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Tomasz EWERTOWSKI, Marcin BERLIK
Poznań University of Technology (Politechnika Poznańska)

FATIGUE RISK MANAGEMENT OF THE OPERATOR BASED ON SELECTED EXAMPLES

Zarządzanie ryzykiem zmęczenia operatora na wybranych przykładach

Abstract: *The article presents issues related to methods of risk management related to operator fatigue. An organization that wants to safely carry out operational tasks need effective methods and tools for risk assessment in safety system to increase the chances and likelihood of the organization achieving its goals. In this case, it is about identifying the risk of fatigue at work, controlling it and minimizing its negative effects. The article presents, on the example of a pilot, the possibilities of managing the risk of fatigue at work, both in the reactive, proactive and predictive dimensions, using selected examples of methods and tools. The summary emphasizes the need for a systemic risk management related to fatigue at work.*
Keywords: risk management, fatigue, safety, human factor

Streszczenie: *W artykule przedstawiono zagadnienia związane z metodami zarządzania ryzykiem związanym ze zmęczeniem operatora. Organizacja, która chce bezpiecznie realizować zadania operacyjne potrzebuje efektywnych metod i narzędzi do szacowania ryzyka w systemie bezpieczeństwa, aby zwiększyć szanse oraz prawdopodobieństwo osiągnięcia przez organizację celów. W tym przypadku chodzi o rozpoznanie ryzyka związanego ze zmęczeniem w pracy, sterowanie nim i zminimalizowanie jego negatywnych skutków. W artykule przedstawiono, na przykładzie pilota, możliwości zarządzania ryzykiem jego zmęczenia w pracy, zarówno w wymiarze reaktywnym, proaktywnym, jak i predyktywnym, wykorzystując wybrane przykłady stosowanych metod i narzędzi. W podsumowaniu podkreślono konieczność podejścia systemowego do zarządzania ryzykiem związanym ze zmęczeniem.*
Słowa kluczowe: zarządzanie ryzykiem, zmęczenie, bezpieczeństwo, czynnik ludzki

1. Introduction

Fatigue affects the whole of human life. The physical and mental fatigue are distinguished. Both types of fatigue interpenetrate each other. Physical/mental fatigue occurs when a person's physical or psychological abilities are reduced due to improper rest as a result of reduced sleep, or physical or mental activity prolonging the awake period. The fatigue may additionally be described as a severe, cumulative and chronic one [1, 2, 15]. The sleep deprivation is one of the most important root causes of fatigue. In terms of safety, the worst case scenario is fatigue at work. The effects of fatigue can be particularly negative in professions such as machine and device operators who perform tasks having a direct and immediate impact on the environment. This group of operators includes persons controlling machines in motion, such as drivers and pilots. Fatigue at work is comparable to alcohol or drug use. The operator loses concentration, misjudges speed and distance, reacts more slowly, and in extreme cases can even fall asleep while performing duties. Particularly people working in shifts experience fatigue because their biological cycle is disturbed, which degrades their operation [10].

Fatigue at work is widely seen as a significant safety risk. The combination of the likelihood of an adverse event related to employee/operator activity due to fatigue and the severity of its effects are called risk of fatigue at work. This risk should be properly managed. The appropriate implemented risk management system allows to increase the chances and likelihood of the organization achieving the objectives.

2. Fatigue risk management

In aviation, the issue of fatigue and sleep deprivation is taken very seriously. Risks associated with fatigue are managed on the basis of appropriate methods and tools, referring to both the strategy of action and the decisions taken. Basically, based on the types of data used, we can distinguish three strategies for detecting and responding to fatigue - reactive, proactive and predictive.

3. Reactive strategy

The reactive strategy detects fatigue once its physical symptoms occur. However, it does not indicate the causes of fatigue, i.e. bad or inappropriate sleep. Actions in this strategy are taken only in response to symptoms [6]. These include:

1. EEG monitoring - is a non-invasive diagnostic method for testing bioelectrical brain function using an electroencephalograph. The test involves the placement of

electrodes on the skin's surface (a band or helmet is needed), which records changes in the electrical potential on the skin of head surface resulting from the activity of neurons indicating fatigue.
2. Psychomotor Vigilance Test (PVT) assessing psychomotor performance, which measures the response time for a series of characters presented on the screen.
3. Monitoring of operator's eye-opening percentage, e.g. PERCLOS (Percentage eye openness tracking).
4. Obtaining information by measuring sensors, for example, cameras recording unnatural operator movements such as nodding head, or rapid changes in the position of control elements (steering wheel or control stick).
5. Investigation of accidents and incidents with severe consequences, caused by fatigue [3].

4. Proactive strategy

A proactive strategy is a strategy in which actions are taken on the basis of past events, in particular those with low impacts to avoid high impact events [2]. This strategy uses the implementation of relevant regulations, tools and methods of risk assessment, analyzes the operator's sleep to indicate if and when fatigue occurs, generating information about the need for appropriate intervention. These include:

4.1. Regulations governing the operator's working and leisure time

Fatigue is often managed indirectly by the organization and regulators through the aspect of working time limitation, which is treated as the only option. Aviation, like any field related to the performance of work, is primarily subject to labor law. In Poland, the most important document in this respect is the Act of 26 June 1974 - Labor Law (Journal of Laws of 1974 No. 24 item 141 as amended). Article 129 §1 states that the working time may not exceed 8 hours a day and an average of 40 hours in an average five-day working week in the accepted reference period not exceeding 4 months. In addition, the article 132 §1 indicates that the employee has the right to at least 11 hours of uninterrupted rest each day. Of course, there are some exceptions to these provisions. The next legal act specifying the provisions in field of aviation is the Act of 3 July 2002 Aviation Law (Journal of Laws of 2002 No. 130, item 1112 as amended). It states in art. 103 §1 that the working time of aircraft crew members in air transport may not exceed 8 hours a day and on average 40 hours a week in the accepted reference period not exceeding 3 months. Art. 103 §2 states that for aircraft crew members in air transport, working time schedules may be extend to 18 hours a day in a long distance flight. In these schedules, working time may not exceed an average of 40 hours per week in the adopted reference period not exceeding 3 months. Importantly, work within the extended daily working time and an average of 40 hours per week in the adopted period does not constitute overtime work. The standardization of pilot's working time is further specified in Commission Regulation (EU) No 83/2014 of 29 January 2014 amending Regulation (EU) No 965/2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council. In this respect, the maximum daily flight period takes into account parameters such as the beginning of the flight period at the reference time and the number of flight sections completed at that time. In addition, acclimatization of crew members is considered. In military aviation, there is the NATO regulation related to aviation fatigue management - STANAG 3527. However, this document only sets monthly, quarterly and annual flight limits depending on whether one considers single or multi-person crew and whether the aircraft has a pressurized system. These limits are depicted in fig. 1.

Flying Hours	Flying Hours	Type of Aircraft	Type of Aircraft
	Single Pilot	Multi Pilot (unpressurized)	Multi Pilot (pressurized)
Per month	90	125	150
Per quarter	240	330	400
Per annum	850	1200	1400

Fig. 1. Limits of flying hours according to [12]

Specifying the remaining limits is the responsibility of NATO members. An example of the solution of daily limits for pilots are the regulations of the US Air Force Department in the instruction AFI 11-202 "General Flight Rules", which details the limits based on the type of aircraft on which the flights are carried out and whether they are performed by the basic or augmented crew. An illustration of these limits is given in tab. 1.

Table 1

Maximum flying duty period (FDP) according to [4, 5]

Aircraft Type	Basic Aircrew	Augmented Aircrew
Single Piloted Aircraft	12	NA
Fighter, Attack or Trainer (Dual Control)	12	16
Bomber, Reconnaissance, Electronic Warfare, or Battle Management (Dual Control)	16	24
Tanker/Transport	16	NA
Tanker/Transport with Sleeping Provisions[1]	16	24
Rotary Wing (without Auto Flight Control System)	12	14
Rotary Wing (with Auto Flight Control System)	14	18
Utility	12	18
Unmanned Aircraft System (Single Control)	12	NA
Unmanned Aircraft System (Dual Control)	16	NA
Tilt-rotor	16	NA
NOTE 1: *Sleeping provisions are crew bunks or other MAJCOM-defined rest facilities aboard the aircraft. Rest facilities should provide adequate privacy and noise levels to obtain suitable rest.*		

Unfortunately, the assumption that determining the maximum working time and minimum breaks and rest time between work is a guarantee of proper rest and lack of fatigue is roughly true only for physical fatigue, but it is not adequate for mental fatigue. It depends to a large extent on factors such as: quality and amount of sleep, time of activity (studies show that alertness and performance begin to decrease after a certain number of hours of activity) and the circadian rhythm (depending on the time of day). That is why the working and resting time is not the only factor associated with recovery from mental fatigue. Additional measures are needed to include mental fatigue in the risk assessment process.

4.2. Special matrices for estimating the risk of fatigue.

Taking into account the issue of mental fatigue in many countries, appropriate matrices are used in aviation to estimate the risk of operator's fatigue before performing a single flight operation. An example of this type of sheet is the matrix used in the United States Air Force USAF illustrated in fig. 2. Completion of such a sheet in accordance with the facts is the duty of the crew in the pre-flight preparation process. Another example of estimating the risk of mental fatigue is a simple assessment consisting of four steps determining the individual likelihood of fatigue used in Canadian civil aviation. This matrix can be printed on a card the size of a payment card and used by employees and managers to assess fatigue. It is depicted in fig. 3.

FATIGUE RISK FACTORS	LOW GREEN *0 Points*	MODERATE YELLOW *1 Point Ea*	HIGH ORANGE *2 Points Ea*
16+ hr Work/Duty Days Past Week	2	3	≥ 4
Combined Prior Sleep (past 72 hrs/3 days)	> 18 hrs	15-18 hrs	< 15 hrs
Combined Prior Wakefulness (past 36 hrs/1.5 days)	< 23 hrs	23-28 hrs	> 28 hrs
Sleep in Last 12 hrs	> 6 hrs	4-6 hrs	< 4 hrs
Sleep Quality	Excellent	Fair	Poor
Net Time Zone Crossings Last Duty Day (jet lag)	≤ 5	> 5	
	Score:**		

****Fatigue Scoring:** Total of all factors 7 or more: overall score SEVERE
- Any factor HIGH: overall score HIGH
- Total of all factors 4 to 6: overall score HIGH
- Total of all factors 1-3: overall score MODERATE
- Total of all factors 0: overall score LOW

Fig. 2. Fatigue Risk Management Worksheet according to [4, 5]

Individual Fatigue Likelihood

Step 1. Sleep in prior 24 hours

Sleep	<2h	3h	4h	5+h
Points	12	8	4	0

Step 2. Sleep in prior 48 hours

Sleep	<8h	9h	10h	11h	12+h
Points	8	6	4	2	0

Step 3. Hours awake since last sleep
Add one point per hour awake greater than sleep in step 2.

Individual Fatigue Likelihood

Step 4.
Add all points together to determine your score

Score	**Control Level**
1-4	Self-monitoring
5-8	Supervisor monitoring
9+	Don't start shift until fit for work

Refer to FRMS policy for detailed explanation of controls

Fig. 3. Individual Fatigue likelihood score (IFLS) according to [7, 8]

The disadvantage of these methods is the subjective assessment of fatigue status by crew members.

5. Predictive strategy

Predictive strategy analyses a person's sleep to determine if and when fatigue will occur, providing both advance notice for appropriate intervention, and root-cause treatment. As an objective method, it is free of previous flaws. These tools use a biomathematic modelling and computer algorithms to analyse a variety of sleep factors that can lead to desynchronization and sleep deprivation, increasing the likelihood of operator fatigue. Data related to the amount and quality of sleep should be obtained in a practical and reliable way. One of this type known solution is called The Fatigue Avoidance Scheduling Tool (FAST). FAST is a software decision support designed to estimate and predict changes in operator performance based on restrictions on the quality and amount of sleep and the circadian rhythm. The information obtained is useful for managers planning tasks and operators' rest, which can reduce the risk of fatigue errors [6]. However, the tool may not include solutions for each case or situation. FAST uses SAFTE (Sleep, Activity, Fatigue, and Task Effectiveness) model calculations developed by Steven R. Hursh [9]. It is based on the technique of recording and testing the activities of the human body during sleep, called polysomnography (headband) or more practical recording of day and night activity using a special motion measure called actigraph (wristband). Recorded data is transferred to the FAST application on a smartphone or tablet, which allows prediction of operator performance, which is a measure of cognitive alertness.

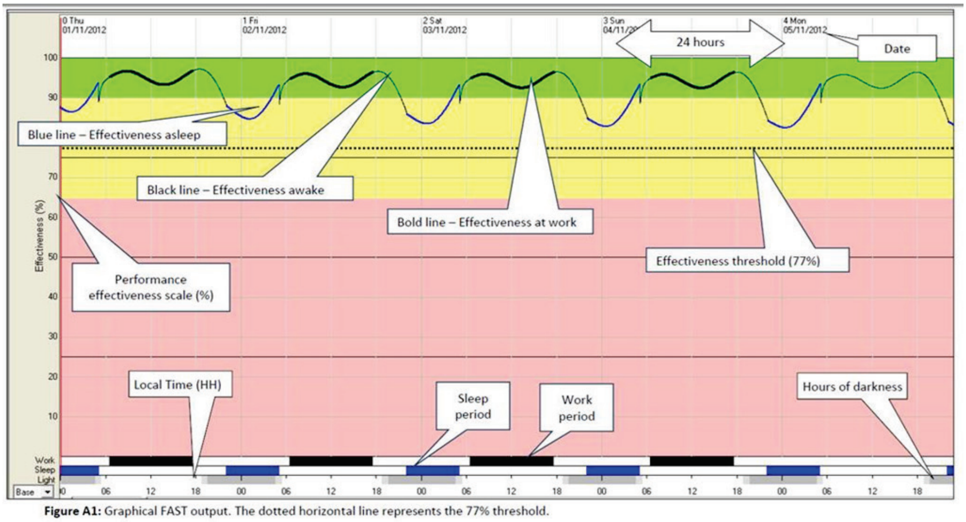

Fig. 4. Individual Fatigue likelihood score (IFLS) according to [9]

Figures 4 and 5 show examples of data for two situations. The fig. 4 shows the performance status of the operator who sleeps 8 hours at night and works 8 hours during the day. Work efficiency is shown in bold. Generally, the level of efficiency varies according to the sleep resources and the operator's circadian rhythm, decreasing during activity and increasing during sleep. The second situation illustrated in fig. 5 shows the state of the operator's performance who, well-rested, loses 8 hours of sleep at night. The performance drops suddenly below 75%. Recovery from a decline may take up to four days, providing 8 hours of sleep per night.

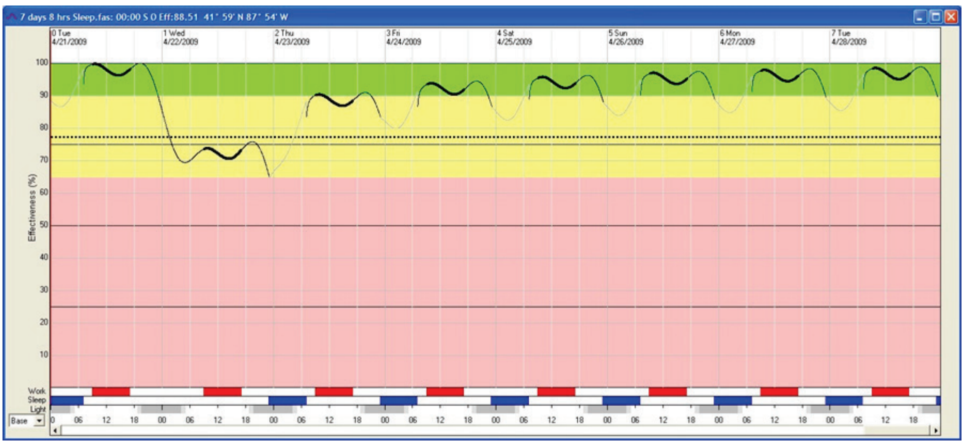

Fig. 5. Individual Fatigue likelihood score (IFLS) after losing 8 hours sleep according to [9]

6. Systemic risk management related to fatigue at work

The presented methods and tools as well as risk management strategies show various opportunities of risk estimation and decision making in this area. The use of these methods, tools and strategies each individually does not allow for comprehensive and holistic management using the principle of synergy. Only collecting all these elements together allows us to take full advantage of their capabilities and achieve the right effects. This ensures that the risk management system is properly implemented to increase the chances and likelihood of organizations achieving their goals. It is about recognizing the risk of fatigue at work, controlling it and minimizing its negative effects. The system can be defined as a combination of various elements into one structure linked with each other and forming a whole qualitatively different from the sum of the elements. An example of a such solution is the Fatigue Risk Management System (FRMS) implemented in Canadian civil aviation [7]. There are six main aspects to FRMS:

a) policies and procedures (an outline of top management's commitments in the area of fatigue risk management, and more detailed procedures at operational level);
b) responsibility (list of personnel responsible for designing, implementing and maintaining FRMS, and documenting the responsibilities of individuals and working groups);
c) risk management/estimation (planned vs current working hours, rest/sleep patterns, list of fatigue symptoms, incident reporting);
d) training (promotion of knowledge about the risks, causes and consequences of fatigue at work, providing training in fatigue management);
e) action and control plans (tools and methods used in FRMS, a clear decision tree when identifying hazards related to fatigue);
f) reviews and audits (documentation and collection of information at specified intervals, FRMS review based on audit results) [7].

The FRMS system is based on the hazard control model depicted in fig. 6. It shows the use of control measures to reduce the risk of fatigue. The model consists of six layers referring to the Reason Swiss cheese model. Some of them are active and some are latent.

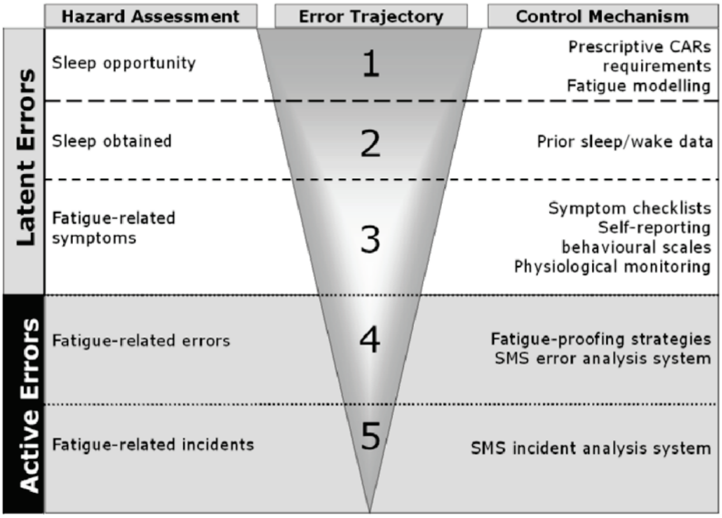

Fig. 6. Hazard Control Model for Fatigue Risk Management according to [7, 8]

The Fatigue Risk Management System (FRMS) as an integrated set of management policies, procedures and practices allows organizations to monitor and improve the state of safety caused by fatigue aspects. This increase in operating efficiency is illustrated in fig. 7.

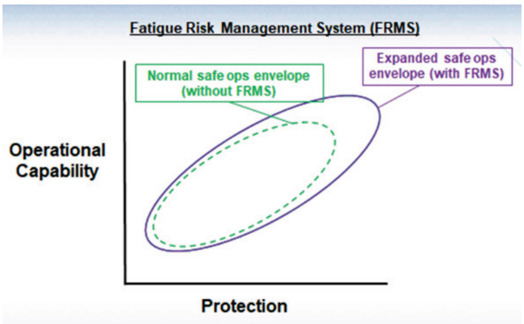

Fig. 7. Fatigue Risk Management System expanded envelope according to [7, 8]

7. Summary

The right amount and quality of sleep is crucial in terms of human effectiveness. Fatigue has a negative impact on the safety, productivity and health of employees. Modern technology allows not only to monitor the level of operator fatigue, but also to predict the possibility of adverse events associated with it. The appropriate implemented risk management system increases the chances and likelihood of organizations achieving their goals. It is about recognizing the risk of fatigue at work, controlling it and minimizing its negative effects. The most effective methods of operator's fatigue assessment are the objective methods using biomatematic modeling and computer algorithms to analyze various sleep factors that can lead to desynchronization and sleep deprivation, causing an increase in the likelihood of operator's fatigue. Basically, based on the types of data used, we can distinguish three strategies for detecting and responding to fatigue - reactive, proactive and predictive. The use of these methods, tools and strategies each individually does not allow for comprehensive and holistic management using the principle of synergy.

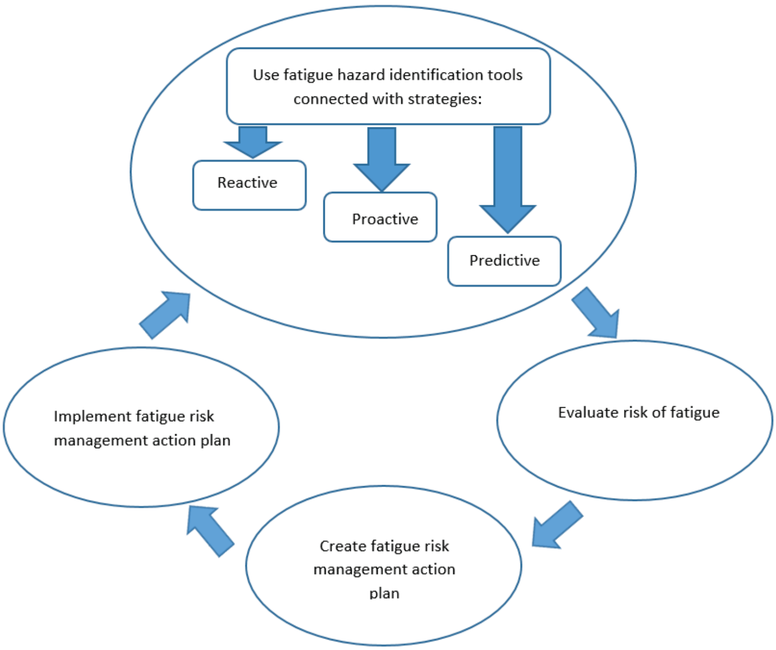

Fig. 8. Fatigue Risk Management Concept according to own elaboration

Only collecting all these elements together allows us to take full advantage of their capabilities and achieve the right effects. The proposed concept of fatigue risk management based on risk assessment process and Deming's cycle was depicted in fig. 8. Modern safety management systems should be dominated by a proactive and predictive approach, as expressed by FRMS. The Fatigue Risk Management System allows organizations to monitor and reduce fatigue hazards to the acceptable risk level.

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