Fatigue Assessment Methods Applied to Air Traffic Control – A Bibliometric Analysis

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Abstract. The International Civil Aviation Organization (ICAO), which supervises the activities and provision of air services, as well as Brazil which is a signatory, issued a formal recommendation pointing fatigue as a criterion of high impact on aeronautical activities and in maintaining the safety of aircraft operations. The proposing management of human fatigue following scientific principles in two approaches: one prescriptive, which stipulates regulatory prescriptive limits, and the other, not mandatory, for data monitoring through a system called FRMS (Fatigue Risk Management System). This article is a bibliometric study on the scientific production in fatigue applied to air traffic control. A bibliometric survey was conducted on three databases "SCOPUS", "ENGINEERING VILLAGE", and "WEB OF SCIENCE", resulting in only 7 documents. Though a survey in other web sources, books, and international regulations was conducted, resulting in 13 methods. Among the subjective methods are: Sleep diaries; Visual Analogue Scale to Evaluate Fatigue Severity (VAS-F); Karolinska Sleepiness Scale (KSS); Samn Perelli Scale (SPS); Epiworth Sleepiness Scale; Stanford Sleepiness Scale. By the results, subjective methods have advantages, such as speed and ease of administration, application on paper or computer, the minimal interruption to the crew, many studies have used SPS and KSS and provide data for comparison. And, disadvantages, such as: relatively easy to cheat, may not have face validity. Until this moment, prescription limits have been adopted in Brazil following regulations, but the fatigue assessment and monitoring phase are still in the study and implementation strategy phase.

Keywords: Bibliometric study · Fatigue · Assessment methods · Air traffic control

1 Introduction

1.1 Problem Statement

The International Civil Aviation Organization (ICAO), which governs and supervises the activities and provision of air services, as well as Brazil which is an ICAO's signatory, issued a recommendation that formally points out fatigue as a criterion of high impact on aeronautical activities and in maintaining the safety of aircraft operations. The proposing

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management of human fatigue follow scientific principles in two approaches: one prescriptive, which stipulates regulatory prescriptive limits, and the other, not mandatory, for data monitoring through a system called FRMS (Fatigue Risk Management System).

According to the ICAO, fatigue is a physiological state of reduced capacity for mental or physical performance resulting from loss of sleep or prolonged wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair alertness and ability of a crew member to safely operate an aircraft or perform safety-related tasks.

Nevertheless, the contributions of factors related to fatigue at work vary considerably between individuals and can be influenced by aspects of the tasks performed, the scheduling of work shifts, the routine, predictability, and planning of the work performed [1].

Among the activities carried out by the air traffic controller are: ensuring that aircraft fly safely, maintaining minimum regulatory separation; following complex operational procedures that are constantly changing (routes, levels, meteorological changes, availability of airport for landing, emergency declarations by aircraft, traffic prioritization, among others) and perform the control of aerodromes (TWR), of approach to terminal areas (APP), area control centers (ACC) and also air defense (CoPM). The controller is the one who makes the final decisions and in a limited time [2].

Also, it must consider that the responsibility for the effectiveness and success of a fatigue management program is shared by the organization and its employees. Therefore, among the measures adopted in an ATC fatigue risk management are reliable and qualified reports with details of sources of hazards; adopt a management committee; commitment of employees with senior management; continuous monitoring; adherence to a reactive investigation process to safety events and, consequently, compliance with safety recommendations, specifically the dissemination of best practices and information; adoption of a training and awareness program; and, effective application of standardized procedures and commitment to continuous improvement [3, 4].

In the study carried out and documented in this article, it was possible to verify few referring works in the field of ATC fatigue management. Among the methods, there are also different approaches, and it is necessary a method that better integrates human factors and is officially recognized for fatigue analysis.

Although scientific methods of fatigue management are already widely recognized in the field of aviation, it was found that this reality is not the same for the control of air traffic, given the few articles found.

Thus, it was possible to verify that there is still a research field for measuring the fatigue of air traffic control operators in Brazil and worldwide, about the scientific principles that must be considered when talking about a fatigue risk management program human.

1.2 Objective/Question

ICAO edited the Fatigue Management Guide for Air Traffic Services Providers [3], or Annex 11, noting that signatory countries should carry out these regulations as of 05/Nov 2020.

In this scenario, this article proposes a bibliometric study on the scientific production in fatigue applied to air traffic control.

At the end pointing out several methods, which most consider aspects of sleep loss and recovery, the biological circadian clock, as well as the impact of the activity and its workload.

1.3 Methodology

In the study of methods for fatigue analysis, bibliometric research was initially used, classified as a quantitative technique, which uses mathematical and statistical methods to quantify the production, dissemination, and use of previously registered information [5].

Bibliometrics consists of a set of laws and empirical principles that contribute to establishing the theoretical foundations of Information Science, a term used for the first time in 1922 by E. WyndhamHulme [6].

A bibliometric search was carried out to verify which assessment methods could be used to manage the fatigue applied to air traffic controllers.

In this way, the search scope was limited to three databases "SCOPUS" (7 documents), "ENGINEERING VILLAGE" (5 documents), and "WEB OF SCIENCE" (no document). The terms used were ("fatigue management" AND "ATC") OR ("fatigue management" AND "Air Traffic Control") OR ("fatigue management" AND "ATM"), resulting in only 7 documents, revealing the need for a more comprehensive search.

The 7 articles found covered subjects such as Samn Perelli Scale (SPS); FRMS as a monitoring tool; fatigue monitoring technologies with methods of assessing working hours, fatigue symptoms and real sleep time; human voice analysis system, which confirmed to measure the degree of activity fatigue.

Thus, through other web sources, books, and international regulations, 13 methods were found, and as described in this article.

2 Results

2.1 Identified Methods

There are different ways to measure fatigue, either in the laboratory or in an operational context, with methods:

Objectives, such as Temperature Measurement; Biological tests; Actigraphy, which is a simple test to detect changes in sleep and circadian rhythm [7]; Polysomnography, which is a non-invasive exam to measure respiratory, muscle and brain activity, in addition to other parameters, during sleep [8, 9]; Simple mental tasks; Complex behaviors.

Moreover, the following subjective methods:

- Sleep diaries analysis, which are records of sleep and waking periods, over a period of days and even weeks [10].
- Visual analog scale to assess fatigue severity (Visual Analogue Scale to Evaluate Fatigue Severity, VAS-F), which uses a scale composed of 18 items related to fatigue and energy, with simple instructions, minimal time and effort. In addition, it compares favorably with the Stanford Sleepiness Scale Standard and the Profile of MoodStates [11].

- Karolinska Sleepiness Scale (Karolinska Sleepiness Scale, KSS) is often used to study sleepiness in various contexts [12].
- Samn-Perelli Scale (Samn Perelli Scale, SPS) classification of the level of attention at seven points before a period of sleep (pre-sleep) and after (post-sleep). Considering: 1. Totally alert, wide awake; 2. Very excited, receptive, but not at the peak; 3. Okay, but little rest; 4. A little tired; 5. Moderately tired, disappointed; 6. Extremely tired, very difficult to concentrate; 7. Completely depleted, unable to function effectively.
- The Epworth Sleepiness Scale (ESE) is a questionnaire completed by the patient himself, whose objective is to determine a general measure of the degree of daytime sleepiness in adults. The subject provides a score, quantifying his sleepiness in monotonous situations of daily life. The main superiority of ESE is its simple, fast application, enabling its use in extensive population studies.
- The Stanford Sleepiness Scale (Stanford Sleepiness Scale), developed by Dement and colleagues in 1972, is a self-report questionnaire that measures sleepiness levels throughout the day. The scale, which can be administered for 1 to 2 min, is generally used to track general attention at each hour of the day.
- The Psychomotor Vigilance Test is a task with sustained attention and reaction time that measures the speed with which individuals respond to a visual stimulus. Research indicates that increased debt or sleep deficit correlates with impaired attention, slower problem solving, decreased psychomotor skills, and an increased rate of false responses. The PVT was developed by David F. Dinges and popularized for its easy scoring, simple metrics, and convergent validity.
- Fatigue Audit InterDyne Biomathematic Model (FAID), software for implementing Fatigue Management through quantification that relates the scheduling of tasks and the hours worked (that is, the start or end time of work periods).
- Biomathematic Model Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) is a computer model that predicts changes in cognitive performance, based on sleep or wake time and the body's internal clock. It contains a circadian process, a circadian propensity to sleep process, an asleep fragmentation process, and a phase adjustment feature for time zone changes.
- Commercial Model System for Aircrew Fatigue Evaluation (SAFE), is an acronym for the Air Crew Fatigue Assessment System: a computer program that includes a set of algorithms that allows evaluating a series of factors that influence the alertness in the crew.
- Commercial Model Aviation Fatigue Risk Model (CAS-5) is a fatigue management software specially optimized for planning the scale of the crew of airlines.
- Circadian Performance Simulation Software (CPSS) business model is designed to predict the effects of sleep or wake times and exposure to light on the human circadian cycle, and the combined effects of the circadian phase and homeostatic sleep pressure on cognitive performance and subjective alert.
- Health and Safety Executive (HSE) model, supported by fatigue management software, constitutes a mathematical basis for assessing the level of fatigue using the analysis of the shifts of the scales, it serves to analyze engineering jobs, in aviation and other professions that deal with complex performance and safety systems, scale routines and fatigue management.

In addition to the methods, it is important to relate the risk analysis of the operation. Table 1 provides some examples of mitigations at the organizational level to manage fatigue risks, giving scope for further studies, as this is not an exhaustive list.

Table 1. Examples of fatigue hazards and operational controls for mitigation [3].

Hazards of fatigue	Controls	Mitigations
Many hours of service	Limit the number of hours of operational service	Have restrictions on operational procedures with minimal opportunity for deviation
Few hours between shifts	Have minimum time requirements between the shift and the start time of the next shift	Programming software programmed to prevent shift assignment with less than the required free time
Many shifts in the week of 7 days	Limit the number of shifts eligible for work in a work week	Ensure that employees have time to replenish the sleep facility, essential for the job
Position during low circadian times	Allow employees the opportunity to sleep restfully before and/or after likely circadian casualties	Ensure that ATCs have ample opportunities for break during shifts and ample sleep opportunities between scheduled shifts
Sleep opportunities after the night shift	Ensure minimum clearance after the night shift	Have limits on shift assignment after the night shift, that is, another night shift or day off the next day

2.2 Discussion

In accordance with the results, subjective methods have advantages, such as speed and ease of administration, application on paper or computer, the minimal interruption to the crew, many studies have used Samn Perelli Scale - SPS and Karolinska Sleepness Scale - KSS and provide data for comparison. And, disadvantages, such as: relatively easy to cheat, may not have face validity, they do not always reliably reflect objective performance measures [13].

Fatigue needs to be assessed as part of a program to identify the level of risk, effective monitoring, and relevant mitigation measures. According to ICAO, it means having a data-driven means to continuously monitor and maintain safety risks related to fatigue, based on scientific principles and knowledge, as well as operational experience that aims to ensure that professionals are performing tasks at appropriate levels of alert [3]. In line with the research, the importance of considering operational aspects related to the execution of the control activity in the operational environment, as well as the organizational aspects, became evident.

3 Conclusions

The issue of implementing a Fatigue Management System is under discussion in several countries and the objective of this article is to concentrate on identify which assessment methods would be effective considering that the concept of fatigue covers several aspects (circadian cycle, sleep-wake cycle, and workload). In this way, a more reliable accurate assessment, encompassing several methods, as presented, the different instruments can only assess specific aspects.

Another important point to be discussed concerns the workload aspect. According to the regulatory documents covered, the workload covers three important aspects that influence the performance of the controller: the nature and amount of work to be done (including time on the task, difficulty, and complexity of the task and intensity); time constraints (including whether the time is driven by task demands, external factors or the individual); and, factors related to individual performance capacity (experience, skill level, effort, sleep history and characteristics of the circadian cycle).

When this article was written, there was still no valid regulation on Risk Management for fatigue in Brazil. In November 2020, the Airspace Control Department (DECEA) published the standardization through a CIRCEA 100-89 that provides for mandatory prescriptive limits for fatigue management in ATC; as well as MCA 81-1 which aims to establish the procedures and processes related to Fatigue Risk Management in the ATC bodies, structured by each operational body according to its complexity and must undergo prior authorization.

This bibliometric study was efficient in that it was able to identify the most applied fatigue assessment methods. Moreover, it is important to highlight that the measurement of fatigue in the context of air traffic control must comply with a management system in order to identify the level of related risk, the monitoring, and the relevant mitigation.

Until this moment, prescriptive limits in accordance with regulations have been adopted in Brazil, but the fatigue assessment and monitoring phase are still under study and implementation strategy. There is still no experimental research to answer this question, as it is still being studied.

Therefore, its effectiveness can only be verified if all the agents involved share responsibilities (regulators, Air Navigation Service Providers, and controllers) and are involved in the management processes in order to contribute to occupational health, quality of life, and maintenance of adequate levels of safety.

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