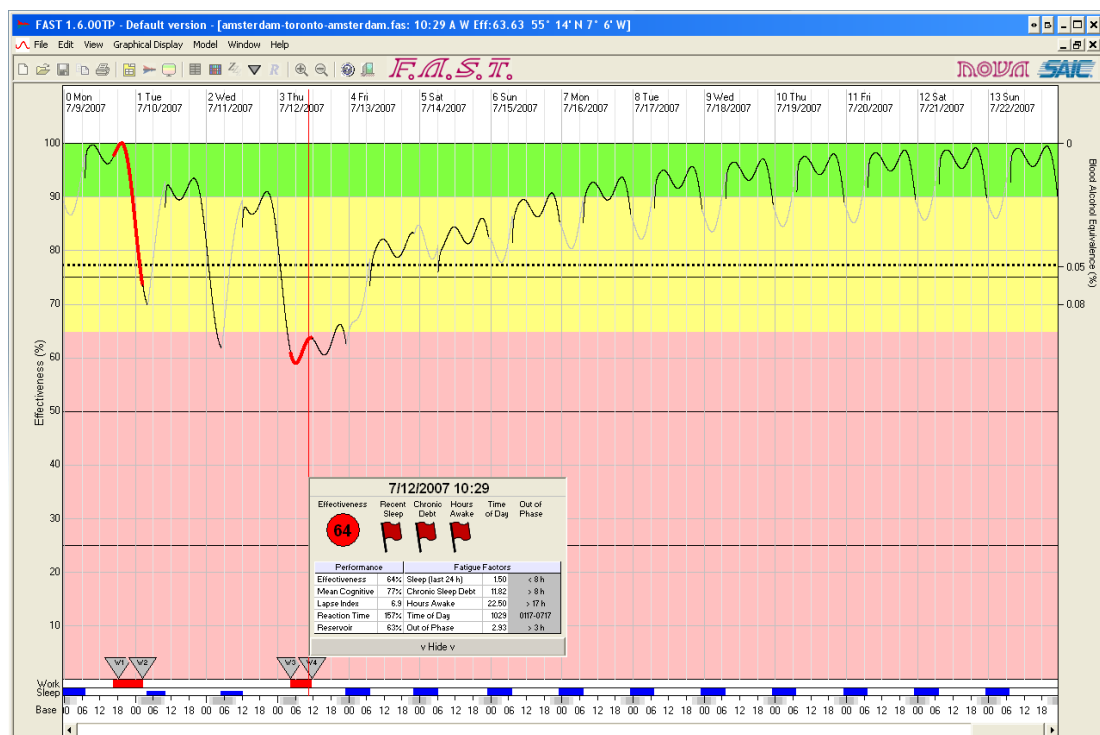
The next step is to determine moments of fatigue during the days the crew is en-route. Since this route is flown daily, a period of two months is used to gather information. The workgroup instructs the crew on when to fill in the fatigue questionnaires and how to operate the activity monitors. When the results of the questionnaire, activity monitors are the duty schedule are compared this specific moment of high levels of fatigue is seen:

*Crew report high levels of fatigue near the end of the return trip to Amsterdam. Activity monitors show high levels of activity in the hours prior to landing and very little sleep in the preceding 24 hours. The duty schedule confirms this because the return flight starts at the end of the day (Toronto) and continues through the night into morning (Amsterdam).*

Now that at specific moment is found, it can be compared with fatigue performance models like those mentioned in a previous chapter. In this case the schedule is fed into FAST. The moments of sleep that were reported by the activity watch are entered as sleep periods. FAST is also able to model the effects of time-zone changes and seasonal changes in sunrise and sunset. As can be seen in this graph, the comparison with the fatigue model (in this case SAFTE) confirms the findings from daily operations. There is an important 'low' near the end of the return flight. *Subjective measurements, objective measurements and the predictive model all 'agree' on this situation.*

When comparing these findings with other schedules, almost identical situations can be found on flights to New York and Chicago.

There are a few factors that cause this period of low performance at the end of the cycle. First thing to consider is the amount of sleep. Although some crew has tried to get some sleep before the return flight and crew was allowed 2 hours rest during flight it was clear that very little sleep was obtained in the 24

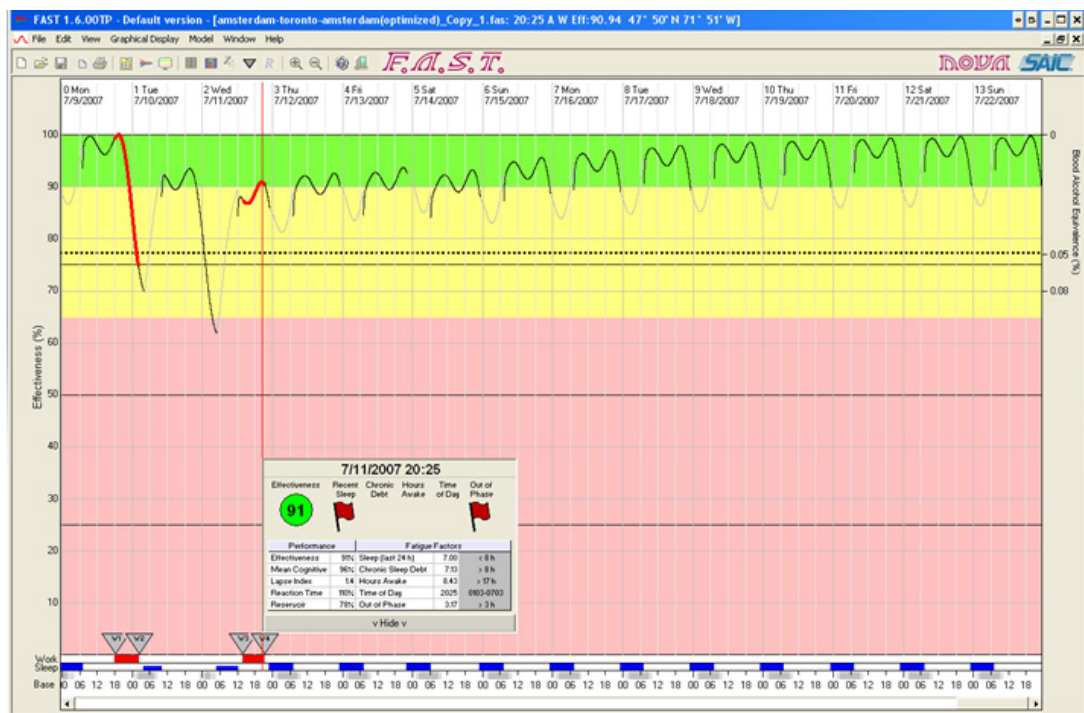


hours preceding the moment of low performance. Second, this moment occurs at a period of 'circadian-low'. For about 48 hours crew was able to adjust to the new (Toronto) time zone. This means that at the end of the return flight, their bodies were at a circadian low. Although local (Amsterdam) time was 12.00 o'clock, their body clocks were between 05.00 and 06.00 o'clock.

Together with experts on fatigue, the project group comes up with several solutions.

1. Advance the return flight to depart at 08.00 o'clock (Toronto time) on day **three**
2. Delay the return flight to depart at 08.00 o'clock (Toronto time) on day **five**
3. Advance the return flight to depart at 11.00 o'clock (Toronto time) on day **four**

Each solution is checked with the FAST fatigue model to determine the probable effects of performance. As an example, the result of the solution to advance the return flight to eight o'clock on day three is show below:



Both airline management and unions agree that this solution is the one to implement. No external expertise was needed because the fatigue model showed a significant improvement. After consulting with the scheduling department, airline management agreed to a change in the flight schedule and unions agreed to a shorter stay in Toronto. This change was also accepted by flight crew because after returning to Amsterdam they were able to get a good night sleep. As predicted by FAST, the performance on the day after returning to Amsterdam was much higher and the recovery period was significantly shorter.

Although the change in the flight schedule is quite significant, the predicted improvement is also substantial. It is decided that the introduction of this change does not need to be in the form of a pilot project.

After implementation the same method that was used in Phase D is now used to evaluate the solution. In the questionnaires crew report less fatigue and the actigraphs show that quality sleep is attained prior to departing.



### 6.3 Chance of adoption

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Sometimes it is unclear why certain recommendations or solutions are widely adopted while other solutions (that may seem better or more appropriate) are not giving the attention they deserve. There are several factors that determine whether a solution of recommendation is adopted. Appendix 7 shows a model that identifies these factors and the influence they have on the 'chance of adoption' (Beuthe, et al., 2004). Although this model was initially designed for use with transportation innovations, the recommendations from this report will be described on these factors in order to get an impression about their 'change of success'.

First, the techno-economic feasibility is composed of two elements; it needs to be technically possible and it should pass a rudimentary cost-benefit analysis (CBA). This CBA is only a minimal requirement (Beuthe, et al., 2004) because of the wide range of criteria and views that can be assumed.

Second, social feasibility is a function of the perception of the problem, the perceived effectiveness of the recommendation, how cost and benefits are distributed (these perceptions are subject to various external influences).

And third, the political feasibility is a factor of how decisions are made, the perception of the problem, industry interest and non-business interests. The full model can be found in the appendixes.

#### **Recommendation 1: Establish an open culture on fatigue**

##### *Techno-economic feasibility:*

Experts agree that an open culture (NASA, 2000) is an important prerequisite for receiving enough reliable information. Only if fatigue can be talked about in an open fashion can management expect flight crew to report issues and experiences surrounding it. Industry interests are expected to be high, especially the aviation industry relies heavily on information that is supplied by people that perform everyday operations. The safety and quality management systems cannot function properly without this information. It is difficult to put together a rudimentary cost-benefit analysis for establishing an open company culture. The basic cost involved are for communicator within the organisation time (man-hours) and resources (administrative). With the use of internet and e-mail these cost can be kept low. Putting a price tag on the benefits is even more difficult.

##### *Social feasibility*

It is socially desirable to have a situation where problems can be discussed and reported in a transparent fashion. Nowadays many different industries are concerned with workload so crew fatigue is likely to a valid issue in the general public opinion. Since the associated financial costs are most likely very low, the issue of "who pays and who benefits" should not be an obstruction to changing and opening up company culture on crew fatigue.

##### *Political feasibility*

The political feasibility of establishing an open culture on fatigue depends on how an airline perceives the problem. When an airlines sees fatigue as a shared responsibility, an establishing an open culture should be relatively easy to establish. When airline management puts the main responsibility with the flight crew, they will most likely not be prone to cooperate to achieve an open environment.

#### **Recommendation 2: Establish and/or clarify responsibilities**

##### *Techno-economic feasibility*

There is no reason to assume that technical restrictions that could prevent the process of establishing or clarifying responsibilities. A comparison of costs and benefits is difficult. As with the previous recommendation, the costs will mainly be in the form of time.

#### *Social feasibility*

Establishing responsibilities will probably be welcomed by every party involved and the effectiveness will be almost immediate. The costs that are involved will mostly be paid by the airline but all parties benefit. Since it is expected that only small costs are involved this will not be a very big issue. In fact it is part of the actual organisation of an airline.

#### *Political feasibility*

Decisions on who has what responsibility are relatively straightforward. The responsibilities presented in the recommendation are all logical implications of the employer-employee relation and fit their different problem perceptions. Industry interests will be considerable because many airlines and other companies will likely struggle with comparable issues surrounding responsibilities.

### **Recommendation 3: Establish a program for health and lifestyle factors**

#### *Techno-economic feasibility*

There do not seem to be technical barriers preventing such a program. In fact information and communication technology provide excellent means to provide a health and lifestyle program. A cost-benefit analysis is difficult.

#### *Social feasibility*

Second, social feasibility is a function of the perception of the problem, the perceived effectiveness of the recommendation, how cost and benefits are distributed (these perceptions are subject to various external influences). The fact that fatigue mainly arises from sleep disorders caused by health, lifestyle and work environment means that a health and lifestyle program will most likely be effective. The broad approach pursues the other facets besides duty times. Cost can be shared between employee and employer. If the employer provides the entire program (and if employee commitment is high) they can share the cost (50% pay) of attending a sleep quality assessment

#### *Political feasibility*

Decisions on what information to include in a health and lifestyle program are mostly dictated by the issue itself. In an educational module, all aspects of fatigue should be included. This may be outsourced to an independent organisation. When an airline decides to implement a monitoring program for flight crew 'sleep status' with a sleep quality assessment, the employee has the free choice whether to cooperate or not. The organising airline may also receive positive public exposure, enhancing company image.

### **Recommendation 4: Provide generic sleep schedules together with the work schedule**

#### *Techno-economic feasibility*

The capabilities of modern software should provide enough opportunities to incorporate and automatic system to provide sleep schedules. The transition from generic schedules to profiled and personal schedules will be more of a challenge because feedback needs to be processed to fine-tune the models behind the sleep schedule. The costs for such a system will be considerable but the benefits will also prove to be substantial.

#### *Social feasibility*

As long as an airline does not make the sleep schedules mandatory, social feasibility is good.

#### *Political feasibility*

The fact that an airline takes the effort to construct sleep schedules to assist flight crew in dealing with time zone changes and odd working hours will be very beneficial to its reputation. Politically this sends out a positive message.

### **Recommendation 5: Introduce a non-punitive anonymous Fatigue Report Form**

#### *Techno-economic feasibility*

A report form can be made available in paper as well as digitally, this should be easy for any airline because several comparable report forms already exist.

#### *Social feasibility*

A report form (provides non-punitive) is socially highly feasible. Crew may encourage each other to make use of these forms and the mere existence of such a form is an indication that management takes crew fatigue seriously.

#### *Political feasibility*

As long as these fatigue report forms remain anonymous and non-punitive the introduction of such a report form will enhance an airlines image. When proper feedback is given about the actions taken as a result of filed reports than employee commitment will also increase.

### **Recommendation 6: Implement the Fatigue Reduction Cycle**

#### *Techno-economic feasibility*

The technical requirements for implement the FRC are fairly straightforward. When using actigraphs and interpreting the data becomes to complex, experts may be asked to assist. The cost for implementation of the fatigue reduction cycle can be split into two categories: the cost for human resources and the cost for hardware and software. The cost for hard- and software is only minor compared to other airline costs. The cost of human resources depends on the size of the airline and will be in proportion to the size of entire flight schedule.

#### *Social feasibility*

Although both airline and flight crew benefit from a decrease in fatigue, the financial resources will have to come from the airline. Unions will need to invest with time by taking part in the process. A mutual vision of shared responsibility is needed to achieve social feasibility.

#### *Political feasibility*

The process is designed around the core values of those who are involved and provides an opportunity to exit a specific cycle or the entire process. Therefore the decision making procedures should not be an obstacle to implementation. The perception of the problems and responsibilities surrounding crew fatigue are (again) important considerations. Consensus within airlines management and between management and unions on the 'rules-of-the-game' is needed for successful implementation because the process implicates a profound organisational change.

## **6.4 Suggestions for further research**

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In the final section of this chapter some suggestions for additional research are presented. These suggestions can be used as complementary to the information presented in this paper.

#### **After duty sleepiness as an indicator of fatigue**

It would be very interesting to know just how sleepy flight crew is after a specific duty period. This can be an indicator of how tiring an entire duty is. In almost all cases a duty period ends approximated 30-60 minutes after the last landing. The level of sleepiness measured at the end of this duty period would therefore also be a good indication of the sleepiness during landing. Research could be performed using the Mean Sleep Latency Tests or the Maintenance of Wakefulness Test. Flight crew would have to participate voluntarily and the test should of course be non-punitive. The results can be useful in getting a better understanding of, and comparison between, the 'weight' of different duty periods. This in turn can help schedule the duty periods more efficiently. 'Light' duties can be awarded less time off while 'heavy' duties could require a longer period for recuperation.

#### **Effectiveness of Fatigue Reduction Cycle solutions**

Research could be performed by benchmarking the effectiveness of the different solutions that resulted from the Fatigue Reduction Cycle. Indicators for the effectiveness can for example be the amount of submitted fatigue report forms. The results from the Mean Sleep Latency Tests or Maintenance of Wakefulness Test can also help indicate the effectiveness.

Simple questionnaires may also be used. By determining the most effective solutions one may be able to derive 'best practices' and promote these.

**Recommendations on how to implement 'recommended sleep schedules' into existing software planning packages.**

Several companies supply software packages to airlines for planning purposes. It would be very interesting to know which software packages are best suited to include the function of providing 'recommended sleep schedules'. Additionally design principles for these schedules could be written.

**Create a cost-benefit analysis of the recommendations**

A cost-benefit analysis of one or more of the recommendations will result in valuable information for airline management decisions on what strategy/recommendation to adopt.

**Investigate the relation between incidents and the preceding flight duty schedules**

Very interesting data may result from an analysis many small to large incidents and the preceding flight duty schedules of flight crew that was involved. Most large airlines maintain a database in which all kind of incidents are stored. This combination of these two large databases might result in new insights.

## DISCUSSION

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During the course of writing this thesis it became very clear that, although crew fatigue is sometimes recognised, there is little open discussion. Crew fatigue is a subject of many missed opportunities. Surely, the discussion on crew fatigue would receive much more attention if the causes and effects were easily measurable as those of alcohol. Airline management and unions should talk to each other about their interests. How big are the (claimed) conflicting interests really? Are the interests not 'two sides of the same coin'? Is it really a case of 'us versus them'?

Putting the recommendation into real world operations will not be easy due to existing (personal) relations and company cultures. A real sense of urgency is needed (Bruijn, et al., 2002) and this can only be achieved by educating airline management and unions on the dangers and cost involved with crew fatigue. All parties should keep in mind that reducing fatigue will benefit both and increase company revenues. Working together should be the prime focus.

Many years ago, wearing a seat belt and not 'drinking and driving' used to be 'optional'. But today everyone is very much aware of the dangers involved with not wearing a seatbelt and driving under the influence of alcohol. This is the ultimate goal that should be aimed for. Fatigue belongs on the top of everyone's priorities.

Good news for airlines that are struggling with costs. The retirement age for pilots is often debated between airlines and unions. In the Netherlands, civil aviation pilots generally retire around the age of 56. They often receive a rather large bonus and retain their monthly wage. This is why airlines are very keen on extending retirement age. With regard to fatigue, airlines have a new opportunity. When airline schedulers take great care in designing and integrating sleep schedules into duty schedules and when fatigue is actively monitored and reduced (i.e. with the fatigue reduction cycle) this will reduce workload and enhance pilot's well being. This in turn will open new possibilities in negotiations with unions on extending the retirement age.

Fortunately, there are pilots that take fatigue very seriously and take action when they feel that they cannot operate an aircraft safely. On April 16<sup>th</sup> 2008 a British Airways pilots told the passengers that he was 'too tired to fly'. Subsequently the passengers were booked into a hotel and continued their journey the next day. A financial loss for the airline but an 'improvement' for safety. The pilot in question had been unable to sleep on the night before due to noises in the hotel. The pilot only had one night of sleep between arriving from and departing to London. This situation emphasises three important factors: (1) sleep is absolutely crucial for preventing and reducing fatigue, (2) airlines need to rethink how safe 24-hour long-haul return flight actually is and (3) the financial cost of fatigue (i.e. hotel costs for the passengers) can be unexpectedly high and unnecessary.

Ideally, ICAO and national civil authorities should make a fatigue reduction/prevention program obligatory for all airlines. Inspecting the use and results of such a program by a CAA will guarantee a continued attention for fatigue. This unfortunately is not to be expected soon, so for now airlines and unions need to take action

*Time for some final thoughts... so let's have a look at flight crew again. They work in a high-tech environment and they need to fully understand how the aircraft works. In aviation a small inconvenience can easily and quickly evolve into a large scale emergency. Changing from calm to an extremely high workload situation within seconds. During such an emergency this means understanding and managing a highly complex machine almost intuitively. This is what makes aviation so unique. Some say that pilots just 'sit and wait' for something to happen. In these cases fatigue and its effects on performance can play a decisive role in the outcome of a sudden emergency. Not to mention emergencies which are brought on by flight crew themselves as a result of unnecessary and avoidable mistakes.*

*Flying is safe but this safety needs constant maintenance and fine-tuning to remain at this level. During every flight it is the 'marriage' of highly flexible flight crew and computer automation that makes that flight a safe one. Therefore we have to make sure that the people that operate the aircraft receive the same level of maintenance as the aircraft that we so highly trust. Especially now that ultra-long haul flights are quickly becoming a reality and that the new European regulations don't seem to provide the needed boundaries it is up to airline management and unions to cooperate.*

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## Appendix 1. SUBJECTIVE SCALES FOR MEASURING FATIGUE

### 1. Checklist Individual Strength

The checklist Individual Strength (CIS) quantifies subjective feelings and behavioural aspects related to fatigue. Answers to this assessment are based on the two weeks prior to the assessment. The CIS is made up of 20 statements for which the person has to indicate whether the statement is true or not, with scores ranging from 1 (true) up to 7 (not true)\*. For some statements a reversed scoring is used. The 20 statements are divided into four categories: subjective fatigue (feeling tired) reduced motivation (not inclined to do anything), reduced activity (not doing much during the day) and reduced concentration. The severity of fatigue is determined by looking at the subset of 'subjective fatigue' statements. If the score in this subset exceeds 35, this indicates a significant problem. Some examples of statements with respect to fatigue are:

- My motivation is lower when I am fatigued.
- Exercise brings on my fatigue.
- I am easily fatigued.
- Fatigue interferes with my physical functioning.
- Fatigue causes frequent problems for me.
- My fatigue prevents sustained physical functioning.
- Fatigue interferes with carrying out certain duties and responsibilities.
- Fatigue is among my three most disabling symptoms.
- Fatigue interferes with my work, family or social life.

There are quite a lot of statements that need rating on a 7-point likert scale, this may take some time. But these statements relate well to situations encountered in daily aviation operations. The CIS has been found to be reliable and valid (Bultmann, et al., 2000) instrument for measuring fatigue in the working population. It is also possible to use only part of the CIS (that is those statements that are directly related to fatigue) to save time. The checklist can be easily integrated into a pda or laptop.

### SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	The checklist has been used numerous times	+++
1.2	This scale may need some adjustment to fit aviation specific situations	++
2.1	The scale needs 20 decisions	+
2.2	Some statements are a little long and need good thought	++
3.1	The statements are divided into four categories. One of which is activity	++
3.2	The statements are divided into four categories. Two of these are motivation and concentration	++++
4.1	Validity is very good, Beurskens (2000) and Bultmann (2002)	+++
4.2	Reliability is very good, Beurskens (2000) and Bultmann (2002)	+++

\* **Note on the Likert Scale:** The likert scale can be used in different sizes, ranging from a three-point to as much as a nine-point scale. In the case of the CIS a seven scale version, like the one below, is normally considered to be most practical.

1. Almost always true
2. usually true
3. often true
4. occasionally true
5. sometimes true
6. usually not true
7. almost never true

## 2. De Dutch Fatigue Scale

This fatigue scale (DUFFS) can be used as an instrument to measure fatigue in a reliable and valid way (Tiesinga, 1999). Relatively little research is done using this scale but below are some examples of the questions in this scale

- Have you had an overwhelming and constant feeling of a general lack of energy?
- Have you lately felt you need more energy to do your daily tasks?
- Have you been feeling apathetic lately?
- Have you been waking up with a feeling of exhausting and fatigue lately?
- Do you feel you have been needing more rest lately?
- Have you been able to do day-to-day tasks lately?
- Do you feel like taking on activities lately?
- Has it been harder to concentrate on a single task lately?

A five-point Likert scale is used to answer these questions. The checklist can be easily integrated into a pda or laptop.

### SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>This scale has not been used very much</i>	+
1.2	<i>This scale may need some adjustment to fit aviation specific situations</i>	++
2.1	<i>The scale needs 8 to 9 decisions</i>	++
2.2	<i>Some questions need some thought to understand</i>	++
3.1	<i>No clear distinction for physical fatigue is made</i>	0
3.2	<i>No clear distinction for mental fatigue is made</i>	0
4.1	<i>Validity is good (Tiesinga) but limited amount of validation studies could be found</i>	++
4.2	<i>Validity is good (Tiesinga) but limited amount of validation studies could be found</i>	++

## 3. Dutch Exertion Fatigue Scale

This fatigue scale (DEFS) can be used as a reliable and valid instrument to measure exertion fatigue in individuals (Tiesinga, 1999). Also with the DEFS relatively little research can be found. There are versions for self assessment and for assessment by somebody else. These are some questions from the Dutch exertion fatigue scale. The checklist can be easily integrated into a pda or laptop.

- Have you been avoiding difficult situations lately?
- Do you find it hard to walk for ten minutes?
- Do you find it hard to walk for half an hour?
- Do you find it hard to take a shower?
- Do you find it hard to walk up and down the stairs?
- Do you find it hard to go to the stores for groceries?
- Do you find it hard to do household task?

A five-point Likert scale is used to answer these questions.

NOTE: Both the DUFS and DEFS have been developed with elderly and medical patients in mind. But as has been shown by Tiesinga it is also possible to assess fatigue in people that are generally healthy and those who are not hospitalized.

## SCORES

Scoring is a 'best effort' attempt based on available information.

1.1	This scale has not been used very much	+
1.2	This scale may need some adjustment to fit aviation specific situations	++
2.1	The scale needs about 7 decisions	++
2.2	Some questions need some thought to understand	++
3.1	The scale ask very specific questions about physical fatigue	++
3.2	No clear distinction for mental fatigue is made	0
4.1	Validity is good (Tiesinga) but limited amount of other validation studies could be found	++
4.2	Reliability is good (Tiesinga) but limited amount of other reliability studies could be found	++

## 4. Situational Fatigue Scale

Most fatigue scales ask the respondents to score their level of fatigue without matching it to specific well known situations. They have to rate how much fatigue they think they will experience after doing these common everyday situations. The Situational Fatigue Scale (SFS) tries to assess the level of fatigue by asking the respondent to rate their (expected) level of fatigue in a six-point Likert scale from 0 (no fatigue at all) to 5 (extreme fatigue). The SFS distinguishes two subsets in these 'situational question': the Physical Fatigue Scale and the Mental Fatigue Scale. The checklist can be easily integrated into a pda or laptop.

It is designed this way in order to measure the available 'resources' in a person while keeping the demands of the situation constant. It is a very simple, reliable and valid (Yang, et al., 2005) scale that is easy to understand and can be done relatively quickly.

Situation	Score					
Playing a ball game for 30 minutes						
Jogging for 20 minutes						
Taking a walk for 1 hour						
Cleaning house for 30 minutes						
Reading (magazines or newspapers) for 1 hour						
Watching TV for 2 hours						
Chatting for 1 hour						
Shopping for 1 hour						
Driving for 1 hour						
Hosting a social event for 30 minutes						
Doing paperwork for 1 hour (typing, writing or making plans)						
Meeting for 2 hours						
Attending a social activity for 1 hour						
SCORE						



## SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>The situational fatigue scale is relatively new, so little research has used it</i>	+
1.2	<i>It is applicable to all (general) situations</i>	++
2.1	<i>13 'situations' need to be scored</i>	+
2.2	<i>The statements are very easy to understand</i>	++++
3.1	<i>A clear subset of statements relate to physical fatigue</i>	+++
3.2	<i>A clear subset of statements relate to mental fatigue</i>	+++
4.1	<i>Validity is good (Yang, et al., 2005) but limited amount of other validation studies could be found</i>	++
4.2	<i>Reliability is good (Yang, et al., 2005) but limited amount of other reliability studies could be found</i>	++

## 5. The Stanford Sleepiness Scale

The Stanford Sleepiness Scale (SSS) is used to get an instantaneous measurement of how likely a person is to fall asleep. The operator usually has to give a score at fixed intervals during a period of time. When a person scores 3 or more in a period in which vigilance is needed, this is usually a reason for concern and further investigation. By combining multiple scores from different people, a graph can be produced that gives an indication of the amount of fatigue during a specific duty period. The checklist can be easily integrated into a pda or laptop. It takes very little time to use Stanford Sleepiness Scale and is therefore suited for use at regular intervals.

Degree of Sleepiness	Score
Feeling active, vital, alert, or wide awake	1
Functioning at high levels, but not at peak; able to concentrate	2
Awake, but relaxed; responsive but not fully alert	3
Somewhat foggy, let down	4
Foggy; losing interest in remaining awake; slowed down	5
Sleepy, woozy, fighting sleep; prefer to lie down	6
No longer fighting sleep, sleep onset soon; having dream-like thoughts	7
Asleep	x

## SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>The Stanford Sleepiness Scale is used in a large variety of research</i>	+++
1.2	<i>It's a general sleepiness scale</i>	++
2.1	<i>Just one assessment needs to be made.</i>	++++
2.2	<i>Some statements resemble each other somewhat, otherwise clear</i>	+++
3.1	<i>Both physical and mental fatigue are taken into account, but no clear distinction is made</i>	++
3.2	<i>See above</i>	++
4.1	<i>Several validity studies were made Hobbes (1973), (Lee KA, Hicks G, Nino-Murcia G.)</i>	+++
4.2	<i>Several reliability studies were made Hobbes (1973), (Lee KA, Hicks G, Nino-Murcia G.)</i>	+++

## 6. The Epworth Sleepiness Scale

The Epworth Sleepiness Scale (ESS) is also used to quantify fatigue using questionnaires but is uses a different scale than the SSS. The ESS asks a person to rate how much they are inclined to fall asleep in eight given situations. If they have not been in a described situation recently that is described, they are asked to vividly imagine the situation. Because it takes more time to fill in the ESS compared to the SSS, the ESS is usually intended for less frequent use. The checklist can be easily integrated into a pda or laptop.

If the total score is between 1 and 6 this usually indicates little to no problem. A score of 7 or 8 indicates and increased tendency to doze off. When scoring 9 or more, this means that a sleep deficit exists and you should take action.

Situation	Chance of falling to sleep			
	0	1	2	3
Sitting and reading				
Watching television				
Sitting inactive in a public place--for example, a theatre or meeting				
As a passenger in a car for an hour without a break				
Lying down to rest in the afternoon				
Sitting and talking to someone				
Sitting quietly after lunch (when you've had no alcohol)				
In a car while stopped in traffic				
<b>SCORE</b>				

### Explanation of the possible scores:

0 = I would never fall asleep or doze off

1 = There is a slight chance that I would fall asleep or doze off

2 = There is a moderate chance that I would fall asleep or doze off

3 = There is a high chance that I would fall asleep or doze off

### SCORES

Scoring is a 'best effort' attempt based on available information.

1.1	The Epworth Sleepiness Scale is used in a large variety of research	++++
1.2	It's a general sleepiness scale	++
2.1	8 statements need to be scored	++
2.2	Some statements resemble each other somewhat, otherwise clear	++
3.1	The ESS assesses the chance of falling asleep so there is no clear distinction for physical fatigue	+
3.2	See above	+
4.1	Several validity studies were made Johns (1992)	+++
4.2	Several reliability studies were made Hobbes Johns (1992)	+++

## 7. The Samn-Perelli Fatigue Scale (SPFS)

This scale is primarily a fatigue scale.

Degree of fatigue	Score
Fully alert, wide awake.	1
Very lively, responsive, but not at peak.	2
Okay, somewhat fresh.	3
A little tired, less than fresh.	4
Moderately tired, let down.	5
Extremely tired, very difficult to concentrate.	6
Completely exhausted, unable to function effectively.	7

- |     |  |      |
|-----|--|------|
| 1.1 | The SPFS is used in a large variety of research (i.e. (M. C. Powell, et al., 2007)                               | +++  |
| 1.2 | It has been used in many studies in aviation   | +++  |
| 2.1 | Very quick, only one score   | ++++ |
| 2.2 | Understandable for everyone  | +++  |
| 3.1 | Fatigue is measured in general terms   | ++   |
| 3.2 | See above  | ++   |
| 4.1 | Little actual research on the validity of the scale could be found but it has been used in many aviation studies | ++   |
| 4.2 | The answers sometimes do not differ very much  | ++   |

## Appendix 2. PHYSICAL METHODS FOR MEASURING FATIGUE AND SCORES

### Systems measuring head, eye, pupil and body movement

#### 1. Posturographic testing, Tel Aviv University, Israel Air Force et al.

Description:

The Posturographic test measures postural sway as an indicator of fatigue. During a full test, the subject has to stand on four metal plates. These force plates are positioned beneath the two heels and the toes. By moving the plates at a specific frequency the system measures four parameters in the subject: stability, weight distribution, synchronizations and intensity of sway. During a standard examination the subject has to stand for 32 seconds in eight different positions. This system is called the Tetrax Posturography System and, in short, measures a stability score.

It is shown in different validations (Avni, et al., 2006) that the stability score correlates with fatigue. During these validation tests the subjects had to regularly perform a psychomotor vigilance tests and subjectively assess their fatigue using the Stanford Sleepiness Scale questionnaire. During these validations it was also concluded that a shortened version of the test also correlates significantly with fatigue. This is important for keeping testing time to individuals to a minimum. The shortened test only required the subject to stand in 3 instead of 8 different positions.



Figure 30 Tetrax Balance Assessment System

This system cannot be used in in-flight situations, and definitely not in the flight deck. The system does however offer possibilities to measure fatigue in crew just before or after boarding the airplane. The system should therefore be portable enough to move through an airport and (possibly) light enough to bring to other destinations as cargo.

### SCORES

*Scoring is a 'best effort' attempt based on available information.*

- |     |  |      |
|-----|--|------|
| 1.1 | The Tetrax balance system and Sunlight Medical both exist since 1995   | ++++ |
| 1.2 | The Tetrax system has already been used in medical situations so it can be ready for an initial project within two years                                   | ++++ |
| 1.3 | Only the brochure talks about an 'analysis of pilots and effects of fatigue' but no further information was found  | ++   |
| 1.4 | The Tetrax system is quite large and it experts are needed to use the system. Cost is also a limiting factor   | +    |
| 2.1 | The fact that the system is widely used in hospitals, the professionalism and the non-invasiveness of the system will probably make it acceptable to users | ++   |
| 2.2 | When standing on the Tetrax plate some might be able to get a better score by motivation. Several studies show there is no learning effect.                | ++   |
| 2.3 | The mechanics of the system may not be able to withstand the daily 'wear and tear' of dozens of measurement.   | ++   |

2.4	<i>To do a measurement a person must stand on the Tetrax plate for at least 5 minutes for each measurement and this may not be very comfortable. Especially after a long duty period</i>	++
2.5	<i>This system cannot be used inside a cabin. Using it at the gates is also not very practical.</i>	0
3.1	<i>It takes at least 5 minutes to get a fatigue score and the measurement must be done by an expert.</i>	+
3.2	<i>The system cannot make predictions</i>	0
3.3	<i>The level of automation is relatively low, an expert is needed to take the measurement and analyse the data</i>	+
3.4	<i>All results can be stored indefinitely</i>	++++
4.1	<i>Because of the cost and time involved it is not likely that the system will be used more than a few times a year.</i>	0
4.2	<i>The expert will be able to give a fatigue score</i>	++
4.3	<i>Information on levels of fatigue can be given within a day through normal communication methods (telephone, e-mail etc.)</i>	+++
5.1	<i>Since the posturographic system is the only product that does not fit in the cockpit or cabin of an airplane it is given an average score</i>	++
5.2	<i>as mentioned before</i>	++
5.3	<i>None of these influence are probable</i>	+++
6.1	<i>An entire section of the website is dedicated to validation. The study by (Avni, et al., 2006) also validates a brief version of the method</i>	+++
6.2	<i>Because it has been used in the past in a medical setting and because there</i>	++
7.1	<i>Implementation cost are high because of purchasing the hardware and educating or hiring experts</i>	+
7.2	<i>Running cost are average</i>	++

2. **FaceLAB** from *Seeing Machines, Asia, Europe and North America (eye feature)*

The application FaceLAB has been developing since 1996. Using *stereo camera's* it can create a three dimensional image of the important features of a human face. The cameras are connected to a stand-alone laptop that tracks the individual features and movements of a face. Using models it analysis fatigue and drowsiness in real-time. The main parameters it uses for fatigue are the percentage of time the eyelids are closed, blink rate and

changes in head angle and position (distractions from the main field of view). The percentage of time the eyelid is closed (PERCLOS) is a validated measure of alertness. This validation is done by de Federal Highway Administration (Federal Highway Administration, 1998). The system is regularly tested by Volvo in real-life situations. Although the system has initially been developed for road use it has also been used in piloting studies in simulators by researchers at Air Operations Division/DSTO in Australia. Facelab is used by many different automotive companies, universities and also by the Dutch NLR.

For use in different lighting conditions it uses an infra-red light source to illuminate the face. Therefore the system works in bright daylight as well as at night. If the person is wearing spectacles this (mostly) does not impair the measurement. The fatigue measurements are done in real-time. If needed, the stream of data can be send across a network and it is stored for later analysis.

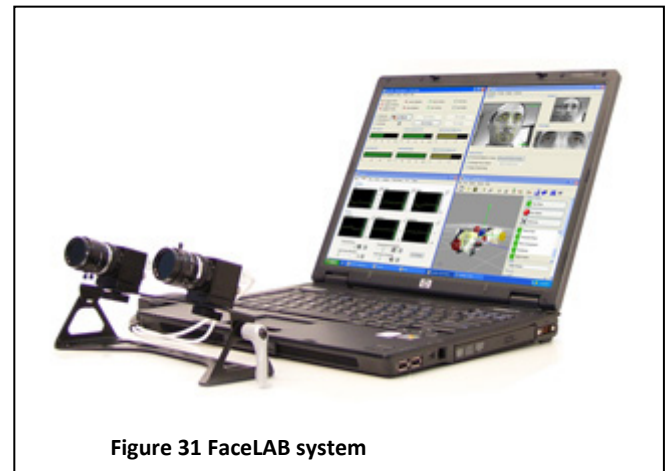


Figure 31 FaceLAB system

There are also some additional features available. One of these is to include an extra camera that records the field of view, inside and outside. By superimposing the recorded gaze of the person on the field of view it is possible to analyze where the person looks and for what amount of time. This can be used to enhance (cockpit) layout and procedures.

It is also possible to add additional cameras. By using more than one camera the person can move more freely while the system is still able to track the face. Using enough camera's it is possible to track the face in all directions (360 degrees). A Software Development Kit (SDK) is available for creating custom applications.

## SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>The company and FaceLab were formed in 2000</i>	++++
1.2	<i>Because Facelab is widely used, it will probably be ready for an initial project within two years after the first inquiries</i>	++++
1.3	<i>Facelab has been used in many different automotive companies, universities and research institutes</i>	+++
1.4	<i>Installing the system on a large scale will not be very easy because it requires a considerable amount of hardware and space.</i>	+
2.1	<i>Acceptability by users will be very high because of it's extensive use in the automotive industry and research institutes</i>	+++
2.2	<i>The systems needs to be able to 'see' a persons eyes. For this it uses two cameras. If the eyes cannot be seen it switches to measuring head movement. Manipulation will not be very easy.</i>	+++
2.3	<i>The cameras and laptop need to be handles carefully</i>	++
2.4	<i>The system does not need to be attached to the body.</i>	++
2.5	<i>The camera's may use valuable cabin/cockpit space</i>	++
3.1	<i>The camera's record eye closure and can report fatigue almost instantaneously</i>	++++
3.2	<i>It can predict fatigue to a certain level, based on eye closure times</i>	++
3.3	<i>Once installed, the system can work autonomously</i>	+++
3.4	<i>Information is only limited by storage capacities. Scenic information can also be recorded and stored to be used as an overlay during analysis</i>	++++
4.1	<i>It can be queried all the time but it needs a laptop</i>	+++
4.2	<i>Alarms seem non-intrusively</i>	++
4.3	<i>Almost immediately after returning form a fligh/trip the data can be analysed. This must be done by an expert, this will take some time</i>	++
5.1	<i>The system is not affected by sunlight or temperature</i>	+++
5.2	<i>The system is not affected by sounds</i>	++++
5.3	<i>The system may have difficulties when sunglasses are worn, it than switches to other measurements ('it degrades gracefully')</i>	++
6.1	<i>The system uses PERCLOS as a main parameter for fatigue. PERCLOS has been often validated</i>	+++
6.2	<i>The system has been tested in daily situations and in simulators. Reliability seems high.</i>	+++
7.1	<i>Implementation costs are high because of purchasing the hardware and educating users. The system also needs adapting to cabin settings</i>	0
7.2	<i>Running cost are average</i>	++

### 3. Optalert from Sleep Diagnostics, Australia (eye feature measurements)

The Optalert system (originally designed for road use) consists of a pair specially designed glasses. It measures fatigue by using infra-red pulses of light to detect coverage of the eye pupil by the eyelid. The pulses of light are emitted by a light source that is built into the glasses. By means of a phototransistor, the light that is returned from the (left) eye and eyelid is measured, resulting in different parameters that are fed into the processing unit.

In laboratory experiments at Austin Hospital in Melbourne it was confirmed that there is a high correlation between the percentage of time the eyes are closed (PERCLOS) and the time that the pupils were covered for at least 80% by the eyelids for a duration of at least 500ms (Optalert).

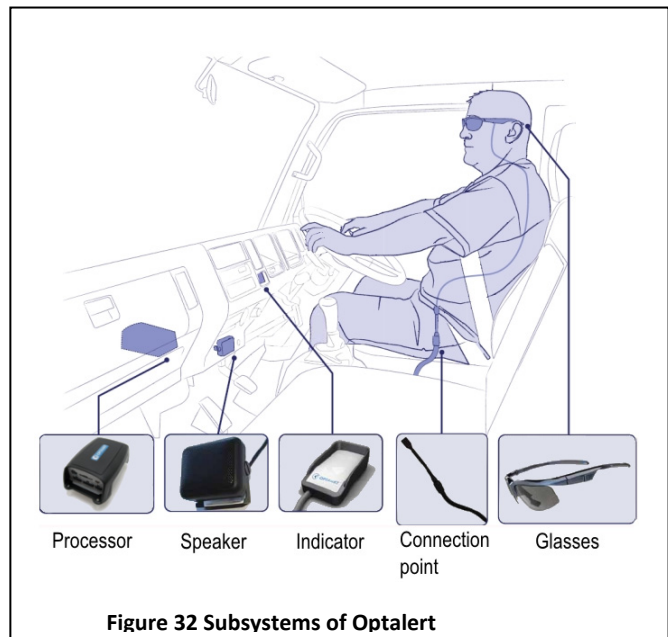


Figure 32 Subsystems of Optalert

The glasses connect by wire to the processing unit that determines the level of drowsiness on the “Johns Drowsiness Scale”. The system further consists of an indicator and speaker. The subject can very easily, and at any time, read the current level of drowsiness from the indicator and is alerted through the speaker with different signals and messages. The system does not use any wireless connection, which is strongly preferred (if not mandatory) in civil aviation.

There is also a tool available for research into fatigue during different activities in certain situations. This is the Optalert Drowsiness Measurement System (ODMS). The system can record and combine data from the Optalert system, vigilance tests and video recordings from the subject and the environment. Based on a standard configuration of a laptop, the glasses and a response keypad it provides a platform for researchers.

Different trials over the last couple of years have been conducted to validate the relation between the drowsiness scale as produced by the system and (driving) performance (Stephan, et al., 2006).

*Note:* The fact that special glasses are used, special attention must be paid to the lenses. Pilots very often use high quality sunglasses because of very bright skies above the clouds. If the quality of sun protection is inadequate, the system can only be used in simulation settings.

## SCORES

*Scoring is a ‘best effort’ attempt based on available information.*

- |     |   |      |
|-----|---|------|
| 1.1 | The company and Optalert were formed in 2002  | ++++ |
| 1.2 | Optalert focuses on road, mining and rail. Readiness could take more than two years   | +++  |
| 1.3 | Optalert has been used in some companies, but the amount of ‘testimonials’ is relatively low                                  | ++   |
| 1.4 | Installing the system on a large scale will not be very easy because it requires a considerable amount of hardware and space. | +    |
| 2.1 | Acceptability will be low, mainly because of wearing special headgear   | +    |
| 2.2 | Simply not wearing the headgear is easy   | +    |



2.3	<i>All the cables and different hardware make in not very resilient</i>	+
2.4	<i>Wearing special glasses is not convenient</i>	+
2.5	<i>All the cables and different hardware make installing in not very easy. Different people need to wear different glasses, depending on eyesight.</i>	0
3.1	<i>The camera's record eye closure and can report fatigue almost instantaneously</i>	++++
3.2	<i>It is designed to predict fatigue based on (among others) eye closure times and 'Johns Drowsiness Scale'.</i>	+++
3.3	<i>Once installed, the system can work autonomously</i>	+++
3.4	<i>Information is only limited by storage capacities.</i>	++++
4.1	<i>It can be queried all the time through the indicator</i>	++++
4.2	<i>Audible alarms are hear through a speaker</i>	+++
4.3	<i>Almost immediately after returning form a fligh/trip the data can be analysed. This must be done by an expert, this will take some time</i>	++
5.1	<i>The system is not affected by sunlight or temperature</i>	+++
5.2	<i>The system is not affected by sounds</i>	++++
5.3	<i>Only practical considerations (because of the wiring)</i>	+++
6.1	<i>The system uses PERCLOS as a main parameter for fatigue. PERCLOS has been often validated. Optalert has a section of the website dedicated to validation</i>	+++
6.2	<i>Reliability is the same as comparable products but the different modules (connect by wire) may introduce some unreliability</i>	+++
7.1	<i>Implementation costs are high because of purchasing the hardware and educating users. The system also needs adapting to cabin settings</i>	0
7.2	<i>Running cost are average</i>	++

#### 4. **AntiSleep 2.0** from Smart Eye, Sweden (eye feature measurements)

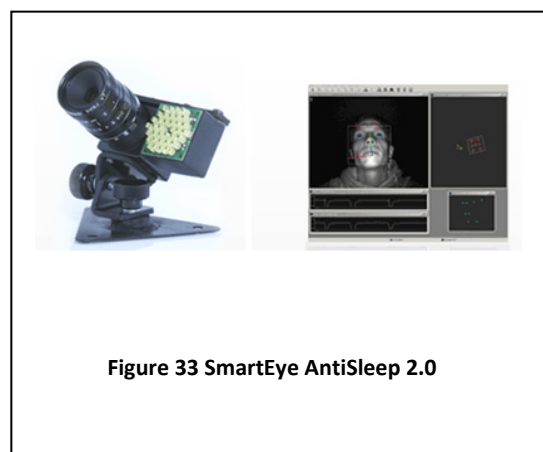
Another system that is similar to the FaceLAB product is the system from Smart Eye. The product uses head pose, gaze direction and eyelid closure as input parameters for its model. The system uses FaceLAB's True Blink Analysis and PERCLOS in its modelling of fatigue. This *mono-camera* system was designed for in-cabin measurements using infra-red to illuminate the facial features. The camera and light source are integrated into a single housing.

Smart Eye was specially designed for use on persons with all possible kinds of eyewear. Using a special (patented) technique for illuminating the face the effects of reflections in glasses are eliminated. Special effort was also put into situations where the frame of glasses blocks part the eye. As for individual differences, the system was tested on a wide range of people from different ages and nationalities.

AntiSleep 2.0 is a software application that was specifically written to monitor fatigue in the automotive industry. Its customers include Toyota, Ford, Audi, and NASA.

An important distinguishing feature that AntiSleep has is profile recognition. When the subject enters the field of view of the camera it recognizes the person. This way the system can accumulate data for individuals for later analysis.

AntiSleep is just one of several applications developed for the SmartEye system. Additional applications for which the system can be used include face identification, facial expression recognition and lip reading. These however are still in a development stage or have yet to be designed.



**Figure 33 SmartEye AntiSleep 2.0**

## SCORES

Scoring is a 'best effort' attempt based on available information.

1.1	The company and AntiSleep were formed in 1999	++++
1.2	Because AntiSleep is widely used, it will probably be ready for an initial project within two years after the first inquiries	++++
1.3	AntiSleep has been used in many different automotive companies, universities and research institutes	+++
1.4	Installing the system on a large scale will not be very easy because it requires a considerable amount of hardware and space.	+
2.1	Acceptability by users will be very high because of it's extensive use in the automotive industry and research institutes	+++
2.2	The systems needs to be able to 'see' a persons eyes. For this it uses two cameras.	+++
2.3	The cameras and laptop need to be handles carefully	++
2.4	The system does not need to be attached to the body.	++++
2.5	The camera's may use valuable cabin/cockpit space	++
3.1	The camera's record eye closure and can report fatigue almost instantaneously	++++
3.2	It can predict fatigue to a certain level, based on eye closure times	++
3.3	Once installed, the system can work autonomously	+++
3.4	Information is only limited by storage capacities. Scenic information can also be recorded and stored to be used as an overlay during analysis	++++
4.1	It can be queried all the time but it needs a laptop	+++
4.2	Alarms seem non-intrusively	++
4.3	Almost immediately after returning form a flight/trip the data can be analysed. This must be done by an expert, this will take some time	++
5.1	The system is not affected by sunlight or temperature	+++
5.2	The system is not affected by sounds	++++
5.3	The system has its own illumination and claims there is no interference from things like reflection from glasses or from frames covering parts of the eye.	++
6.1	The system is focuses on eye tracking. How it measures fatigue is clearly shown	++
6.2	The system has been tested in daily situations and in simulators. Reliability seems good.	++
7.1	Implementation costs are high because of purchasing the hardware and educating users. The system also needs adapting to cabin settings	0
7.2	Running cost are average	++

### 5. **Copilot** from Carnegie Mellon University, Pennsylvania, USA (eye measurements)

The Copilot is a monitoring system for fatigue/drowsiness. The development of this system was sponsored by the National Highway Traffic Safety Administration and the Federal Motor Carrier Safety Administration. The system is an all-in-one design. The camera, light source and operation feedback are all in integrated into a single housing. Feedback on the amount of fatigue is done by an audible tone and a visual gauge on the front of the product. The gauge consists of three amber and three red LED's



Figure 34 Copilot

The Copilot system identifies the eyes of the operator by taking two images with a very small interval. Both snapshots are made with an infra-red light sources but only one snapshot produces the distinctive red-eyes as seen in amateur photography. By subtracting

the images from each other and image is created that has little to no other information than the pupils.

A small drawback of the system, in comparison with other similar systems is the relatively small head movements so that the operator is still 'in the picture' and the closeness of the camera, which has to be installed at a distance of 30 cm in front of the face of the operator.

The Copilot system is designed around PERCLOS.

## SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>Copilot is the result of 10 years of research by Carnegie Mellon University</i>	++++
1.2	<i>Because CoPilot is widely used, it will probably be ready for an initial project within two years after the first inquiries</i>	++++
1.3	<i>It is unclear in how much the system has been deployed</i>	+
1.4	<i>Installing the system on a large scale will not be very easy because, but the fact that every component is in one housing is an improvement</i>	++
2.1	<i>Acceptability by users will be high because of it's extensive use in the automotive industry and research institutes</i>	+++
2.2	<i>The systems needs to be able to 'see' a persons eyes. For this it uses one camera.</i>	+++
2.3	<i>The camera and processing unit are in a robust casing</i>	++++
2.4	<i>The system does not need to be attached to the body.</i>	++++
2.5	<i>The relatively large housing may block the view in cockpit situation</i>	++
3.1	<i>The camera's record eye closure and can report fatigue almost instantaneously</i>	++++
3.2	<i>CoPilot was designed to predict fatigue for up to an hour</i>	++++
3.3	<i>Once installed, the system can work autonomously</i>	+++
3.4	<i>Copilot does not seem to be designed to store data for later analysis</i>	+
4.1	<i>It can be queried all the time, an indicator is present near the camera</i>	++++
4.2	<i>Alarms seem non-intrusively, through different coloured LED's</i>	++
4.3	<i>Data does not seem to be specifically designed for extensive data analysis</i>	++
5.1	<i>The system is not affected by sunlight or temperature</i>	+++
5.2	<i>The system is not affected by sounds</i>	++++
5.3	<i>The system has its own illumination. Glasses may obstruct measurement</i>	++
6.1	<i>The system is focuses on PERCLOS (very well validated)</i>	+++
6.2	<i>The system has been tested in daily situations. Reliability seems good.</i>	++
7.1	<i>Implementation are average because of the all-in-one concept</i>	++
7.2	<i>Running cost low because little maintenance is needed and the system requires no data analysis</i>	+++

## **Systems measuring activity**

6. **The Sleep Watch** from *PrecisionControlDesign, Florida USA* (sleep/wake monitoring)  
[www.pcdsleepwatch.com](http://www.pcdsleepwatch.com)

There are four different kinds of actigraph watches available from Precision Control Design. These watches record various environmental parameters ranging from temperature to humidity and solar radiation. It also records when the person that is wearing the watch is awake and asleep.

Of the four different products the "Sleep Watch" is the most useful for use in a civil aviation setting. It graphically shows the last 24 hours of wake/sleep history. It also stores information on the amount of light it receives. Thereby combining wake/sleep with day and night. The watch can record this information for several months without the need for user input.

The data can be downloaded from the watch. By comparing this data with duty times and specific actions (i.e. take-off and landing) it is possible to draw conclusions about for example the time between wake-up and departure or to see whether the subject has been able to sleep during (long) flights.



**Figure 35 The Sleep Watch**

## **SCORES**

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>Precision Control Design has been making wrist worn actigraphs since 1984</i>	++++
1.2	<i>It can be ready within two years because the product is commercially available</i>	++++
1.3	<i>It is in use US army aviation</i>	++++
1.4	<i>No need for installation is needed, education can be done on paper</i>	++++
2.1	<i>The watch will not interfere with normal procedures and will only require minimal user input or maintenance.</i>	+++
2.2	<i>If the watch is not worn most of the time measurements of wake/sleep cycles may become useless. Given the small size and weight this is not expected</i>	++
2.3	<i>The watch is designed for intensive use</i>	+++
2.4	<i>Minimal</i>	+++
2.5	<i>Very easy and it does not require the user to be in a certain place of the cabin. Measurements can continue 24/7</i>	++++
3.1	<i>No, it measures sleep/wake moments and environmental variables</i>	0
3.2	<i>See above</i>	0
3.3	<i>Very high</i>	++++
3.4	<i>The watch can store many days of data for later downloading and analysis</i>	++++
4.1	<i>Only after analysis by an expert</i>	+
4.2	<i>No</i>	0
4.3	<i>Directly after downloading from the watch and analysis by an expert</i>	++
5.1	<i>The watch actually records light and temperature</i>	+++
5.2	<i>No</i>	++++
5.3	<i>Non known, perhaps by clothing</i>	+++
6.1	<i>The system records sleep history, additional models are needed to analyse the implications for levels of fatigue. Average score</i>	++

- |     |  |     |
|-----|--|-----|
| 6.2 | <i>The product seems very reliable given it's use in military operations</i> | +++ |
| 7.1 | <i>Initial costs are hardware (watches) and education of users/analysts</i>  | ++  |
| 7.2 | <i>Running cost can be minimal (replace broken hardware)</i>                 | +++ |

**7. The Sleeptracker PRO from Sleeptronix, Georgia, USA (sleep/wake monitoring)**

The company has been producing the watches for a couple of years and has considerable attention from newspapers and online media.

There are many similarities between the SleepTracker and the Sleep Watch. Both record periods of wakefulness and sleep. The difference between the two watches is what the recorded data is used for. In the case of the SleepTracker, the data is used for detailed analysis of the sleeping period. By comparing the 'almost awake' moments with the typical sleep cycles in an adult sleep profile (as mentioned in chapter 3) the watch determines the ideal moment to wake up and sounds an alarm to wake the person up. Waking up at the right moment in a sleep cycle shortens or prevents the sleep inertia during the first 30 minutes after wake-up. This can be very helpful when sleeping a couple of hours during flight. By using the watch for a prolonged period of time it can prevent cumulative fatigue as well.



**Figure 36 SleepTracker**

**SCORES**

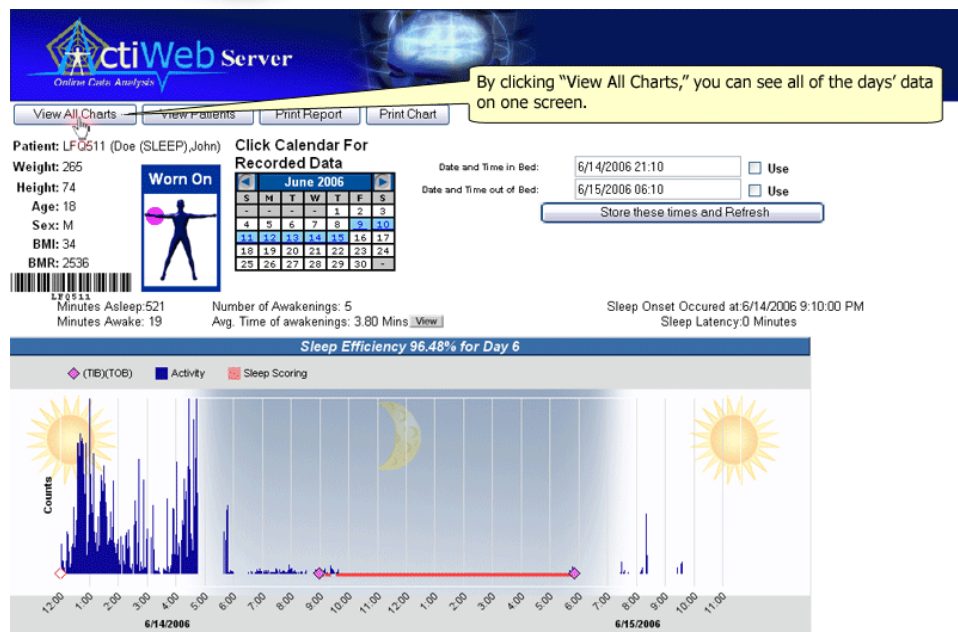
*Scoring is a 'best effort' attempt based on available information.*

- |     |  |      |
|-----|--|------|
| 1.1 | <i>Sleeptronix was established in 1986. The original sleepwatch has been around for many years, the PRO version is an evolution.</i>   | ++++ |
| 1.2 | <i>The product just needs to be bought and distributed in the organisation</i>   | ++++ |
| 1.3 | <i>The watch is mainly for personal use. No information on implementation in other industries could be found</i>   | +    |
| 1.4 | <i>No installation of any kind is required so deployment is easy</i>   | ++++ |
| 2.1 | <i>Acceptance will be high because the watch does not interfere with normal work. Design, weight and size are well within limits of normal watches</i>   | ++++ |
| 2.2 | <i>If the watch is not worn most of the time measurements of wake/sleep cycles may become useless. Given the size and weight this is not expected</i>  | ++   |
| 2.3 | <i>Designed for normal use</i>   | +++  |
| 2.4 | <i>Little physical invasiveness</i>  | +++  |
| 2.5 | <i>Easy to wear in any situation</i>   | ++++ |
| 3.1 | <i>No</i>  | 0    |
| 3.2 | <i>No</i>  | 0    |
| 3.3 | <i>High level of automation, very little user effort is needed</i>   | +++  |
| 3.4 | <i>The watch will store data on multiple days. This data can be downloaded and analysed with Sleeptracker Software</i>   | ++++ |
| 4.1 | <i>No</i>  | 0    |
| 4.2 | <i>The user is awoken by the watch at optimal times</i>  | ++   |
| 4.3 | <i>After downloading and analysis</i>  | ++   |
| 5.1 | <i>No influence</i>  | ++++ |
| 5.2 | <i>No influence</i>  | ++++ |
| 5.3 | <i>Non known, perhaps by clothing</i>  | +++  |
| 6.1 | <i>The watch uses scientifically validated sleep patterns and cycles to determine when to wake up the user. Otherwise raw information must be analysed by an expert on sleep/wake cycles, circadian rhythm and fatigue</i> | ++   |
| 6.2 | <i>Based on company experience and testimonials, reliability of data collection and effectiveness is high.</i>   | +++  |

- 7.1 The watches are cheap to buy. Education and use of experts is needed +++++
- 7.2 Simple maintenance and data analysis +++

8. **Actigraph** from [www.theactigraph.com](http://www.theactigraph.com)

This product comes with (Windows based) server or desktop software to view the recorded information. This information can be easily downloaded with a USB connection. The Actigraph is worn on the wrist and records information on sleep and activity patterns by accurately and consistently measuring accelerations. Almost 200 technical documents and studies can be found on the website that includes subjects like validation.



## SCORES

Scoring is a 'best effort' attempt based on available information.

- 1.1 ActiGraph has been manufacturing these monitors for over 10 years +++++
- 1.2 The product can be purchased and put in use at any moment +++++
- 1.3 It's in use at other companies, no aviation customers could be found +++
- 1.4 Very easy, the product is pretty much self explaining +++++
- 2.1 Simple versions of actigraphs can be found in everyday life (i.e. step counters in sport activities). It requires little user input +++
- 2.2 Only not wearing the device could impair good measurements +++
- 2.3 It's used for sporting activities so durability is good +++
- 2.4 Wearing the device for long periods may be a little uncomfortable ++
- 2.5 The device does not get in the way of normal operating and working procedures +++
- 3.1 No, it needs data analysis 0



3.2	No, it needs data analysis	0
3.3	High	+++
3.4	The device can store data on multiple days	++++
4.1	Only after analysis	+
4.2	No	0
4.3	After analysis	++
5.1	No influence of light	++++
5.2	No influence of noise of sounds	++++
5.3	No influence of clothing of any kind	++++
6.1	A section of the website has almost 200 studies on validation and in which the product has been used	+++
6.2	The product is robust and experience with actigraphs is extensive	+++
7.1	The devices are in a cheap price range. Education and use of experts is needed	++++
7.2	Simple maintenance and data analysis	+++

### **Systems measuring stimulus – reaction time**

These tests are also commonly known as Psychomotor or Performance Vigilance tests.

#### **9. Fatigue Monitor from ARRB, Australia**

In 1999 the company started a review of technological systems that could be used to monitor operators of heavy vehicles in the mining industry. The result of the report was that (at that time) there were no real practical solutions available. ARRB developed a fatigue monitoring system as part of an overall Fatigue Management System for vehicle operators. At least at three different sites, the system was installed and the data was validated.

The system measures reaction times to visible en audible stimuli. The idea behind the use of two different stimuli is that the reaction to a single stimulus can become so automated that operators can perform the task, no matter how fatigue they are. By using two stimulus-reaction systems (left and right) the operator has to make a conscious decision. In the cabin, the operator has to hit a switch when one of the lights turns on. Based on the reaction time, the on-board system decides when to request another input. When reaction-times become slower, the frequency increases. At certain thresholds the systems notifies a central location at which a pc is based that gets inputs from all subjects in the vicinity. Depending on how slow the reaction time is, the operator also hears an alarm.

#### **SCORES**

*Scoring is a 'best effort' attempt based on available information.*

1.1	The Fatigue Monitor has been developed in 1999	++++
1.2	It was developed for the mining industry and the system is quiet large. Changing the system to fit inside and airplane needs some time. The fact that it needs a 'central' computer and is not stand-alone needs to be changed.	++
1.3	Mainly in the mining industry, for operators of very heavy vehicles. Only some project could be found	++
1.4	If it is small enough, it could be deployed relatively easy	++
2.1	The product requires the person to 'hit a switch' when a light comes on. This kind of measurement is probably not very well accepted by pilots	+
2.2	By not paying attention to the device or by over actively focussing on it, it is easy to manipulate results. People can choose to ignore the alarms until they become to frequent.	+
2.3	The original device was constructed for heavy vehicles on rugged terrain.	++++
2.4	The fact that a button needs to be pushed is very invasive and requires action in al already busy airplane	+



2.5	<i>If it is made in a pocket sized version it will be easy to use</i>	++
3.1	<i>Based on the internal software, it can detect fatigue almost real-time</i>	++
3.2	<i>Yes, but only to a certain extend</i>	++
3.3	<i>Other than reacting to the stimulus, the system does not need any other user input</i>	++
3.4	<i>In the original setup, the devices inside the vehicles were all connected (wireless) with a central computer. This computer monitors all reaction times. It is unclear how data can be stored in a stand-alone device</i>	0
4.1	<i>In the original setup, the devices inside the vehicles were all connected (wireless) with a central computer. This computer monitors all reaction times. A central person is than informed, not the operator. The operator is informed by this person. How this can be applied in aviation is unclear</i>	0
4.2	<i>See above</i>	++
4.3	<i>If the same strategy is used as in the mining situation, management is the first to know</i>	++++
5.1	<i>Little to no influence, other than being able to see the lights of the system</i>	++
5.2	<i>No influence</i>	++++
5.3	<i>No influence</i>	++++
6.1	<i>Slow responses indicate fatigue. Reaction time is a known effect of fatigue. How the system is actually validated is unknown</i>	++
6.2	<i>The original heavy duty design secures reliability</i>	++
7.1	<i>Implementation are high because many modifications are necessary</i>	+
7.2	<i>Running cost low because little maintenance is needed and the system requires no data analysis</i>	+++

#### 10. **Fatigue Warning System** from Muirhead/Remote Control Technologies, Australia

This fatigue warning system is very much like the fatigue monitor from ARRB. At the moment the company has over 800 systems in operational settings. This system is not part of an overall fatigue management system but is a stand-alone device. The system uses only a single 'action-reaction' system, but has a warning system to warn that being over-fatigued is predicted. Relatively little additional information is available on this system

#### SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>The company has 35 year of experience, but the system has only been in use for a couple of years.</i>	+++
1.2	<i>It needs some modification to use in a cabin but it is simple enough (stand-alone) to be modified</i>	+++
1.3	<i>Over 800 systems have been deployed, but none in aviation</i>	+++
1.4	<i>If the system Is integrated into a single device it should not be to hard, but this has to be changed</i>	++
2.1	<i>Acceptance will probably not be too high due to its relative simplicity and because it may interfere with regular work. Social acceptability of a stimulus-reaction may also be low.</i>	+
2.2	<i>By not paying attention to the device or by over actively focussing on it, it is easy to manipulate results. People can choose to ignore the alarms until they become to frequent.</i>	+
2.3	<i>The device is simple enough be resistant to destruction</i>	++++
2.4	<i>A button needs to be pushed regularly, this imposes an extra workload</i>	+
2.5	<i>If small enough (pocket size), it should be easy to use</i>	++
3.1	<i>It detects 'fatigue' when the reset button is not pressed. So there is a slight delay in detection</i>	++
3.2	<i>It detects delays in response time. If delays become longer, fatigue is predicted.</i>	++
3.3	<i>It needs constant user input, but no other 'administration'</i>	++
3.4	<i>Non could be found</i>	0
4.1	<i>There is no way for the user to query the system</i>	0

4.2	<i>The system uses visible and audible alerts</i>	++++
4.3	<i>No method for storing and analysis of data could be found</i>	0
5.1	<i>The user needs to push the reset button based on a visual warning. Bright light may interfere with seeing this warning light</i>	++
5.2	<i>Sound should not be a problem</i>	++++
5.3	<i>If the user can move freely to push the reset button, this should not be a problem</i>	++++
6.1	<i>Several studies show that reaction time decreases with fatigue, but only measuring reaction time may be an over simplification. Validation studies of the product itself could not be found</i>	++
6.2	<i>The technology which is used is simple and reliable</i>	++
7.1	<i>Implementation are high because many modifications are necessary</i>	+
7.2	<i>Running cost low because little maintenance is needed and the system requires no data analysis</i>	+++

### **Systems measuring sleep related factors**

#### **11. Mean (or Multiple) Sleep Latency Test**

Simply put, the MSLT is a nap study. It determines how fast you fall asleep in a quiet, dark a comfortable room. This way it removes unwanted environmental interferences. Although it must be said that some things cannot be taken out of the equation like anxiety or tension. The MSLT is the standard way for testing what is called daytime sleepiness.

The idea behind the test is that the time it takes for someone to fall asleep is a measure for his or her feelings of sleepiness. The MSLT takes different measurements during this test among which: brain waves (EEG), heart rate, eye and chin movements. Since the period of REM sleep is an indication for the cycle and depth of sleep it also measures the time it takes to enter REM sleep.

Usually the test is taken four times during a single day. Each test takes about 20 minutes to complete. As soon as the person falls asleep he or she is awakened.

The Multiple Sleep Latency Test is a validated objective measure of the ability or tendency to fall asleep. (Littner, et al., 2004)

### **SCORES**

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>MSLT and MWT tests have been used for many years by different companies</i>	++++
1.2	<i>Both tests are well established in sleep research so they can be used quickly</i>	++++
1.3	<i>The tests are often used by "health services" of large airlines</i>	++++
1.4	<i>External companies can be asked to perform the tests</i>	+++
2.1	<i>Given the professionalism and experience with this test, acceptance will be good. But the tests take a considerable amount of time and energy</i>	++
2.2	<i>The person has to be cooperative at all times</i>	++
2.3	<i>Not applicable, average score used</i>	++
2.4	<i>High, the person must undergo a full day of testing</i>	+
2.5	<i>Not applicable, average score used</i>	++
3.1	<i>The tests cannot detect fatigue real-time but only do one assessment per test</i>	0
3.2	<i>The test cannot predict fatigue, only measure the sleep tendency</i>	0
3.3	<i>A lot of manual and mental effort is needed</i>	+
3.4	<i>All information can be stored for later use</i>	++++
4.1	<i>Only once, after the test</i>	++
4.2	<i>Not applicable, average score used</i>	++
4.3	<i>Within a few days</i>	++
5.1	<i>The tests need to be taken in specially prepared rooms</i>	+++
5.2	<i>The tests need to be taken in specially prepared rooms</i>	+++

- |     |  |     |
|-----|--|-----|
| 5.3 | <i>The tests need to be taken in specially prepared rooms</i>  | +++ |
| 6.1 | <i>Both tests receive considerable scientific attention and validity of the test has been proven. But the relation between the test results and fatigue are debateable</i> | ++  |
| 6.2 | <i>Reliability of the test depends on cooperation subject</i>  | ++  |
| 7.1 | <i>The tests can be performed by external companies/experts</i>  | +++ |
| 7.2 | <i>The tests can be performed by external companies/experts</i>  | +++ |

## 12. Maintenance of Wakefulness Test

The Maintenance of Wakefulness Test is another sleep study. Again, in a standard and controlled environment, four sessions of approximately 20 minutes and about 2 hours apart are held. During these sessions the person is instructed to try to stay awake, but he or she has to remain quiet en still. This test can be seen as the opposite as the MSLT. The MWT is also a validated objective measure of the ability to stay awake. (Littner, et al., 2004). Because of strong similarities, the same scores are used at the Mean Sleep Latency Test

### Other systems

## 13. DVTCS from Neurocom, Russia (Skin conductibility)

The Driver Vigilance Telemetric Control System (DVTCS) is a system that continuously measures electro dermal activity. Based on many tests and statistical data, the system gives an audible signal before a person falls. The state of the person can be viewed in real-time on an indicator.

The DVTCS system is very easy to install as it is completely wireless. The test subject has to wear a bracelet. The bracelet sends information to a secondary information processing unit. This unit in turn send information to be displayed on the indicator.

Besides automotive applications, the system has also been extensively in use on locomotive drivers. By means of an actuator the system can even bring the train to a halt if the driver is unwell or asleep.



Figure 37 Components of the DVTCS system

Note: due to the fact that all units communicate wireless (radio waves), it may very well be undesirable to use it in airplanes as mobile phones are also not allowed due to possible interference with flight systems.

### SCORES

*Scoring is a 'best effort' attempt based on available information.*

- |     |   |      |
|-----|---|------|
| 1.1 | <i>The company has been working on fatigue related products for twelve years</i>  | ++++ |
| 1.2 | <i>Although it is designed for use in road and rail industry, little or no changes seem necessary for aviation</i>  | ++++ |
| 1.3 | <i>No evidence, it is only in use in other industries</i>   | +++  |
| 1.4 | <i>Installation on a large scale is relatively simple because only one device needs to be placed in the vicinity of the user. The use of radio waves may pose a threat!</i> | ++   |
| 2.1 | <i>The system uses skin conductibility as a measure of fatigue. This is quiet unusual</i>   | ++   |

	<i>and requires the wearing of a watch/bracelet. This may be less acceptable</i>	
2.2	<i>Not wearing the watch/bracelet means no measurement can be taken</i>	++
2.3	<i>The devices are simple and made of metal</i>	+++
2.4	<i>It is necessary to wear the watch/bracelet. But this does not impair movement</i>	+++
2.5	<i>The system is small and does not impair movement</i>	+++
3.1	<i>It continuously monitors the person</i>	++++
3.2	<i>It detects the moment someone falls asleep tens of seconds in advance</i>	++++
3.3	<i>Automation is very high, no input is needed</i>	++++
3.4	<i>Unknown</i>	0
4.1	<i>The indicator shows the level of fatigue</i>	++++
4.2	<i>Yes, seconds before falling asleep an alarm sounds</i>	+++
4.3	<i>Unknown</i>	0
5.1	<i>The system only measures electro dermal activity</i>	++++
5.2	<i>The system only measures electro dermal activity</i>	++++
5.3	<i>Clothing may be in the way</i>	+++
6.1	<i>Documents and papers on validity of skin conductivity and fatigue are</i>	+
6.2	<i>Due to it's simplicity and claims made by the company reliability seems high</i>	+++
7.1	<i>Implementation cost is average because the system is simple and requires little installation</i>	++
7.2	<i>Running cost low because little maintenance is needed and the system requires no data analysis</i>	+++

#### 14. Tiredness and Fatigue Warning System from Total Control Pty. Ltd, Australia

The company Total Control in Australia produces the 'Tiredness Warning System'. This is another device in the shape of a watch that measures the state of fatigue that the company has developed over the last 7 years. Not much information can be found on the 'inner workings' of the device or about the validity. It does however seem to work similar to the **DVTCS** system and measure heartrate. It has contact plates on the bottom of the watch.

The device shows the state of fatigue with a number on the watch. The lower the number, the more fatigue is measured. At certain threshold the device sounds an alarm, starts to vibrate or even emits an electric impuls. There is a patent pending for this product and although not much background information is available, it looks like a promising technology.



Figure 38 Tiredness Warning System

#### SCORES

Scoring is a 'best effort' attempt based on available information.

1.1	<i>The warning system has been available for a few years</i>	+++
1.2	<i>It can be used out-of-the-box</i>	++++
1.3	<i>It is not known to be in use in aviation but its use in aviation is advertised. It has been used in the road transport industry</i>	+++
1.4	<i>Very easy, no installation is required</i>	++++
2.1	<i>The system is relatively acceptable as it is designed as a watch. The use of a special conduction gel might lower acceptability</i>	++
2.2	<i>Not wearing the watch/bracelet means no measurement can be taken</i>	++
2.3	<i>Acceptable</i>	++
2.4	<i>Average, has to be worn on the wrist</i>	++

2.5	<i>Small and easy to use in airplane cabins</i>	+++
3.1	<i>Yes it measures fatigue and tiredness real-time</i>	++++
3.2	<i>Prediction is possible to a certain extend</i>	+++
3.3	<i>The user just needs to wear the watch appropriately and acknowledge warning signals of fatigue. Signals increase in frequency if not acknowledged</i>	+++
3.4	<i>Storage and download/analysis facilities are limited</i>	+
4.1	<i>The device monitors continuously</i>	++++
4.2	<i>Audible, visible and electrical impulses are used to alert the person</i>	++++
4.3	<i>Data management is non-existed or limited</i>	0
5.1	<i>No influence of light</i>	++++
5.2	<i>No influence of sound or noise</i>	++++
5.3	<i>Non are known</i>	++++
6.1	<i>Little information could be found</i>	+
6.2	<i>Little information could be found, average score</i>	++
7.1	<i>Relatively costly at around \$ 500,00 a piece</i>	++
7.2	<i>Running cost low because little maintenance is needed and the system requires no data analysis</i>	+++

15. **AWAKE** from the *European commission* (European Commission)

AWAKE (Assessment of driver vigilance and Warning According to traffic risk Estimation) is a European research project funded by the IST Initiative of the FIT framework program. Its aim is to increase road safety by reducing accidents due to driver fatigue and hypovigilance. This project is primarily aimed at road use but, with modifications, it can be used in aviation setting.



The Awake system consists of several subsystems which monitor the driver and the environment. This is done in an unobtrusive manner, no devices are attached to the operator. The system uses for example the direction of gaze, eye blinking rate and grip force on the steering wheel for internal parameters and the position of the car on the road and in relation to other vehicles as external parameters. To capture these parameters many different sensors have to be installed. Warning signals are visible, audible and through vibration in the seatbelt.

The system uses operator profiles using an individual smartcard. To inform the operator to fatigue onset a combination of visual and audible notifications are used.

## SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>The AWAKE project finished in 2004 and it has been tested in luxury cars, heavy vehicles and simulators.</i>	+++
1.2	<i>Changing the product to fit the specific characteristics of an airplane (for example: lane deviations are not useable as a measure of fatigue) may require a significant of time</i>	+
1.3	<i>The systems is used in very few luxury production cars</i>	+
1.4	<i>If it is changed to fit an aviation setting, it will still need considerable effect because of the many different sensors it uses</i>	+
2.1	<i>Since a lot of research has been done on fatigue by the Awake consortium and because of its road expertise, acceptability will be good (provided it does not interfere with normal work procedures).</i>	+++
2.2	<i>The many sensors make it hard to 'fool' the system</i>	+++
2.3	<i>Generally good</i>	++

2.4	No sensors need to be worn by the user. The use of camera's steering wheel sensors (driver needs to keep the hands on steering wheel) may have an impact on driving	+++
2.5	The user only needs to carry a 'profile card' for personalised measurements. No other input is required	+++
3.1	The system is designed to detect fatigue in real-time	++++
3.2	Prediction seems possible but only for a limited time period	++
3.3	The system is design to be completely stand-alone	+++
3.4	No detailed information on data storage could be found but the systems seems capable of storing 'critical results' (time and reason of fatigue warning)	++
4.1	The system only shows 'fatigue' information when drowsiness is detected	++++
4.2	The system warns through visible audible and vibrating alarms	++++
4.3	No information could be found, but it seems possible to download data and send it through normal methods (internet/email)	++
5.1	Light/darkness does not influence the system	++++
5.2	Sounds do not influence measurements	++++
5.3	Glasses may impair the use of eye closure	+++
6.1	The system was scientifically tested in a range of simulators and real world situations. Subsystem are commonly validated	+++
6.2	Awake claims a recognition rate of over 90% and only a 1% false alarm rate.	+++
7.1	Initial costs to modify the system are high. Installation costs are also expected to be high	0
7.2	Once installed, costs will remain considerable because the system uses many sensors and subsystems that require maintenance and care.	+

#### 16. **SiCECA** from Electronic Navigation Research Institute, Tokyo Japan

This fatigue and drowsiness predictor is a system that uses the mathematics of chaos theory to compare pattern changes in the voice of the operator. The voice pattern of an alert operator is much more well-defined than the jagged pattern of a fatigued operator. SiCECA is a computing algorithm that computes the level of brain activity. By comparing this with information from other studies on brain activity and fatigue it can measure the level tiredness of an operator. The value of brain activity increases as fatigue set in since more 'brainpower' (motivation) is needed to carry out the task. The level of brain activity is, in contrary to self observation, an objective measurement.

The first prototype of this system was made in 1999. Using a moderate standard pc, speakers and a microphone the voice can be continuously measured and analyzed in less than 10 seconds. Since all the systems needs is a processing unit, microphone and speaker the dimensions of such a system can, today, be estimated to be the size of a standard PDA.

Developers of the system claim that it can not only monitor but also make good predictions for fatigue. It can predict a state of fatigue 10 to 20 minutes before the operator notices the feeling.

Non-obtrusiveness is an important benefit of the system. The operator does not have to perform any tasks or even look in the direction of a camera. The system is able to pick-up speech from normal conversations and communications with Air Traffic Control. Also, differences in language do not matter.

*At this moment it is possible to 'test-drive' the SiCECA on its website by sending wave samples for analysis. Results will be e-mailed and stored for later comparison A commercial product called Parole is also available.*

## SCORES

*Scoring is a 'best effort' attempt based on available information.*

1.1	<i>The first prototype is made in 1999. The concept was presented in 2000 and a commercial product is available in the form of windows software</i>	+++
1.2	<i>SiCECA is not yet in use in any daily operations but demonstrations and experiments have taken place with many research partners. Full implementation may take a while</i>	+
1.3	<i>Implementation for cockpit and air traffic control is underway</i>	++
1.4	<i>Once the product has reached the stage of completion it should not be too hard to introduce install it in aircraft</i>	++
2.1	<i>Acceptance will be good, because it requires no user input</i>	++
2.2	<i>Very resistant to manipulation because users cannot change their voice on purpose for a long period of time</i>	++++
2.3	<i>Depends on the final product but no special fragile equipment seems necessary</i>	+++
2.4	<i>None, voice activated</i>	++++
2.5	<i>Very good, no user input is needed</i>	++++
3.1	<i>The system only needs a few seconds of voice to determine brain activity/fatigue. But if nothing is said, there may be a slight delay</i>	+++
3.2	<i>Prediction of fatigue is possible. About 10 – 20 minutes before the subject notices it.</i>	++++
3.3	<i>Automation is very high, no user input is needed. It is language independent</i>	++++
3.4	<i>This depends on the final product, but it should be possible</i>	++
4.1	<i>Continuous measurements are done, but how often the system can be queried again depends on the final product</i>	+++
4.2	<i>Depends on final product but, no further information is available</i>	++
4.3	<i>Depends on final product but, no further information is available</i>	++
5.1	<i>No influence</i>	++++
5.2	<i>Outside noises may influence good measurement</i>	++
5.3	<i>No influence</i>	++++
6.1	<i>Studies done by Kakuichi Shiomi show a valid relation between the voice measurements, brain activity and fatigue. No independent validations could be found</i>	++
6.2	<i>Reliability score is average due to lack of information</i>	++
7.1	<i>If there are no development cost, implementation cost should be average because the amount of hardware/software is relatively simple</i>	++
7.2	<i>Running cost can be low if the system is fully automatic</i>	+++



### Appendix 3. BOW-TIE OF CAUSES AND EFFECTS OF FATIGUE

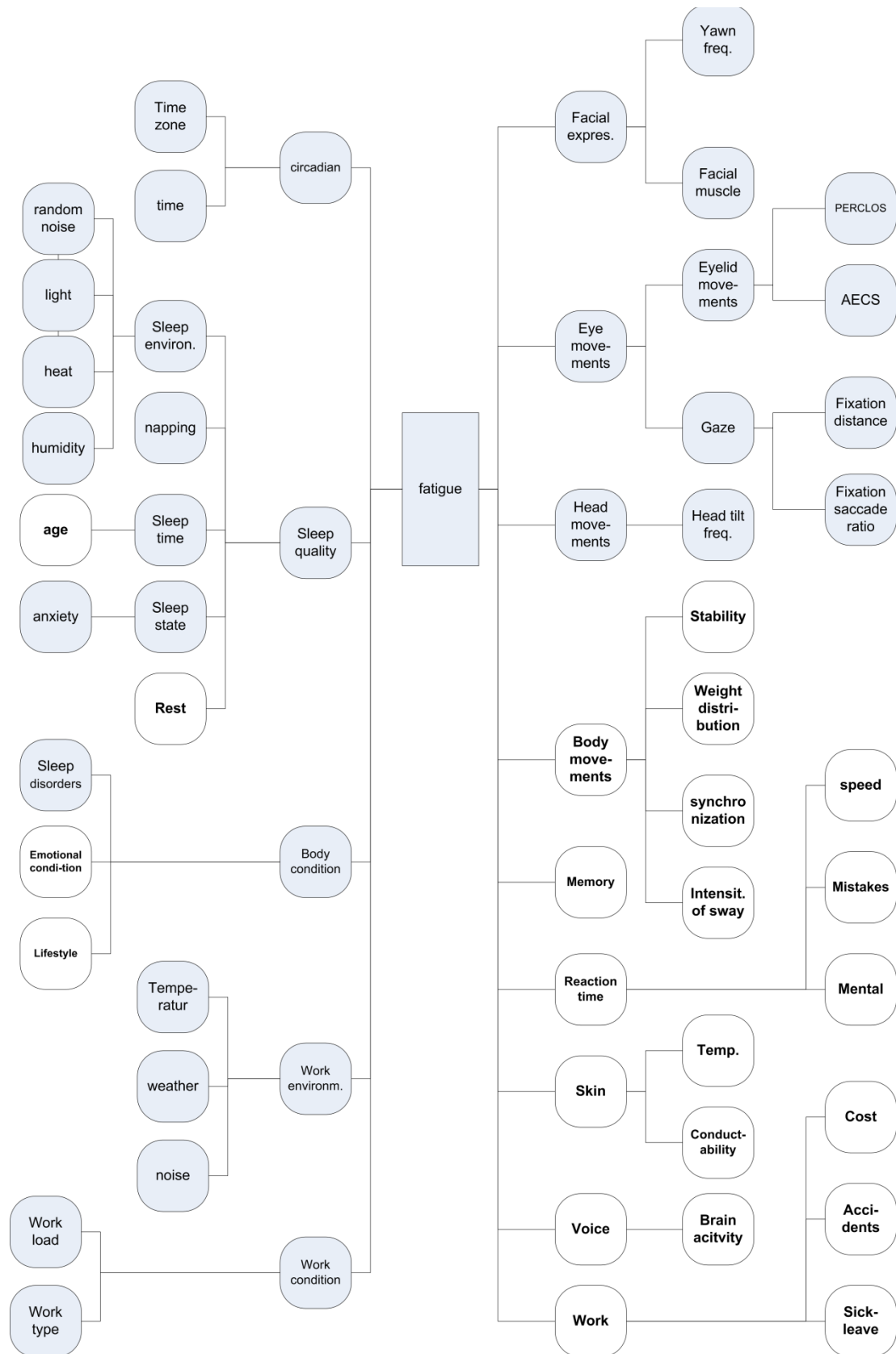


Figure 39 Bow-tie of cause and effect

Source: Qjang, et al. 2006. Non shaded items added by the author.

## Appendix 4. METHOD USED IN MULTI-CRITERIA ANALYSIS (EXAMPLE)

Suppose we want to plan a daytrip to an amusement park. The whole family will be coming along, the children, parents and grandparents. Because it is a daytrip we need to decide what snacks we want to bring with us. We have three options: apples, candy or ice cream. First we need to define some criteria that we are going to judge these options on. We could think of price, taste and practicality. Then we need to give each a weight from 1 to 10: a one for totally not important and a 10 for extremely important. All weights are normalized. After that we write down sub criteria for each main criterion. For 'taste' we could think of whether young, adult or elder family members like it. Each of the sub criteria is again given a weight. After that the three options need to be scored on each sub criteria. All weights are normalized to compensate for the fact that some main criteria have more sub criteria than others and would otherwise contribute too heavily to the outcome.

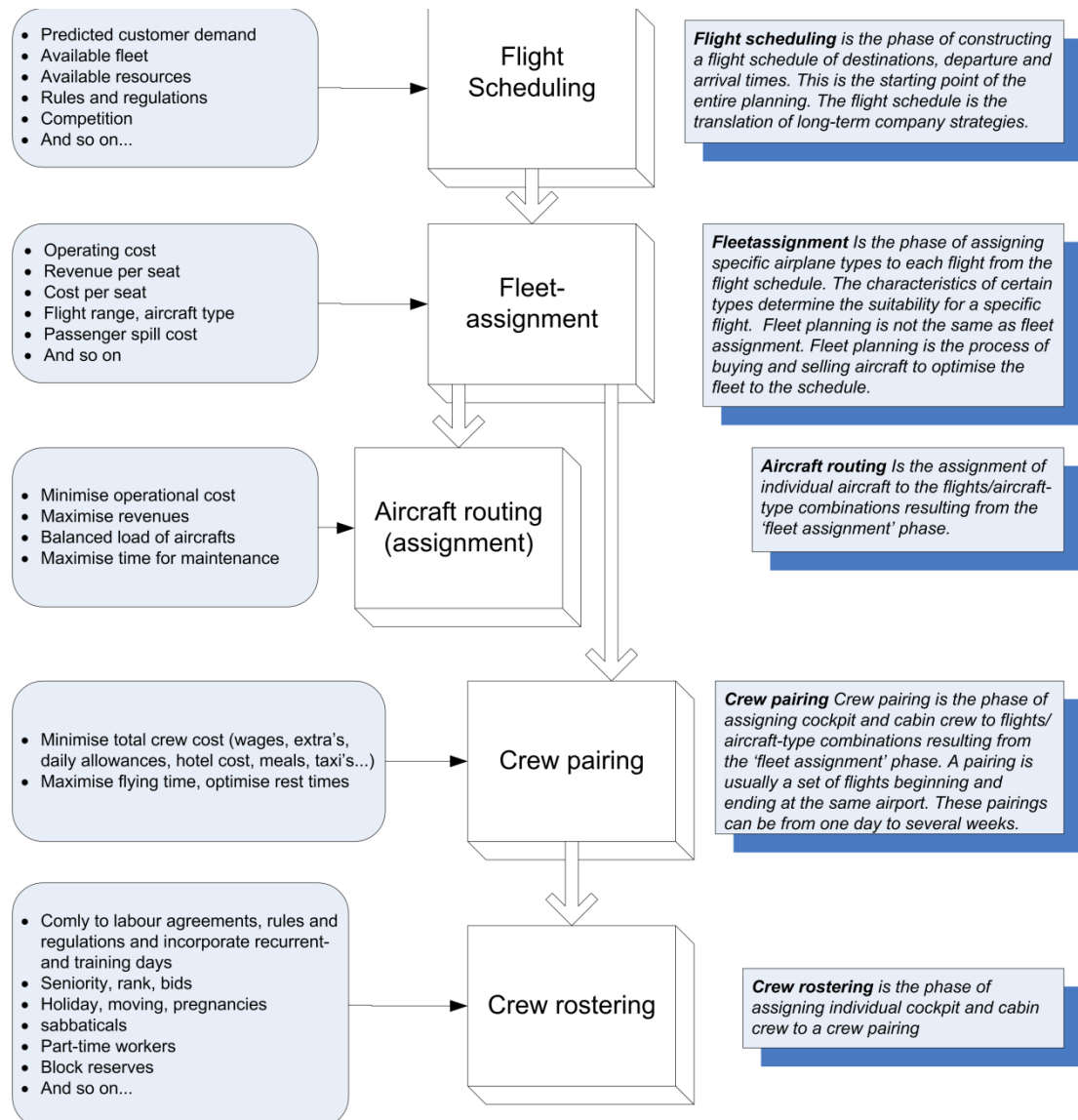
Finally we have to score the options on each alternative. Let's look at sub criteria 2.2: "can it be stored outside the refrigerator?". Apples and candy both score high but ice cream (obviously) does not. You can give the scores: 0, +, ++, +++ and ++++ each corresponding to a value of respectively 0, 0.1, 0.3, 0.6 and 1. For each sub criteria/option a weighted score is then calculated. In the example of 2.2 and 'apples' this is:  $0.6 * 0.62 * 0.29 = 0.11$ . Finally all weighted scores are added concluding that it is best to take candy to the daytrip.

Description		Weight (0 – 10)		Normalized weight		Apples		candy		icecream					
						Score	Weighted score	Score	Weighted score	Score	Weighted score				
1	Taste	Taste of the fruit?	7	0,33											
	1,1	Do young people like to eat it?			9	0,39	+	0,1	0,01	+++	0,6	0,08	++++	1	0,13
	1,2	Do adults like to eat this it?			6	0,26	+++	0,6	0,05	+	0,1	0,01	++	0,3	0,03
	1,3	Do elderly like to eat it?			8	0,35	+++	0,6	0,07	0	0	0,00	+	0,1	0,01
		Weighted score:				0,13				0,09			0,17		
2	Practicality	How practical is it to bring along?	6	0,29											
	2,1	Can it withstand little bumps			5	0,38	++	0,3	0,03	++++	1	0,11	+	0,1	0,01
	2,2	Can it be stored outside the refrigerator?			8	0,62	+++	0,6	0,11	++++	1	0,18	0	0	0,00
		Weighted score:				0,14				0,29			0,01		
3	Price	What are the costs involved?	8	0,38											
	3,1	Is it cheap to buy			8	0,62	++	0,3	0,07	+++	0,6	0,14	+	0,1	0,02
	3,2	Is it cheap to store			5	0,38	++++	1	0,15	++++	1	0,15	0	0	0,00
		Weighted score:				0,22				0,29			0,02		
TOTAL SCORE:						0,4901				0,6599			0,2025		
RANKING						2				1			3		

## Appendix 5. EUROPEAN PILOT UNIONS

Abbreviation	Country	Full Name	Website
ACA	Austria	Austrian Cockpit Association	<a href="http://www.aca.or.at">www.aca.or.at</a>
ALPASL	Slovenia	AirLine Pilots Association of Slovenia	
ALPL	Luxemburg	Association Luxembourgeoise des Pilotes de Ligne	<a href="http://www.alpl.lu">www.alpl.lu</a>
ANPAC	Italy	Associazione Nazionale Piloti Aviazione Commerciale	<a href="http://www.anpac.it">www.anpac.it</a>
APPLA	Portugal	Associação dos Pilotos Portugueses de Linha Aérea	<a href="http://www.pilotos.com.pt">www.pilotos.com.pt</a>
BALPA	United Kingdom	British Airline Pilots Association	<a href="http://www.balpa.org">www.balpa.org</a>
BECA	Belgium	Belgian Cockpit Association	<a href="http://www.beca.be">www.beca.be</a>
BUL-ALPA	Bulgaria	Bulgarian Airline Pilots Association	<a href="http://www.bulalpa.org">www.bulalpa.org</a>
CZALPA	Czech Republic	Ceské sdružení dopravních piloto CSA	<a href="http://www.czalpa.cz">www.czalpa.cz</a>
DALPA	Denmark	Danish Airline Pilots Association	<a href="http://www.dalpa.dk">www.dalpa.dk</a>
ESTONIAN ALPA	Estonia	Estonian Airline Pilots Association	
FPA	Finland	Finnish Pilots Association	<a href="http://www.fpapilots.fi">www.fpapilots.fi</a>
HALPA	Greece	Hellenic Airline Pilots Association	
HUNALPA	Hungary	Hungarian Airline Pilots' Association	<a href="http://www.hunalpa.hu">www.hunalpa.hu</a>
IALPA	Ireland	Irish Airline Pilots Association	<a href="http://www.ialpa.net">www.ialpa.net</a>
NF	Norway	Norsk Flygeerforbund	<a href="http://www.flyger.no">www.flyger.no</a>
POLALPA	Poland	Polish Airline Pilots Association	
PTUL	Latvia	Pilots Trade Union of Latvia	
PULPA	Cyprus	Cyprus Airline Pilots Association	
SEPLA	Spain	Sindicato Español de Pilotos de Líneas Aéreas	<a href="http://www.sepla.es">www.sepla.es</a>
SNPL	France	Syndicat national des Pilotes de Ligne	<a href="http://www.snpl.com">www.snpl.com</a>
SPF	Sweden	Svensk Pilotförening	<a href="http://www.swealpa.se">www.swealpa.se</a>
VC	Germany	Vereinigung Cockpit	<a href="http://www.vcockpit.de">www.vcockpit.de</a>
VNV-DALPA	Netherlands	Vereniging van Nederlandse Verkeervliegers	<a href="http://www.vnv-dalpa.nl">www.vnv-dalpa.nl</a>

## Appendix 6. ROSTERING PROCESS



Source: (Bazargan, 2004)

### A simple example:

**Flight schedule:** Every Monday a flight from Paris to Madrid, departing at 07.00 hours  
Every Tuesday a flight from Madrid to Paris, departing at 08.00 hours

**Fleet assignment:** These flights are operated with the Boeing 737-900 fleet

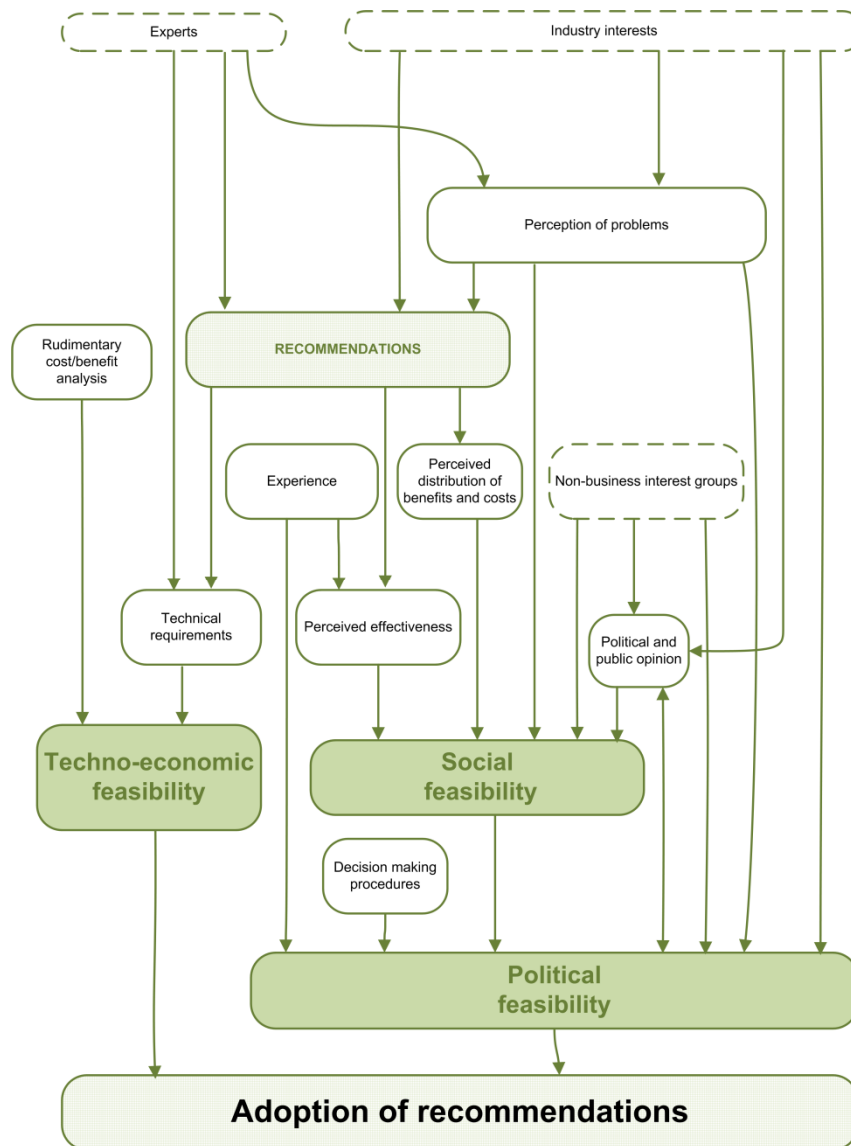
**Aircraft routing:** Both flights are operated by the PH-ABC

**Crew pairing:** Crew consists of one captain, one first officer, one purser and three cabin attendants. One crew operates both flights and stays overnight at Madrid from Monday to Tuesday.

**Crew rostering:** Monday 1<sup>st</sup> of January 2008 departure 07:00 arrival: 08:40  
Tuesday 2<sup>nd</sup> of January 2008 departure 08:00 arrival: 09:40

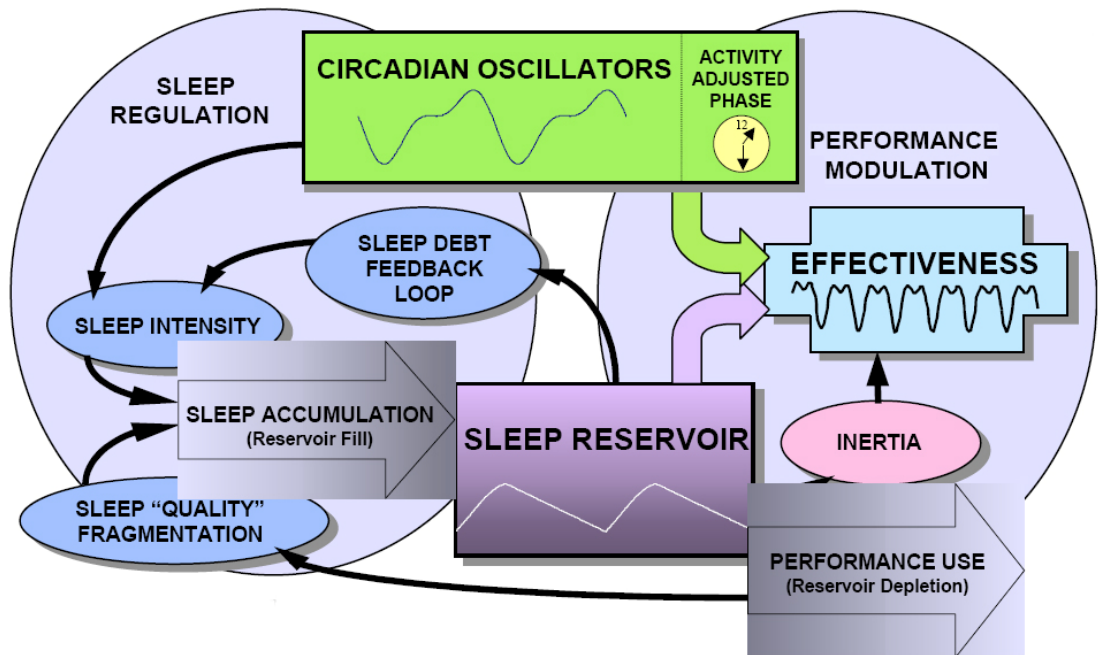
Captain:	Mr A.
First Officer	Mr. B
Purser:	Mrs. C
Cabin attendants:	Ms. D, Ms. E. and Ms. F

## Appendix 7. MODEL FOR THE CHANCE OF ADOPTION



(Feitelson, E., Salomon, I. 2004)

## Appendix 8. SAFTE MODEL



The SAFTE model (Sleep, Activity, Fatigue and Task Effectiveness) is developed by Dr. Steven Hurhs and is the basis behind FAST, a tool which can be used to predict levels of fatigue and performance. The model incorporates (among others) quantitative information on human (hormonal, digestive and day/night) circadian rhythms, recovery by sleep, and depletion of resources due to performance. FAST also takes other changes in account such as seasonal changes in light and darkness and travelling across time-zones. Variables the user can enter into this model are for example: start-of-duty, end-of-duty, location of departure and destination and sleep quality. The SAFTE model has been validated against real world data. After entering the needed information, FAST produces a graph that indicates the expected 'Task Effectiveness'.

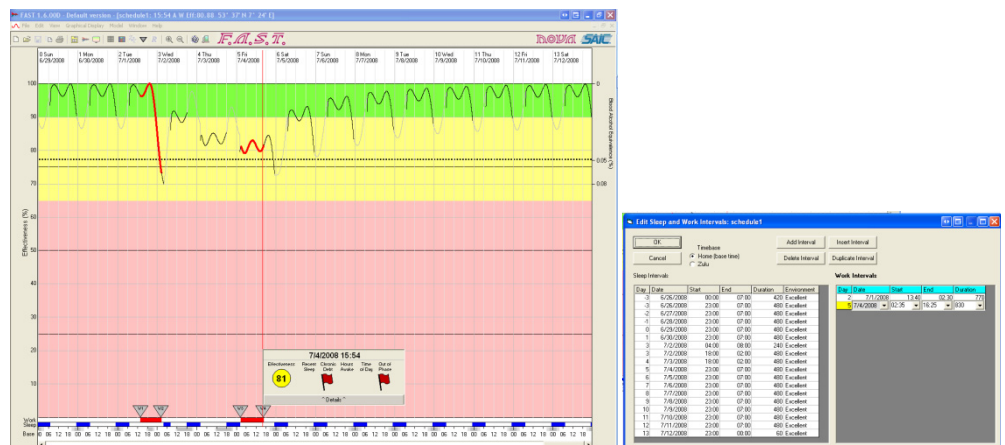
## Appendix 9. SLEEP SCHEDULE EXAMPLE

Different sleep schedules for the same return flight from Amsterdam to Hong Kong

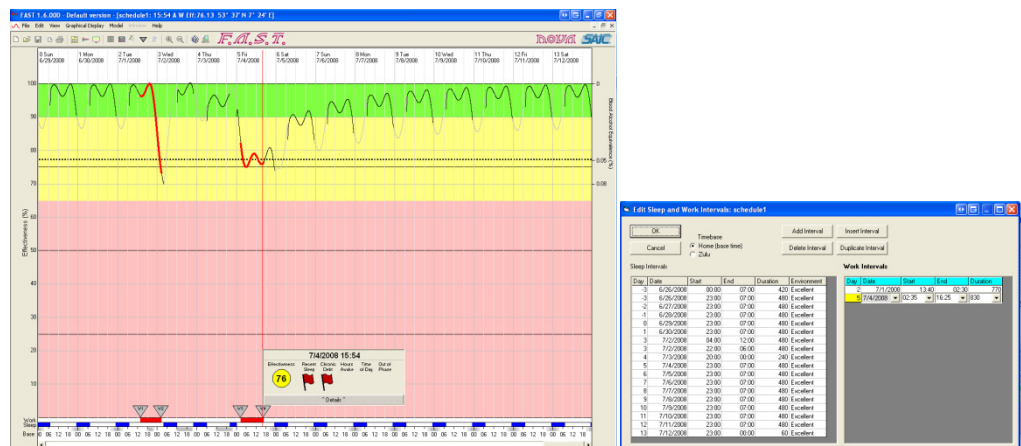
1. Adjust to local time immediately and fully: effectiveness during lading at Amsterdam: **69%**



2. Adjust to local time partially: effectiveness during lading at Amsterdam: **81%**



3. Stick to base time, don't adjust to local time: effectiveness during lading at Amsterdam: **76%**





## Appendix 10. FATIGUE REPORT FORM

Fatigue Report Form	
This form can be issued to inform management of a situation in which you experienced a level of fatigue that you considered highly uncomfortable or a particular risk to safety. This form is non-punitive and can be submitted anonymous. IT IS ADVISED TO USE THIS FORM AT THE MOMENT FATIGUE IS EXPERIENCED.	
<b>About the occurrence:</b>	
Date	
Approx. time	
Flight number	
How many hours had you been awake?	
How many hours of sleep did you have in the preceding 72 hours?	
How many time zones did you cross (cumulative hours) in the preceding 24 hours?	
How many days were you in the new time zone?	
<b>Self assess the fatigue level:</b>	
Please describe what level of fatigue you experienced (Samn-Perelli fatigue scale)	<input type="radio"/> Fully alert, wide awake. <input type="radio"/> Very lively, responsive, but not at peak. <input type="radio"/> Okay, somewhat fresh. <input type="radio"/> A little tired, less than fresh. <input type="radio"/> Moderately tired, let down. <input type="radio"/> Extremely tired, very difficult to concentrate. <input type="radio"/> Completely exhausted, unable to function effectively.
Please describe what level of sleepiness you experienced (Stanford Sleepiness Scale)	<input type="radio"/> Feeling active, vital, alert, or wide awake <input type="radio"/> Functioning at high levels, but not at peak; able to concentrate <input type="radio"/> Awake, but relaxed; responsive but not fully alert <input type="radio"/> Somewhat foggy, let down <input type="radio"/> Foggy; losing interest in remaining awake; slowed down <input type="radio"/> Sleepy, woozy, fighting sleep; prefer to lie down <input type="radio"/> No longer fighting sleep, sleep onset soon; having dream-like thoughts <input type="radio"/> I fell asleep
Please describe your fatigue in the past 24 hours in as much detail as possible.	
<b>Safety:</b>	
Please describe whether you think your fatigue could have been a risk to flightsafety	
Please describe what you think were the causes of your fatigue:	

Source: author