Analysis on Flight Fatigue Risk and the Systematic Solution

Wang Lei and Sun Ruishan

Research Institute of Civil Aviation Safety,
Civil Aviation University of China
Tianjin, 300300, China
wanglei0564@hotmail.com

Abstract. The aim of this study was trying to analyze flight fatigue risks and find out a systematic solution for risk controlling. Firstly the model of Human Information Processing was introduced to analyze fatigue manifestations and risks in flight operation. Secondly causes leading to flight fatigue were specified from the 4 aspects of personal, organizational and social factors. Thirdly a framework of controlling flight fatigue risk was put forward in the systematic perspective. The framework contains three levels which are Fatigue Contributing Factor Level, Fatigue Measurement Level and Fatigue Prevention Countermeasure Level. Then a Fatigue Measurement and Warning System was worked out as a case study. Finally it concluded that flight fatigue is an important and long-term issue in aviation transportation industry, the systematic solution proposed in this paper is effective but there is a long way to go for implementing it.

Keywords: flight fatigue, risk, fatigue measurement.

1 Introduction

Fatigue refers to a degradation of mental and physical abilities and a demotion of emotional status due to the isolated or combined effects of insufficient sleep, working/resting against the body's natural circadian rhythms, and certain aspects of the work demands and workload such as time on task, ergonomic considerations and so on[1] [2].

Fatigue is a threat to aviation safety because of the impairments in alertness and performance it creates. Fatigue risk exists widely among flight and cabin crews, air traffic controllers, technicians, mechanics, dispatchers and ramp workers. Especially for pilots who should suffer the tire brought by sleep loss, night and shift work, and long duty cycles, and also the pressure of remaining alert by their actions, observations and communications. For example, fatigue played an important role in the crash of Comair Flight 5191, according to the report of US National Transportation Safety Board (NTSB) report where pointed out that lack of sleep hindered the performance of three important players in the crash – the captain, the co-pilot and the air traffic controller [3].

The Federal Aviation Administration (FAA) has now recognized that "incorporating fatigue risk management systems into everyday operations is the ultimate goal, but

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doing so will take innovation in addressing a myriad of regulatory issues" [4]. Not only in US, but also in other countries or organizations the fatigue issue attracted more and more attentions in recent years. European Aviation Safety Agency (EASA) also implemented new regulation on Flight Time Limitations (FTL) for controlling flight fatigue in 2010, International Air Transport Association (IATA) established its own FTL Task Force under its Operations Committee and International Civil Aviation Organization (ICAO) proposed to mandate pilot fatigue risk management and addressed crew member fatigue in regulation [5] [6] [7].

Fatigue risk management system (FRMS) currently is seen as a popular tool and has been applied in aviation industry of many countries. But mostly this kind of system was developed by just consideration of one or two fatigue contributing factors such as flight and duty time limitations. Generally to say, fatigue risks exist in aviation industry universally and chronically. Especially in the countries or regions where there is large air traffic volume or air transport volume is increasing rapidly, the fatigue problem is becoming more visible and serious. So it needs to explore a more systematic and effective solution to solve it.

2 Fatigue Manifestations and Risks

The definition has indicated that fatigue is one kind of human mental or physical state, so individuals play a critical role when they face fatigue. Some research has pointed out that fatigue can manifest itself both physically and psychologically. Physical manifestations were demonstrated as general feeling of tiredness, nodding off / inadvertent napping, slowed reaction time, growing and irresistible need to sleep and so on. Mental manifestations were demonstrated as difficulties in memorizing information, lack of concentration, slow understanding, and poor decisions and so on.

After analyzing on lots of flight incidents related to fatigue, we found that most of crew personal errors always happened in every link of human information processing. Therefore we tried to use a Model of Human Information Processing to illustrate fatigue influences on operator [8] [9]. The model is as following and the fatigue influences in every stage were listed.

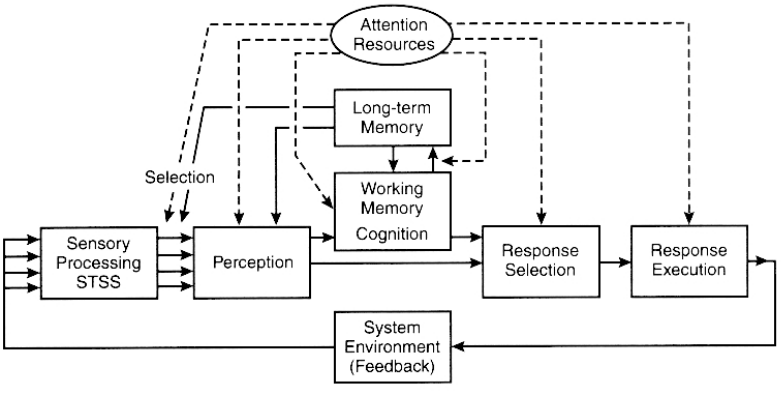

Fig. 1. Human Information Processing Model

Table 1. Fatigue Manifestations in Information Processing

Stage of Information Processing	Fatigue Manifestations
Perception	• Diminished vision • Lack of awareness • Slow understanding
Attention	• Channeled concentration • Easily distracted by unimportant matters • Impossible to be distracted • Reduction in vigilance
Memory	• Short-term memory problems • Difficulties in memorizing information • Diminished standards
Response selection	• Poor judgment • Poor decision-making • Slowed reaction time
Response execution	• Diminished motor skills • Slow reactions

As seen from above analysis, the main harmful result of fatigue is its impairment on information processing ability and performance, and then further leading to occurrence of human errors. Meanwhile it should be noted that these manifestations are just the external features of fatigue. In fact, the risk arising from fatigue is the outcome of a chain of preconditions and contributing factors. Fatigue risks exist in personal level, organization level and even beyond where there are contributing factors. For example, Holmes and Stewart (2008) indicated that "fatigue risk" is not a simple reflection of how fatigued an operator (pilot, AME) or a team of operators is; rather, it depends on how fatigue interacts with operational processes and in turn threatens the integrity of the operation as a whole[10]. Obviously fatigue problem is complicated that we should find a systematic solution to control the risks it arouses. We will analyze the contributing factor in detail in next section.

3 Statistics and Contributing factors of Fatigue

3.1 Statistics

Although estimates vary, official statistics indicate that fatigue is involved in at least 4-8% of aviation mishaps. Lyman and Orlady (1980) showed that fatigue was specifically implicated in 77 (3.8 %) of 2,006 incidents reported by pilots to NASA's Aviation Safety Reporting System (ASRS) [11]. When the ASRS analysis was expanded to include all factors that could be directly or indirectly linked to fatigue,

incidents potentially related to fatigue increased to 426 (21.2 %). Since NASA added a fatigue category in June 2009 there have been more than 200 reports from flight crew members concerned about fatigue affecting work performance and safety.

A study in Victoria found that approximately 70 deaths and 500 serious injuries occur each year in road accidents as a result of fatigue [12].

The incidents regarding with crew factors which happened in Chinese civil aviation from 2006 to 2010 were analyzed and the statistic result shows that there were 3 incidents (3.9%) caused by pilot fatigue directly. There is also a typical case of flight accident happened in July of 1992 in Nanjing airport, the fatigued crew members did not execute checklist carefully and have not found the stabilizer was set in a wrong position when they took off. It leads to aircraft crash and 106 passengers were killed. Except for this case, there are several cases that fatigue made an indirect influence such as the Captain left cockpit for sleep. Seen from reports of Sino Confidential Aviation Safety reporting System (SCASS), the reports related to flight duty time hold a great proportion (around 25%) among total pilot reports.

Major problems with statistics relating fatigue to accidents and incidents include the lack of a coherent definition of fatigue itself and the absence of a reliable and valid assessment tool to measure it retrospectively. Fatigue is generally difficult to investigate on a systematic basis and to code in databases. Therefore, any statistics related to fatigue and incidents/accidents are likely to be an underestimate and should be interpreted as such.

3.2 Contributing Factors

The contributing factors of fatigue are various in the commercial aviation environment and there have been many research outcomes which mostly were focusing on analysis of sleep loss, circadian disturbances and so on. In this research we tried to find out the deep reasons leading to fatigue in an integrated perspective and analyze these contributing factors from the 3 levels which are social level, organizational level and personal level.

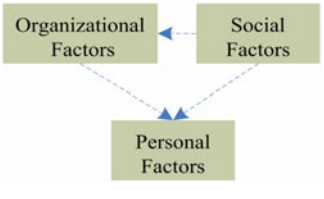

Fig. 2. Three Levels of Fatigue Contributing Factors

As showing in Fig.2, individual is the last level facing fatigue and also the most important defense line to fatigue meanwhile. Combining with previous research and incident analysis results, we listed all contributing factors as following table.

Table 2. Fatigue Contributing Factors

Level	Fatigue Contributing Factors
Social factors	• Recognition degree of administration • Regulations and policies • Social competition pressure • Interpersonal relationship • Social activity
Organizational factors	• Fatigue management measures • Flight shift arrangement • Working area and environment (flight deck) • Human resources (pilot numbers and quality) • Fatigue reporting mechanism • Safety culture (positive reporting culture) • Fatigue education and training
Personal factors	• Sleep loss • Circadian Disturbances • Medical factors • Physical factors (Health state) • Psychological factors (ability of information processing) • Emotional factors • Age and gender • Diet factors • Team factors (ability of cooperation)

4 Integrated Framework of Managing Flight Fatigue

The analysis results show that the flight fatigue was caused by multi-level factors and the controlling flight fatigue risk is a systematic engineering. So finally this paper puts forward a framework of preventing flight fatigue incidents in the systematic perspective.

The framework model contains three levels which are Fatigue Contributing Factor Level, Fatigue Measurement Level and Fatigue Prevention Countermeasure Level. The function of Contributing Factor Level is to reveal the total personal and environmental factors causing flight fatigue, the Fatigue Measurement Level aims to develop and find new method or technique to monitor flight fatigue in real time and in a period. The Prevention Countermeasure Level is the last and critical level founded on the former two levels.

The contributing factors of fatigue were classified into social factors, organizational factors and personal factors which were discussed carefully in last section. Here what needs to be reinforced is the relationship existing among the 3 factors. Social factors and organizational factors may lead to fatigue by influencing personal physical and mental state. For example, bad shift arrangement and unexpected social activity both will cause sleep loss in some extent. The psychological pressure from social competition or family life also will affect personal fatigue accumulation.

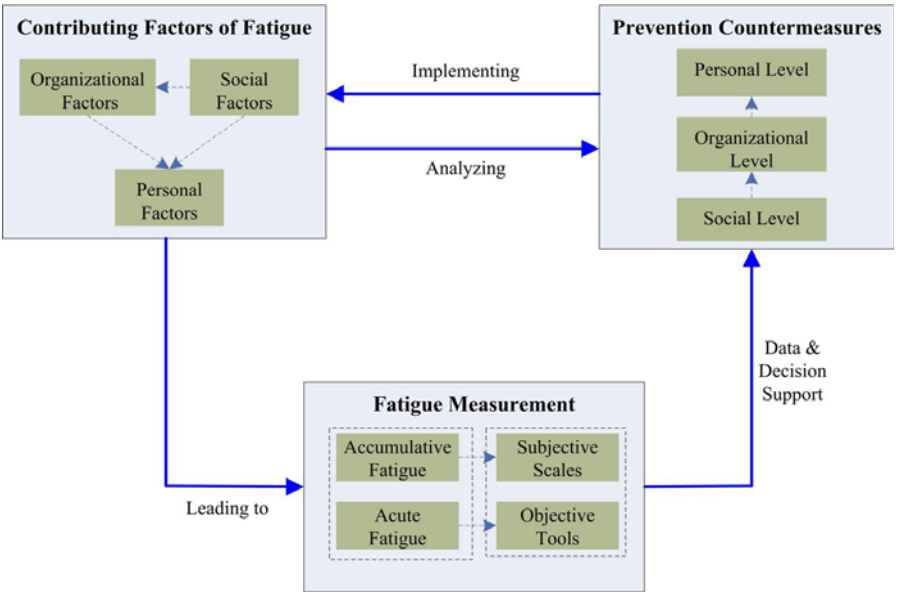

Fig. 3. Integrated Framework of Managing Flight Fatigue

Table 3. Fatigue Countermeasures in Systematic Perspective

Level	Countermeasures
Social Level	• Regulations and requirements from administration • Actions of controlling fatigue risk (assessment, audit, investigation and so on) from administration • Develop voluntary reporting system of fatigue incident • Social concern and understanding on pilot
Organizational Level	• Develop and implement Fatigue Risk Management System • Make rational shift plan for pilot • Create comfortable flight deck environment (temperature, no smoking, space for rest or nap and so on) • Nourish positive safety culture • Ensure enough human resources and training
Personal Level	• Keep effective sleep (duration and quality) • Maintain regular circadian rhythm • Obtain adequate rest and recovery (proper nap) • Report errors and incidents caused by fatigue • Keep healthy and steady psychological state • Be cautious to use of medicine and alcohol drinks • Keep a healthy dietetic habit (avoid high fat and high carbohydrate foods)

In the Fatigue Measurement Level, two ways of fatigue measurement were proposed to be applied into practice together. One of them is subjective scales to measure accumulative fatigue and the other one is objective tools to measure acute or real time fatigue. The results of the two measuring ways should be analyzed in an integrated perspective and then expected to provide data and decision-making support for fatigue prevention.

In Prevention Countermeasure Level, we put forward that fatigue prevention countermeasures should be found from the three levels corresponding to fatigue contributing factors. Here we list these countermeasures generally.

5 Case Study-Fatigue Measurement and Warning System

Fatigue measurement is a key link in the fatigue management framework because it can provide objective data for decision-making of fatigue prevention. Here a prototype of Fatigue Measurement and Warning System which we designed and developed was introduced as a case.

Combining with face recognition and eye tracking technique, a framework of real time Fatigue Measurement and Warning System (FMWS) was proposed out as follow figure.

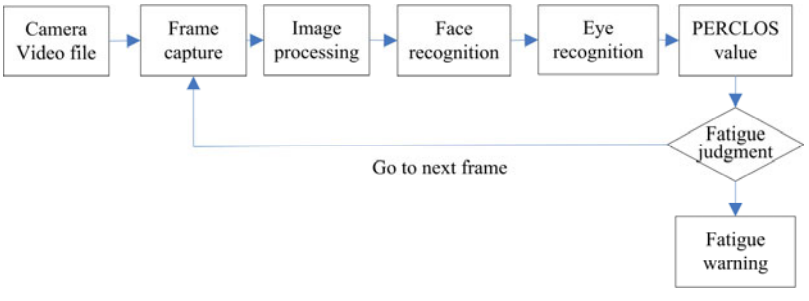

Fig. 4. Framework of Fatigue Measurement and Warning System

The system consists of four components: face detection, eye detection, eye tracking, and fatigue detection. Firstly a frame of image will be captured from an ordinary camera or video files. The first frame will be processed by using image process methods and then used for initial face detection and eye location. If any one of these detection procedures fails, then go to the next frame and restart the above detection processes. Otherwise, the current eye images are used as the dynamic templates for eye tracking on subsequent frames, and then the fatigue detection process is performed. If eye tracking fails, the face detection and eye location restart on the current frame. These procedures continue until there are no more frames. When all frames in a time limit were detected over and a statistic regarded with eye-closed frames will be made later. The statistic value is called PERCLOS which is an accredited threshold of judging fatigue.

Based on above framework, we used Visual C++ and Open CV as tool and finished the developing of prototype system. The main interface of the FMWS is as the following figure. It was tested in laboratory environment and proved to be effective and extensible for applying into practice.

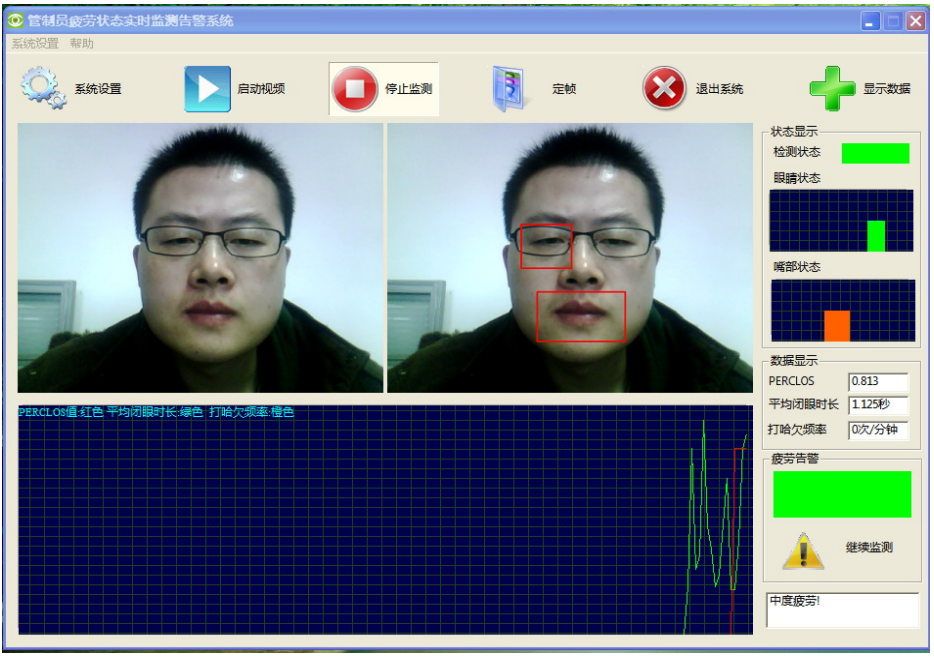

Fig. 5. Interface of Fatigue Measurement and Warning System

6 Conclusions

Flight fatigue is a stubborn but very significant issue in aviation transportation industry. The main viewpoint of this paper is to illuminate that it requires a systematic solution for controlling of flight fatigue risk. Based on this idea, we started this research and the main works are concluded as following.

1) Fatigue manifestations and risks were listed out basing on flight incident analysis and a model of Human Information Processing was introduced to illustrate fatigue influences on operators. Fatigue always makes negative affecting on information processing of human.
2) The statistic on incidents showed that fatigue is a universal and realistic problem existing in many countries and areas. But the problem probably is more serious than what we expected because of the statistic limitations.
3) The contributing factors of fatigue were analyzed from three aspects. Then a framework of preventing flight fatigue was put forward in the systematic perspective. The framework model contains three levels which are Fatigue Contributing Factor Level, Fatigue Measurement Level and Fatigue Prevention Countermeasure Level.
4) A prototype system (FMWS) was designed and worked out. This system is a key component of flight fatigue management and expected to be perfected and applied into use.

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