Roster and Air Traffic Controller's Situation Awareness

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Abstract. Fatigue has been identified as a leading contributor to incidents and accidents within high-risk industries, in particular, the aviation sector. Traditional approaches used to mitigate fatigue, predominantly for air traffic controllers and flight crew, have largely focused on duty time limitations. FRMS is a data-driven means of continuously monitoring and managing fatigue-related safety risks, based on scientific principles and knowledge as well as operational experience, which aim to ensure relevant personnel are performing at adequate levels of alertness. It allows operators to adapt policies, procedures and practices to the specific conditions that create fatigue in a particular aviation setting. The ages of 36 participants in this study were from 23 years to 58 years old. The results demonstrated that ATCO's alertness indicate as functioning at a high level of alertness between 9 am and 5 pm during working hours. ATCOs' alertness levels deteriorated between working day-1 to day-5. Furthermore, there are significant differences over the 8 working hours per day among 5 working days. Particularly, the 6th, 7th and 8th working hours demonstrate much worsened alertness on day-4 and day-5. The pro-active approach of FRMS is to increase ATCOs fatigue resilience to cope with demanding situations while ATCOs are on position and while resting on breaks. FRMS is data driven, and data is collected from the operation, fatigue management decisions are made against this data, and the measurements that are required can be identified and implemented to improve the safety of operations.

Keywords: Air traffic management · Fatigue Risk Management · Human performance · Safety Management System · Situation awareness

1 Introduction

Fatigue Risk Management Systems (FRMS) came into being in the context of outcome-based regulation and Safety Management System (SMS) in the 1990s. Regulators and operators had concerns about the human and financial costs associated with fatigue and began to identify fatigue as another risk that could be managed using a systematic approach. Fatigue Risk Management progressively crystalized and today can be defined as explicit and comprehensive processes for measuring, mitigating and managing the actual fatigue risk to which an organization is exposed [1]. Factors that cause fatigue, such as circadian rhythm, sleep homeostasis and task-related influences have been demonstrated to have negative impacts to pilot's performance, thus creating

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safety concerns in the aviation domain. In order to manage adverse consequences of fatigue, airlines have to implement fatigue risk management systems for flight crew and flight attendants. An FRMS, which is a scientifically-based on data-driven process, represents an alternative to the traditional prescriptive hours of work limitations. It manages employee fatigue in a flexible manner appropriate to the level of risk exposure and the nature of the operation. However, there are many FRMS variations for airlines pilots but not many for air traffic controllers. Therefore there is a need to develop an FRMS to optimize ATCOs' performance and increasing ATCOs' wellbeing.

1.1 Understanding the Impacts of Fatigue

Fatigue is a common complaint with a prevalence between 6.0 and 7.5% in Britain and the United States. A cross-sectional survey of United States workers found the two-week period prevalence of fatigue to be 38%, with an estimated annual cost to employers exceeding $136 billion in lost productive work time [2]. Fatigue has been identified as a leading contributor to incidents and accidents within high-risk industries, in particular, the aviation sector. The traditional approaches applied by regulators to mitigate fatigue, predominantly for air traffic controllers and flight crew, have largely focused on duty time limitations. However, these were often based more on the outcome of industrial negotiations, rather than being supported by scientific research. Fatigue is a complex physiological and psychological entity, it has negative affects to human operators in different ways and is influenced by numerous inputs, often outside the direct managerial responsibility or control of the employer. After some significant accidents, there has been a move to change the focus of fatigues analysis and mitigation towards managing the risk related to fatigue in a more scientific and evidence-based way.

Although fatigue is understood to have led to many aviation incidents and accidents, quantifying the exact share of fatigue as per these events is problematic because of the challenge of collecting hard evidence. Having this highlighted, fatigue is undoubtedly well established as a causal factor for many safety-related events. The negative effects of fatigue contribute to a general reduction in human performance, overall health drawbacks, and other social implications at the far end. Human operators experiencing fatigue may suffer from decreased decision-making skills, memory, judgment, reaction time and situational awareness. Compounding this is the fact that the effect of fatigue means that none of these symptoms may be apparent to the sufferer. Fatigue as a major symptom is found in all populations and is associated with multiple factors. Fatigue can be manifested as difficulty or inability initiating activity (perception of generalized weakness); reduced capacity maintaining activity (easy fatigability); and difficulty with concentration, memory, and emotional stability (mental fatigue) [3]. Duration of fatigue can be recent (less than one month), prolonged (more than one month), or chronic (over six months). The presence of chronic fatigue does not necessarily imply the presence of systemic exertion intolerance disease (SEID), also known as chronic fatigue syndrome (CFS).

1.2 Fatigue Risk Management in Flight Operations

FRMS is a data-driven means of continuously monitoring and managing fatigue-related safety risks, based on scientific principles and knowledge as well as operational experience, which aim to ensure relevant personnel are performing at adequate levels of alertness. It allows operators to adapt policies, procedures and practices to the specific conditions that create fatigue in a particular aviation setting. Operators may tailor their FRMS to unique operational demands and focus on fatigue mitigation strategies that are within their specific operational environment. As in Safety Management System, the FRMS relies on the concept of an "effective reporting culture and active involvement of all stakeholders where individual personnel have been trained and are constantly encouraged to report hazards whenever observed in the operational environment [4].

Fatigue, psychosocial workload and insufficient sleep have been recognized as a major concern of increased work intensity amongst working populations. Changes in the global economy and working life have increased the speed of business processes and the emergence of an increasingly '24/7 society' [5]. In addition, the need to increase work force flexibility and productivity has lengthened the average work day, shortened average recovery times and increased the irregularity of start and finish times. Indeed, fatigue is a common, almost universal feature of modern life. The effects of fatigue can vary but are best viewed as a continuum, ranging from mild, infrequent complaints to severe, disabling manifestations including burnout, overstrain, or chronic fatigue syndrome. The influence of fatigue on reduced individual performance that leads to incidents and accidents is well documented. NASA Ames Research Centre considers the role of fatigue in accidents as the contributory or causal role that fatigue may play in an accident is often underestimated or potentially ignored [6]. The U.S. National Transportation Safety Board has continually listed fatigue as one of its 'most wanted' safety improvements since 1996. According to Rosekind, a fatigue specialist and NTSB Board Member who proposed that it's not like you can't make decisions, it's just that you make bad decisions [7]. Extrapolating this analogy to the wider airline community, means that all levels of staff are vulnerable to the negative effects of fatigue and are generally worst placed to identify the problem.

1.3 Fatigue Risk Trajectory

Scheduling factors and non-scheduling factors are two useful categories to frame causal factors of fatigue in aviation. Scheduling factors are primarily connected with the rest periods and working intervals experienced by flight crew [11]. Operator fatigue in high risk industries is increased by extended time awake and reduced prior rest. In addition, changes in time-zones can present complex interactions between circadian lows and fatigue, further degrading performance [8]. In aviation, some of the present rules or proposed modifications of rules are in conflict with one or more of these factors [9]. The operational time limitations review panel organized by EASA [10] documented the key factors that can cause fatigue for flight crew members. There are multiple layers that precede a fatigue-related incident which are identifiable hazards and controls. An effective FRMS should attempt to manage each layer of risk as shown as Fig. 1. Dawson has described a multi-layered system of defenses based on assessing fatigue hazard and control mechanism [5]:

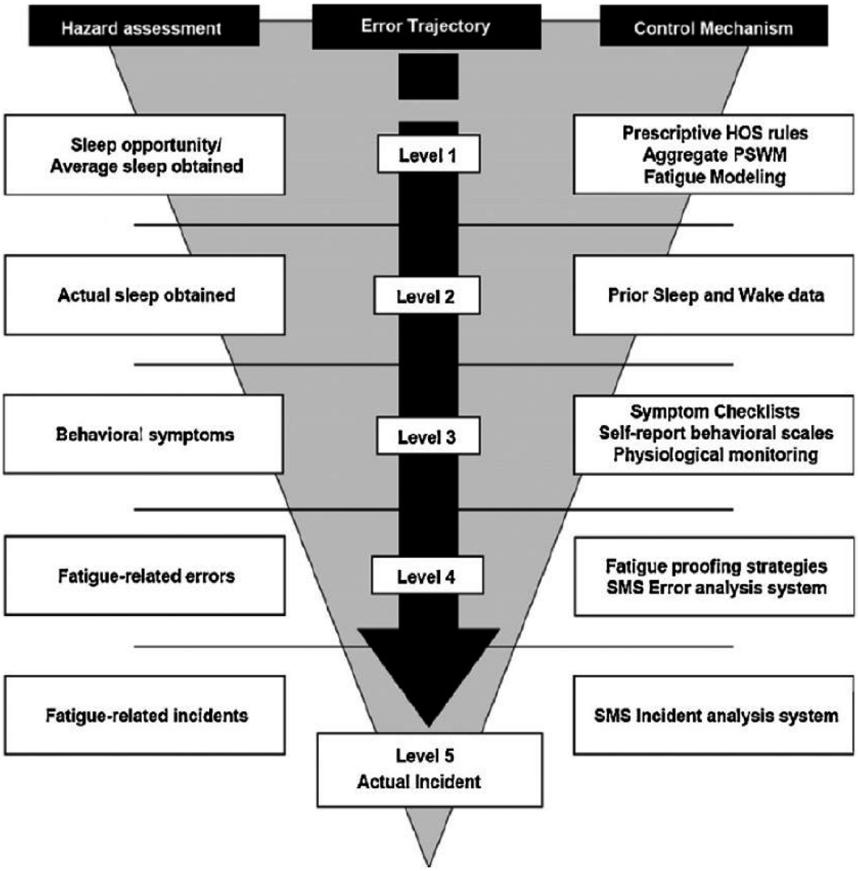

Fig. 1. Fatigue risk trajectory [13]

Level 1. Sleep opportunity afforded employees by the schedule.
Level 2. Actual prior sleep-wake behaviour experienced by the individual.
Level 3. Signs and symptoms of fatigue experienced by the individual.
Level 4. Nature, extent and preventability of fatigue-related errors.
Level 5. Fatigue-related incidents as organizational learning opportunities.

FRMS includes an accountable manager, who is ultimately accountable for fatigue risk, and it needs to exist within a just culture in which employees and management trust one another and information about fatigue is openly reported. A primary reason why FRMS is supposed to deliver enhanced protection against fatigue risk is because it measures actual risk and establishes tailored controls to mitigate or eliminate risks. Sleep is a key variable when considering the cause of fatigue in its most general sense [11]. The daily quantity of sleep required varies from one individual to the next, but on average it is eight hours [12].

2 Method

2.1 Participants

36 ATCOs participated in this research including 7 female and 29 male controllers. The ages of participants were from 23 years to 58 years old. The experiment process was reviewed and approved by the Research Ethics committee. The research objective is to offer the best rostering for ATCOs, and to provide the best approach for Fatigue Risk Management.

2.2 Alertness Rating Scale

The alertness rating scales start from 1 (the highest alertness) to 7 (the lowest alertness) contained 24 h a day for 8 days. The alertness can be divided into seven levels from 1 (the highest alert) to 7 (the lowest alertness) based on ATCO's experience while working on the position, meeting, taking breaks, at home including domestic activities such as watching TV, gardening, cleaning, cooking…; and other activities including social activities such as; gym, socializing, and exercising (Table 1). It is not required to indicate the alertness level for sleep (Table 1). This is a quick and easy way to assess ATCO's alertness levels while ATCOs are working and reflect the living patterns of day-to-day activities. This research only focused on ATCO's alertness level during their working hours on duty, as ATCO's alertness level reflect to situation awareness and therefore the potential impact on aviation safety.

Table 1. Example of alertness rating scales in ATM

	day-1	day-2	day-3	day-4	day-5
1am	S	W 1	S	S	W 2
2am	S	W 1	S	S	W 2
3am	S	W 2	S	S	W 3
4am	S	W 3	H2	S	W 4
5am	S	W 4	W 2	S	W 5
6pm	S	W 4	W 3	H1	W 6
…	H 1	W 3	W 3	W 1	W 5
…	H 1	W 3	W 4	W 2	W 4
11pm	O 1	H 4	W 4	W 2	H3
12pm	O2	H4	W4	W3	H3

2.3 Research Design

The participants were invited individually to a meeting room to receive instructions of how to use the alertness rating scales (Table 1) including 24 h a day across 5 shifts of working days in total. ATCOs have to record their alertness levels for each hour either working (W), social activities (S) or at home (H) using a7-points Likert scales. There is no requirement to indicate sleep (S) on the Likert scale, as the hours of sleep are considered as no alertness. Furthermore, ATCOs were encouraged to provide their feedback to develop the best practice of fatigue risk management to the project manager. There are demographical diversities of participants including male vs female, experienced ATCOs vs novice ATCOs, married vs not married, with children vs without children etc. It is a form of qualitative research consisting of interviews in which ATCOs been asked about their perceptions, opinions, beliefs, and attitudes towards the policy, procedures, training program and mitigation strategy regarding roster and fatigue risk management.

3 Result and Discussion

Participants' level of alertness is related to situation awareness on the controller working position. The collected data included 24 h among 5 shift working days shown as Fig. 2. The scheduled working hours over the 5 shift days are shown as following, day-1 from 13:30 to 21:30; day-2 from 14:30 to 22:30; day-3 from 07:45 to 16:00; day-4 from 06:30 to 13:30; and day-5 from 22:30 to 06:30. Scheduling factor is a useful category with which to frame causal factors of fatigue in aviation domain. Scheduling factors are primarily connected with the rest periods and working intervals experienced by operators [11]. Operator's fatigue in high risk industries is increased by extended time awake and reduced prior rest. In addition, changes in time-zones can present complex interactions between circadian and fatigue, further degrading situation awareness and human performance [8].

3.1 Roster Impacts to ATCO's Situation Awareness

The results demonstrated that ATCO's alertness is at a high level of alertness between 9 am and 5 pm during working hours (Fig. 2). A sample of these results further emphasized influences of time of day, time on duty, the complexity of tasks in one shift, the timing of sleep prior to duty starting, and effect of consecutive late finishes on fatigue. It was found that the effect of time of day was highly significant, and closely reproduced the trends observed under laboratory conditions, with lowest levels of alertness in the late night and early morning (23:00–05:00). The changes with time on duty were also highly significant, and this is critical factor on the design of roster for ATCOs.

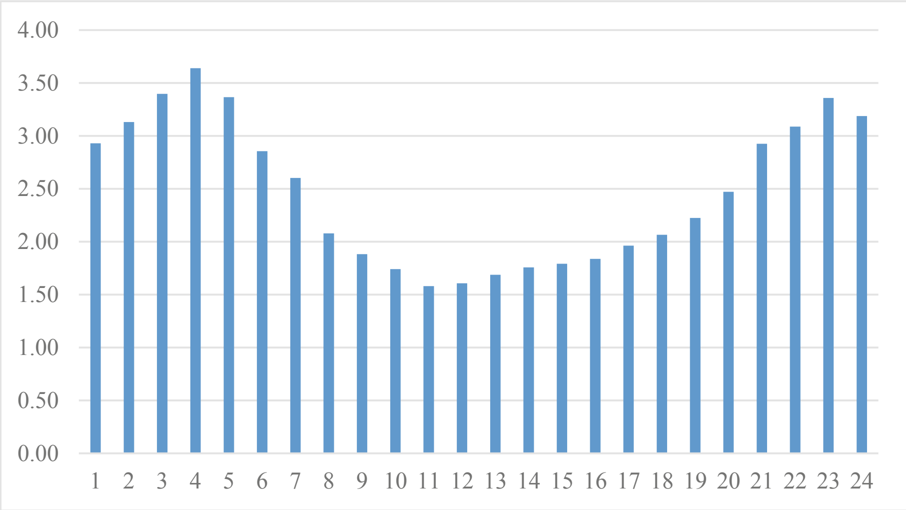

Fig. 2. The fluctuation of ATCO's alertness level among 24 h (1 indicates the highest alertness, 7 indicates the lowest alertness)

3.2 ATCO's Alertness Levels Among Shift Works

ATCOs' alertness levels deteriorated from working day-1 to day-5. Furthermore, there were significant differences during the 8 working hours among the 5 working days. Particularly, the 6th, 7th and 8th working hours, where alertness levels are much worse on day-4 and day-5 (Table 2). This is a safety concern as the rest time between day-4 and day-5 is only 9 h which does not provide sufficient sleep to maintain high alertness for high quality monitoring performance. Moreover, the working hours on both day-3 and day-5 include early morning and late night duty commencements. Sleep loss, and the resultant fatigue, both acute and cumulative, increases the experience of sleepiness, tension, confusion and decreased vigor. As little as two to three hours sleep loss on a single night can produce measurable increases in fatigue and resulting performance impairment on a variety of tasks both in the lab and in real-world settings. Further reductions in sleep or extensions in wakefulness can produce increasing levels of performance impairment similar in nature to moderate alcohol impairment. At more than 40 h of wakefulness, the resulting cognitive impairment can be both profound and debilitating [11, 13]. Hartzler [9] demonstrated that 24 h of continuous wakefulness was associated with significant deterioration on measures of reasoning and vigilance. The dangers associated with this level of impairment are then compounded by the fact that fatigued individuals are typically unaware of how severely their performance has deteriorated and thus may believe that they are safe to perform their duty when they are not [14, 15].

Table 2. ATCO's alertness levels among 5 shifts of working days

Age	Experience	Gender	1	2	3	4	5
58	38	1	2.28571	3.55556	2.44444	2.88889	5.33333
52	28	1	2.125	1.5	1.44444	1.5	1.5
43	23	2	1.125	1.33333	1.25	1.44444	1.44444
46	24.5	2	1.22222	1.22222	1.125	1	2
34	3	1	1.125	1	1.25	1.42857	2
39	15	1	1.625	1.25	1.875	1.90909	3.33333
29	3	1	1.5	2	2.25	2.625	4.5
32	10	1	2.3	1.75	1.375	2.125	3.42857
48	28	1	1.33333	1	1.375	1.33333	1.33333
47	24	2	1.25	1.25	1	1.22222	1.16667
42	20	2	1.44444	1.57143	1.44444	1.55556	1.55556
30	9	1	1	1.14286	1	1	1.125
49	30	1	1.125	1.125	1.25	1.14286	1.375
40	17	1	1	1	1.16667	1.55556	3
41	20	1	1.5	1.33333	1.33333	1.72727	3.83333
32	13	1	1.71429	1.75	1.75	1.5	1.42857
32	4	1	2.44444	2.125	2.44444	2.33333	4.16667
45	24	1	1	1.33333	1	1.11111	No Data
42	20	1	1.2	1.22222	1.125	1.41667	3.25
35	1	1	2.5	2.5	2.42857	2.6	3.83333
48	20	1	1.55556	1.625	2.11111	1.42857	No Data
55	37	1	2.33333	2.22222	3.22222	3.54545	4.66667
34	1	2	1.625	1.625	1.125	1.42857	1.42857
44	16	1	3	2	1.77778	2	2.55556
45	24	2	1.33333	1.5	1.75	2	2.33333
50	31	1	1.33333	1.33333	1.33333	1.2	1.5
42	19	1	1.125	1	1.625	1.1	2
42	18	1	1.22222	1.88889	1.55556	2	2.5
47	24	1	1.375	1.75	1.125	1.75	2.72727
23	1	1	1.5	2.25	3.11111	3.27273	5.5
39	17	1	2	3.33333	4.3	3.8	4.57143
46	23	2	3	2.75	2.75	3.11111	3.83333
47	23	1	1.55556	2.33333	1.44444	1.81818	2.83333
49	25	1	1	1.33333	1.14286	2.27273	3.5
37	8	1	1.33333	1.42857	1.22222	1.33333	3.42857
41	13	1	1.625	1.5	1.25	1.125	1.125

(green ball indicates high level of alertness, yellow ball indicates middle level of alertness, red ball indicates low level of alertness)

4 Conclusion

The effects of fatigue can vary but are best viewed as a continuum, ranging from mild, infrequent complaints, to severe, disabling manifestations including burnout, overstrain, or chronic fatigue syndrome. In spite of the complex nature of fatigue, the operational implications are strikingly consistent across diverse types of air traffic controllers. Based on the findings of this current research, it is impossible to develop a roster to satisfy all controllers, as each individual ATCO has differing preferences for a roster schedule catering to different genders, ages, marriage, family sizes and patterns of life. The operational demands in air traffic management continue to change in response to changes in volume of aircraft, new technology (remote tower) and commercial pressures (cost-efficiency), however human physiology remains unchanged. Both prescriptive fatigue management regulations and FRMS represent an opportunity to use advances in scientific understanding of human physiology to better address fatigue risks for ATCOs. The research has identified some concerns regarding the interval times between day-4 and day-5. Arguably, there is no evidence to suggest that the roster has directly affected the safety of service delivery over the duration of the established roster within the organization. The pro-active approach is to increase ATCOs fatigue resilience to cope with demanding situations while ATCOs are on the position and while resting on breaks. FRMS is data driven, and data are collected from the operation, fatigue management decisions are made against this data, and the measurements that are required can be identified and implemented to improve the safety of operations.

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