Lappeenranta – Lahti University of Technology
School of Engineering Science
Software Engineering
Master's Programme in Software Engineering and Digital Transformation

Bibek Bam

Framework for identifying Fatigue Characteristics of Aviation Cabin Crew's Risk Management Systems

Examiner : Professor Ajantha Dahanayake

Supervisor : Irem Cevik (MSc) Turkish Airlines

ABSTRACT

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Fatigue in aviation is a hazardous concurrence that has troubled the industry for a long time. It has compromised safety and has cost the aviation industry a great sum of financial asset. Mainly circadian rhythm has been identified as a culprit in over the years with new risk factors being identified gradually. FRMS and SMS had been made a necessity in aviation all over the world.
In the research, the framework for accessing fatigue is developed showcasing its risks and characteristics using design science research method for artefact development. The framework tries to predict fatigue in cabin crew before work initiation in hopes to avoid any risks that may arise. A handful of variables declared in the research alongside with the other procedures of aviation can help to counter or mitigate fatigue. Validation with case study shows the framework to be useful due to the inclusion of multi variables, but a live test would still need to be conducted to see its potential and efficiency.

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LIST OF SYMBOLS AND ABBREVIATIONS

AIAA	Institute of Aeronautics and astronautics
CASA	Civil Aviation Safety Authority
CFF	Critical Flicker-Fusion Frequency Test
CFS	Chalder's Fatigue Scale
DSR	Design Science Research
ECA	Euro Cockpit Association
EEG	Electroencephalography
FAA	Federal Aviation Authority
FAID	Fatigue Audit InterDyne
FAST	Fatigue Avoidance Scheduling Tool
FIT	Fatigue Index Tool
FLT	Flight Time Limitation
FRMS	Fatigue Risk Management System
FSS	Fatigue Severity Scale
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IS	Information System
KSS	Karolinska Sleepiness Scale
PSG	Polysomnography
PVT	Psychomotor Vigilance Task
SAFE	System for Aircrew Fatigue Evaluation
SAFTE	The Sleep, Activity, Fatigue and Task Effectiveness
SARP	Standard and Recommended Practices
SLR	Systematic Literature Study
SMS	Safety Management System
SPI	Standard Performance Index
SPS	Samn-Perelli seven point scale
SSP	State Safety Program
SSS	Stanford Sleepiness Scale
VAS	Visual Analogue Scale

1 INTRODUCTION

The aviation industry has identified "*Fatigue*" as a prime factor for most if not all of the problems which have arisen due to flight crew. There have been many incidents in the aviation industry where fatigue has been pointed a prime factor or cause for it. In recent years the global airline industry has even started to conceptualize and adopt different means of guidelines to minimize fatigue in crew members.

1.1 Background

The literal meaning of fatigue as prescribed by oxford Dictionary is - Extreme tiredness resulting from mental or physical exertion or illness.

International Civil Aviation Organization (ICAO) defines fatigue as – "*a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety-related duties*"[1].

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[4]. Although easily overlooked and taken sceptically, fatigue relates to many performance losses and contributes to workplace hazards[3].

According to US Federal Aviation Authority, fatigue is defined as a condition which is characterized by increased discomfort with and lessened capacity for work, reduced work efficiency, loss of energy or capacity to respond to stimulation, and is usually accompanied by a feeling of weariness and tiredness.[22]

Many organizations suffer from the impact of fatigue on their employees and none of which are beneficial to the organization. As identified through the definitions - everyone is well aware of themselves and their mental and physical conditions but due to the scepticism and ignorance, overlooking of the hazards that fatigue causes lead to many mishaps, accidents and other unfavourable conditions. After many encounters with problems related to fatigue, nowadays it is finally being taken seriously and many measures to either prevent fatigue or to counter it are being placed in various agencies and organizations.

Fatigue Risk Management System(FRMS) is a branch of safety research and science which plays a vital role in this. FRMS is defined as a scientifically-based, data-driven addition or alternative to prescriptive hours of work limitations which manages employees fatigue in a flexible manner appropriate to the level of risk exposer and the nature of the operation[2] [5]. There are various methods or applications in use for the FRMS in the industry which the research will subsequently deal with.

1.2 Objectives

The prime goal of the thesis is to collect and analyse the findings to formulate a framework representing FRMS characteristics for the aviation cabin crew members. There are mainly FRMS for the pilots that are prevalent, suggesting them as a prime candidate for the Fatigue risk. On the contrary, this research will disregard the pilots and primarily focus on the cabin crew for the analysis and result. The framework should encompass not only the medical statistical data for the evaluation but should also include and look into other various factors/elements that play a vital role in the determination of fatigue in cabin crew and propose a solution.

Thus, the following research questions are addressed in this research:

1. What are the fatigue characteristics of the airline cabin crew?
2. What should constitute the framework for the identification of fatigue characteristics for FRMS?

1.3 Research Methodology

To detect and evaluate the available materials concerning Fatigue in aviation cabin crew Systematic Literature Review(SLR) is used and for the artefact generation, Design Science Methodology is adopted.

All the documents reviewed and chosen for the literary work of the thesis have been selected with the utmost care, keeping in mind the border of the topic itself. Various databases are taken into account whilst searching for the literature with keywords such as Fatigue in aviation, Fatigue management system, Symptoms/causes of fatigue, Fatigue in Cabin crew, FRMS, monitoring fatigue, mitigating fatigue. As a result, a large number of sources are found and from these, snowballing is done to further narrow down the literature to find desired content suitable for the thesis.

Mainly the LUT online database (LUT FINNA) and google scholar is used along with others such as IEEE, Science Direct, Springer, Elsevier, ResearchGate.

The design science approach is used to further develop an artefact for the thesis work. A nominal DSRM process is shown in the figure below:

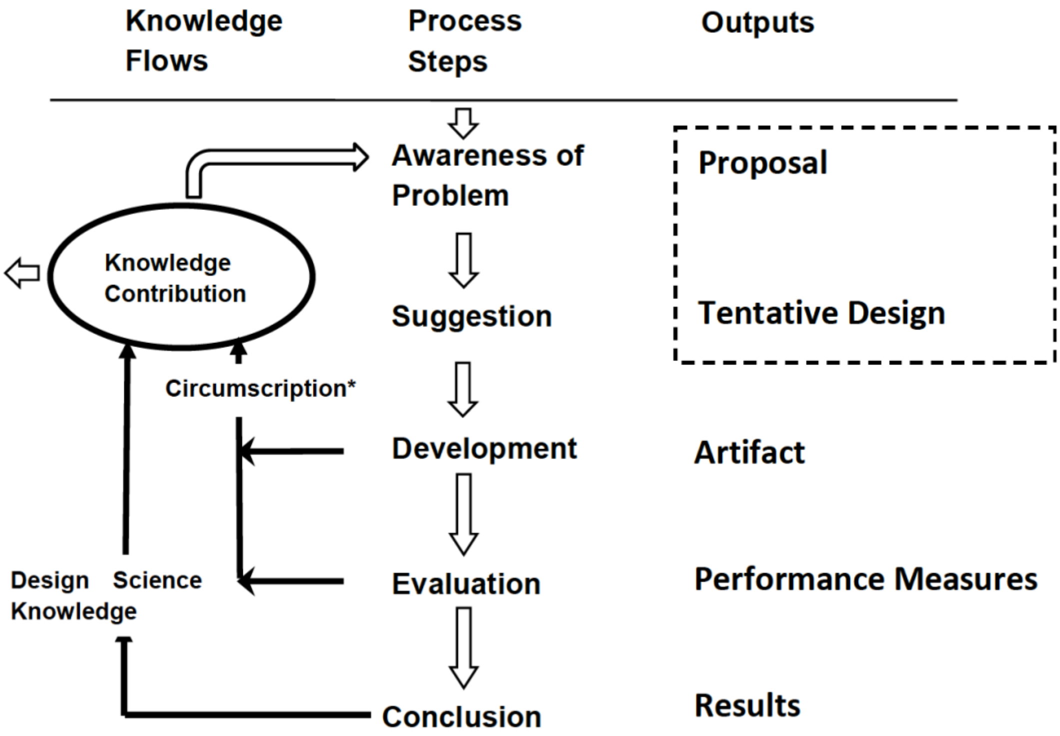

Figure 1: Design Science Research methodology[93]

Component of the above model is described using details from [93]

Awareness of problem: identification of any problem can arise from various means. Normally the output is a proposal for new research. For this research, background ideas are explained in the introduction section. The motivation is to seek a better way of characterising fatigue and try to mitigate and prevent fatigue efficiently.

Suggestion: normally the functionality is anticipated looking at new ways or existing elements. On the research, the suggestion is taken from existing elements but in hopes to better them. this is elaborated in the objectives part.

Development: the main idea of this phase is the actual development of artefact and implementation. The provisional design is expanded and constructed productively into a complete design. On the research, the artefact is developed using the resources and ideas jotted down in the section.

Evaluation: after the construction of an artefact it needs to be validated and evaluated through different means. The research uses a previously made standard model for evaluation of the artefact as well as a localised case study for the purpose of validation.

Conclusion: this is the final phase and although there might be some abnormality from the proposed initial estimates, there is still a good result to follow through with the proposal. In the research, this constitutes the result that satisfies most of the proposed design but has some limited infrastructures. Further, the artefact here needs to be tested in a live environment to better understand it's working.

1.4 Structure of the Thesis

The thesis starts with introduction which details briefly the topic at hand. Secondly the literature review follows, presenting the previous work on the topic which acts as the groundwork for the thesis. The chapter two continues with the literature and some foundation for the paper's management digging into more of some background studies. The third chapter deals with the main topic at hand and works into the development of the framework systematically. This chapter is followed by the validation of the developed framework. Finally, concludes with conclusion and limitations of the research.

2 Related literature Review

The succeeding subsections will deal in more depth about the issue at hand concerning fatigue, fatigue risk, fatigue in Aviation and crew, causes, symptoms and consequences of fatigue, monitoring fatigue concerning factors of fatigue , some fatigue management tools currently in use and counter measures for fatigue. We also look briefly into the design science research method, this is used for formulation of an artefact for the result of the thesis by taking in all the gathered information from the literature in the later section.

2.1 History of Aviation

The earliest record of any type of aviation related invention dates back as much as 1000 BC, where; to scout for troops the Chinese invented kites which carried the men. American Institute of Aeronautics and astronautics(AIAA) has provided a very detailed historical collection of the aeronautics and astronautical incidents in https://www.aiaa.org/about/History-and-Heritage/History-Timeline#Top. These information has been taken as reference to build a historical timeline in a tabular form, where only the most recognizable incidents of aeronautics/ aviation are depicted to limit the information surge.

Table 1: Records of Aviation achievements[92]

TIME STAMP	INCIDENTS RELATED TO AVIATION
1000 - 1300 BC	Chinese invented kites for scouting troops, Witnessed by Marco Polo
1488-1514	referencing bird wings, Leonardo Da Vinci formulates model for first flying machine
1600s	Hezarfen Celebi attempts first flight by jumping from a tower at Galata. Royal Society of Great Britain passes out papers on aeronautics and hopes to gain more information through research
1709	model hot air balloon demonstration to King John V
1784	Joseph Montgolpher takes flight with six passengers
1799	concept of fixed wing aircraft is invented by Sir George Calay
1804	first successful model glider is built and flown by Sir George Calay
1852	steam engine powers first airship

1884	experiments on curved airfoil shapes conducted in wind tunnel by Horatio Phillips
1889	"Bird flight as basic aviation" Book published, containing measurements of drag and lift of wings (which are concept of airfoils even today)
1896	first successful launch(flight) of large steam powered model aircraft by Samual P. Langley
1899	Wilbur Wright confirms his thoughts on human flight by writing to Smithsonian Institute
1900	Zeppelin first flight(airship with large rigid metal structure)
1902	Wright brothers make changes to their initial glider on wings and tail fins for better control
1903	first test flight of wright brothers flying machine on Dec 14 is unsuccessful. However on Dec 17 the wright flyer takes off ground at 10:35 am for 12 seconds, which makes it first powered, manned and heavier than air controlled flight.
1904 - 1905	the second iteration of wrights flying machine accomplishes initially a flight of 45 mins and subsequently completes a circular flight in Dayton
1905	in October the Flyer III (the wright Brothers plane) flies for 24 miles
1906	first official flight in Europe is recorded which lasted for 8 seconds
1908	Wilbur Wright's first flight in Europe first demonstration flight for army at fort myer
1909	First international aviation competition in France
1910	hydro-aero plane is developed by Gleen H. Curtiss first night flight conducted first successful carrier take-off
1911	first amphibian type aero plane demonstration fitted with wheels and floats first transcontinental flight
1913	development of gyroscopic compass and gyroscopic stabilizer development of "aviaphone"(airphone) which enabled communication between pilot and passengers
1914	inauguration of first four-engine aircraft
1916	William E. Boeing constructs and test flies his first aero plane communication between in-flight aero plane via radio for the first time
1919	First sustained international commercial passenger air service initiated
1927	water cooled engines replaced by air cooled engines making aero planes less heavier and faster
1934	Air mail act- provision for appointment of Federal Aviation Commission signed

1935	first successful passenger airline take off
1936	Lockhead Aircraft corporation built world’s first pressurized cabin plane
1940	Boeing Stratoliner takes flight being the first airline with a pressurized cabin. Flight upto 20000 ft.
1949	prototype flight of first commercial jet aircraft
1954	Boeing 707 test flight
1956	first ever air traffic accident killing 128 passengers
1957	Boeing 707 first flight marking era of jet airways for passengers
1958	NASA commences operation The Federal Aviation Administration(FAA) established
1962	First flight of Boeing 727
1966	Jumbo Jet (Boeing 747) revolutionizes air transport
1969	first flight of Concorde
1970	Jumbo jet commences its passenger service
1974	Airbus A300B2 starts its services
1976	first supersonic passenger service operated
1994	Boeing 777 becomes first aircraft designed entirely on a computer and conducts its maiden flight
1997	First flight of Boeing 737 - Next Generation aircraft
2003	final flight of the supersonic jet Concorde
2005	Airbus A380 double deck super jumbo(commercial aircraft) makes its maiden flight
2010-2011	Boeing 787 makes appearance first commercial flight of Boeing 787 on October 26,2011
2014	Global airline accident rate hits record low The European Aviation Safety Agency(EASA) approves Airbus A350-900 for passenger flights FAA certifies Airbus A350
2015	FAA introduces and switches to newer air traffic control system called En Route Automation Modernization(ERAM)
2016	report of no fatal accidents(loss of life) globally from a commercial jetliner accident attributing to pilot error, jet malfunction
2020	report on commercial plane crash drop 50% in 2019 Boeing completes first test flight of world's largest twin-engined jetliner 777X

2.2 Fatigue

The oxford dictionary defines fatigue as the tiredness due to mental or physical exertion. And many if not all industry's definition of fatigue revolves around the same idea. Fatigue is regarded as one of the prime factors relating to human errors causing a decrease in cognitive tasks and higher-order intellectual processing[6]. Fatigue is also described as a physiological state of reduced mental or physical performance capability that can weaken a person's alertness and ability to perform duties[1]. So in layman term, we can say that – if a person is exhausted, tired or unable to properly address various actions and function he/she is fatigued. But it is not limited to a single symptom but comprises of a combination of symptoms such as impaired performance, slower reaction time, impaired judgement, increased probability of falling sleep, subjective feeling to drowsiness, etc.[5]. Similar to stress, fatigue can pile up and grow as each small incident/ factor provides fuel for it, thus fatigue can either be short-term(acute) or long- term(chronic) [6].

Some of the earliest studies done on fatigue date back to the 20th century where mental fatigue is taken into consideration but later on during the 1913 focus is shifted to the psychological aspects[14]. Even with such early identification of fatigue, the topic remains new to this day, since the risks it poses are varying and the measurement of fatigue is complicated.

2.3 Fatigue in Aviation crew

ICAO regards fatigue in crew members as a major human hazard factor because it affects most aspects of a crewmember's ability to do their job. It, therefore, has implications for safety and thus must be treated accordingly.[7] Fatigue has always been a concern in aviation [8], there have been various cases where accidents have occurred and the exact causes have been unclear. One of the earliest cases, where fatigue might have played a role in aviation disaster is recorded in 1928[8]. The paper "*Human Fatigue and The Crash of Air Italia*" presents the case of air Italia which crashed during the return flight from the north pole in 1928[8][10]. The author here presents how being awake for almost 3 days led to bad judgement of situation during flights, causing a fatal accident that haunted the industry. It has also been reported that almost 70% to 80% of aviation accidents involve human errors[11][12]. It has long been pointed out that - long work hours, fluctuating work schedules, insufficient sleep lead to various negative effects, which are the prime reason for aviation errors and accidents[13]. Although preventive measures as flight time limitations, layover durations and aircrew sleep recommendations are developed as early as the 1930s, there have only been few changes to such measures since their introduction[13].

2.4 Some notable problems and accidents reported in aviation

Although with the advancement in technology and implementation of strict rules/regulations the number of overall accident have been decreasing in the last decade in the aviation industry. But still, there have been some notable accidents in the past years which have been fatal in the aviation industry; Some due to mechanical failures and some due to human failures. In this section of the research, some of the notable accidents and problems that took place in the airlines are reported.

A captain who had been grounded due to medical reasons took off in an ATR-42 on 11 October 1999 at Gaborone Airport, Botswana. After a short communication on the radio stating various demands, he then crashed the plane into another parked plane at the same airport.[74]

A BBC news report has said that the continental flight 3407 departing from New Jersey to New York stalled mid-flight and fell into a house below killing 50 individuals in total. The report further talks about how fatigue played a role in the poor response of the pilot to changing conditions which led to the disaster.[76]

On 29th of November 2013, a commercial pilot deliberately puts in faulty control input directing a plane to the ground after the first officer left the flight deck resulting in 33 fatalities. Similarly, on 24th of March 2015 while the captain was locked out of the flight deck the co-pilot of a Germanwings Airbus A320 directed the plane to crash into a mountain causing a total of 150 fatalities.[74]

In August 2019, a sole flight attendant of the United Express flight was found to be intoxicated and impaired while on duty. The ordeal was recorded by a passenger and later reported on the ABC News channel[73]. Similar to the case, another flight attendant of delta airlines was found to be intoxicated while on duty at London Heathrow airport in the June of 2019 and was charged and taken legal actions later in the year.[75]

According to a report by Boeing on their website, during the early days of flight, the human error involved only 20 % of the accidents in air flights. Whereas in today’s context it has jumped to a staggering 80 %.[79]

2.5 Fatigue Risk Management System

To combat the various problems that have arisen due to fatigue FRMS has been implemented in various areas of industry including in the aviation industry. As pointed out by [5] – "FRMS is a Safety Management System (SMS), or part of an SMS, which manages fatigue in a comprehensively and systematically using formal risk-based processes". ICAO defines FRMS as – "A data-driven means of continuously monitoring and managing fatigue-related safety risks, based upon scientific principles and knowledge as well as operational experience that aims to ensure relevant personnel are performing at adequate levels of alertness".[7]

The following figure is modelled as such by the SMS team of International Air Transport System (IATA) to illustrate the use of reactive processes for identifying fatigue hazards as part of an operator's SMS:

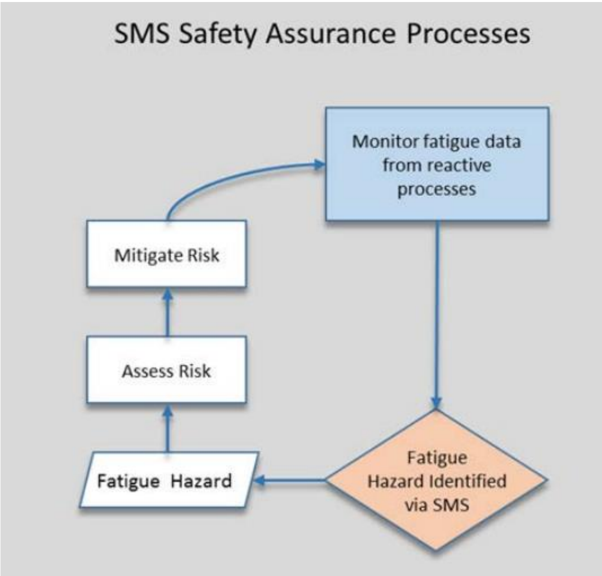

Figure 2: Identification of fatigue hazards as part of operator's SMS[21]

In the context of FRMS, two common challenges are identified during studies which are 1) what types of data need to be observed for fatigue identification; 2) how they should be measured to see if FRMS is adequately managing fatigue risks [15]. ICAO has briefed Safety Performance Measurement as – "process of measuring safety-related outcomes associated with a given operational system or organization, which is written in the context of today's State Safety Program (SSP) and Safety Management System(SMS) environment"[16]. ICAO also has its Standards and Recommended Practices(SARPs) that are used in managing fatigue risk[20].

Similarly, Flight Time Limitation(FTL) are also introduced which consist of a duty time limit, flight time limit, minimum rest requirement, etc. as a simpler method of accounting fatigue in the aviation industry [17]. The Euro Cockpit Association (ECA) – a representative body of European pilots at EU level also points out the importance of FTL, stressing over how it is necessary for ensuring aircrew fatigue does not endanger flight safety[18]. The traditional way of trying to manage fatigue has been by the use of FTL, i.e. prescriptive limit on-duty hours and rest duration between consecutive flights/ duty period[19]. [19] clearly emphasizes the importance of the role played by the cabin crew and how fatigue can be a hindrance to the crew.

Various data need to be analysed to conclude if any errors/ hazardous incidents that occurred as a result of fatigue or not. FRMS tries to monitor such key indicators in real-time to mitigate or minimize the rise of fatigue risk[15]. The following figure shows the use of Standard performance indicators(SPIs) in FRMS:

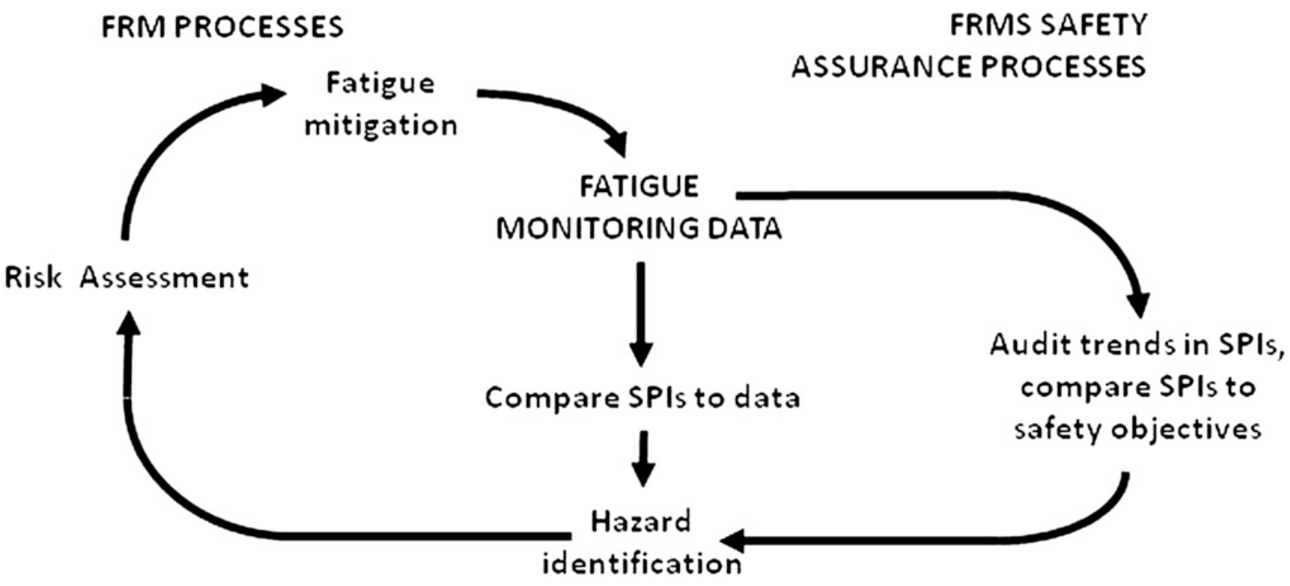

Figure 3: Recommended use of SPIs in FRMS[15]

2.6 Causes, Symptoms and consequences of Fatigue

As briefly discussed in the above section, fatigue although seems to have a simple description its meaning is rather broad and confusing. Similarly, the causes symptoms and consequences of fatigue cover very large aspects which will be discussed in detail in this section. As, when any problem is identified, there always follows its causalities. In this section, the research will try to distinguish some of them related to fatigue.

According to Göker Z (2018), fatigue symptoms differ with different aspects like physical, mental and emotional manifestations[6]. In regards to such symptoms, Australian government civil aviation safety authority has developed workbook on fatigue management strategies which provides some specific effects of fatigue on performance briefed as; reduced attention, communication difficulties, mood changes, inability to concentrate, increasing omission and carelessness, decreased vigilance, slowed comprehension and learning, encoding/decoding difficulties, faulty short-term memory, muddled thinking, slowness in perception, slow and uneven responsiveness, differential impacts due to task complexity, hallucinations [22][6]. Staying within the peripheral of fatigue, Göker Z (2018) has summarised the symptoms, causes and consequences of fatigue as in figure 4.

The figure below illustrated by[6] comprises of the different causes of fatigue their concerning factors, what the symptoms might look like in various forms in an individual and what consequences will these generate at the end.

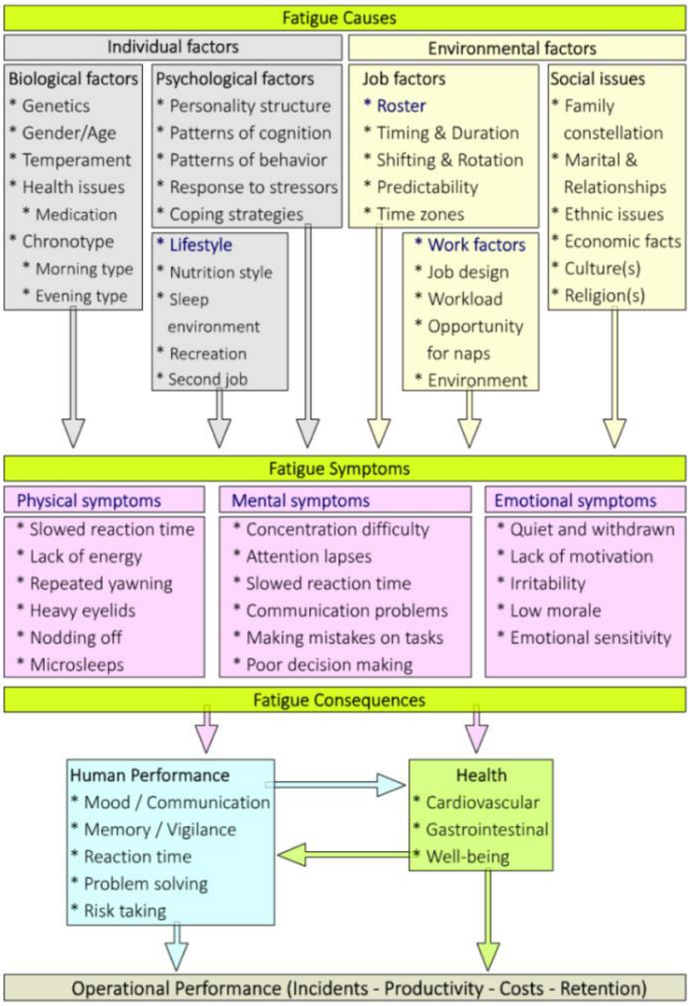

Figure 4: causes, symptoms and consequences of Fatigue[6]

Table 2: Common Causes of Fatigue[23]

Common Causes of Fatigue	
metabolic/ Endocrine	anaemia; hypothyroidism; diabetes; electrolyte abnormalities; kidney disease; liver disease; Cushing's disease
Infectious	infectious mononucleosis; hepatitis; tuberculosis; cytomegalovirus; HIV infection; influenza(flu); malaria and other infectious diseases
Cardiac (heart) and Pulmonary(lungs)	congestive heart failure; coronary artery disease; valvular heart disease; COPD; Asthma; arrythmias; pneumonia
Medications	antidepressants; anti-anxiety medications; sedative medications; medication and drug withdrawal; antihistamines; steroids; some blood pressure medications; some anti-depressants
Psychiatric (Mental Health)	Depression; anxiety; drug abuse; alcohol abuse; eating disorders(example: bulimia, anorexia); grief and bereavement
Sleep Problems	sleep apnea; reflux esophagitis; insomnia; narcolepsy; shift work or work shift changes; pregnancy; Extra night hours at "work"
Vitamin Deficiencies	vitamin B12 deficiency, vitamin D deficiency, folic acid deficiency, iron deficiency
Other	cancer; rheumatology illnesses such as rheumatoid arthritis and systemic lupus; fibromyalgia; chronic fatigue syndrome; normal muscle exertion; obesity; chemotherapy and radiation therapy

Benjamin Werdo a medical doctor has given some highlights on fatigue in an internet article – mainly types of fatigue with its causes, this has been provided in table 1 above. This structure only highlights some of the causes of fatigue but does not encompass all of them, but rather can be used as a reference on how fatigue is seen through other areas/ organisational fields.

2.7 Monitoring and measuring Fatigue

There is no definite way of measuring fatigue which ensures 100% accuracy, but there exist two ways of measurements that have appeared in literature; Subjective and Objective measurement.

Subjective measurement of fatigue

[6] writes in his article that subjective measurement of fatigue is dependent upon self-reporting and self-perceived feelings. This can be challenging to present the actual level of fatigue as each individual's self-perspective can differ. [24] has depicted the following as well-established subjective measures for fatigue:

Visual analogue scale(VAS), Samn-Perelli seven-point fatigue scale(SPS), The Karolinska Sleepiness Scale(KSS).

In addition to these measures there are also others; Fatigue Severity Scale(FSS), Chalder's Fatigue Scale(FS), Stanford Sleepiness Scale(SSS).[6]

- Visual Analogue Scale – VAS; due to its easy administration and easy understanding for the user has been a commonly used instrument for the measurement of subjective feelings[27]. It is a self-reported scale consisting of a horizontal or vertical line, anchored at the extremes by two verbal descriptions referring to pain status.[32]

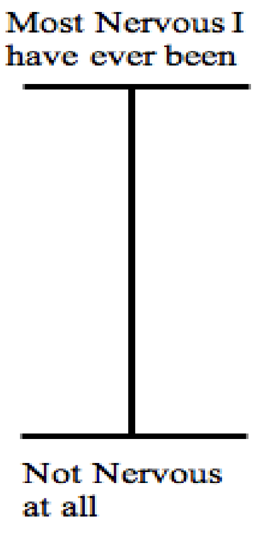

Figure 5 : VAS Scale[24]

- Samn – Perelli Seven Point fatigue scale – this is a seven-point scale which subjectively measures a patient's level of fatigue at the moment of time. The scores are predetermined and range from 1 (being fully awake and refreshed) to 7(exhausted and unable to perform tasks properly). Following tabular form is conceptualized from [24]

Table 3 : Samn-Perelli Seven Point Fatigue Scale[24]

Samn-Perelli Fatigue Checklist	
1. Fully alert, wide awake	
2. Very lively, responsive, but not at peak	
3. Okey, somewhat fresh	
4. A little tired, less than fresh	
5. Moderately tired, let down	
6. Extremely tired, very difficult to concentrate	
7. Completely exhausted, unable to function effectively	

- The Karolinska Sleepiness Scale – it is mainly used for evaluating subjective sleepiness. It was originally developed as a one-dimensional scale of sleepiness and was validated against alpha and theta electroencephalographic(EEG) activity[28]. [29] conducted a study for validating KSS and found that it was highly correlated to EEG and behavioural variables. The tabular form below is conceptualized from [24]

Table 4 : Karolinska Sleepiness Scale[24]

Karolinska Sleepiness Scale(KSS)	
Extremely Alert	1
Very alert	2
alert	3
Rather alert	4
Neither alert nor sleepy	5
Some sign of sleepiness	6
Sleepy, but no effort to keep awake	7
Sleepy, but some effort to keep awake	8
Very Sleepy, great effort to keep awake, fighting sleep	9
Extremely sleepy, can't keep awake	10

- Fatigue Severity Scale (FSS) – [30] points out in their article that, fatigue severity scale is simple and time-efficient which makes it more desirable over other measuring scales. Fatigue severity scale consists of nine items and is one of the most frequently used instruments measuring fatigue.[31] In a study conducted by [30], it was found that FSS helped distinguish the severity of fatigue between healthy persons with sleep-wake disorder along with other factors. The following severity scale is taken from [30]

Table 5 : Fatigue Severity Scale [30]

Fatigue Severity Scale(FSS)	
	Strongly Disagree ⟵⟶ Strongly Agree 1 2 3 4 5 6 7
1. My motivation is lower when I am fatigued 2. Exercise brings on my fatigue 3. I am easily fatigued 4. Fatigue interferes with my physical functioning 5. Fatigue causes frequent problem for me 6. My fatigue prevents sustained physical functioning 7. Fatigue interferes with carrying out certain duties and responsibilities 8. Fatigue is among my three most disabling symptom 9. Fatigue interferes with my work, family or social life	

- Chalder's Fatigue Scale – In 1993 developed by [33], with a 14- item scale to measure fatigue, later on, this was finalized to 11 – item scale[34]. According to [39], it is a self-administered questionnaire for measuring the extent and severity of fatigue within both clinical and non-clinical, epidemiological population. The following is derived from [33].

Table 6 : Chalder's Fatigue Scale[33]

	Less than usual	No more than usual	more than usual	Much more than usual
Do you have problem with tiredness?	☐	☐	☐	☐
Do you need to rest more?	☐	☐	☐	☐
Do you feel sleepy or drowsy?	☐	☐	☐	☐
Do you have problem starting things?	☐	☐	☐	☐
Do you lack energy?	☐	☐	☐	☐
Do you have less strength in your muscles?	☐	☐	☐	☐
Do you feel weak?	☐	☐	☐	☐
Do you have difficulties concentrating?	☐	☐	☐	☐
Do you make slips of tongue while talking?	☐	☐	☐	☐
Do you find it more difficult to find correct words?	☐	☐	☐	☐
How is your memory?	☐	☐	☐	☐

- Stanford Sleepiness Scale – The Stanford Sleepiness Scale (SSS), designed to quantify subjective sleepiness levels, consists of a seven-point scale of equal intervals varying from very alert (point 1) to excessively sleepy (point 7) [37]. It is mainly a subjective measure of sleepiness and is used for both clinical and research purpose[35]. The Stanford Sleepiness Scale (SSS) is a self-rating scale which is used to quantify progressive steps in sleepiness[36]. According to Shahid et al., SSS is a single-item measure and is best suited for repeated use throughout a research study or treatment intervention[35].

Table 7 : Stanford Sleepiness Scale[35]

The Stanford Sleepiness Scale(SSS)	
Degree of Sleepiness	**Rating**
Feeling Active, vital, alert, or wide awake	1
Functioning at high level, 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**

In addition to such measurements, some biomathematical models are also developed to better predict the individual's alertness level or performance efficiency before duty to determine if he/she can maintain the same level of performance throughout their duty period[6][25]. Some of such models are Fatigue Avoidance Scheduling Tool(FAST), The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE), Fatigue Audit InterDyne(FAID), Fatigue Index Tool(FIT) and System for Aircrew Fatigue Evaluation model(SAFE)[6][26].

Objective Measurement of Fatigue

On contrary to the subjective fatigue, objective fatigue is performance-based and determined by decline or attenuation on a quantifiable measure [38]. [40] defines objective measurement as – " one in which there is reasonable intertester (interobserver) reliability". Rothstein further goes in detail on the matter in his paper and writes that measurements are supposedly objective that have shown to be valid for some inference i.e. conclusion reached based on evidence and reasoning[40]. According to [41], objective measurement allows one to examine the various elements in an assessment situation and gives us straight lines, precise measures and separated elements that remain stable across time and sample.

In the aviation industry, the objective measurement of fatigue on subjects is mainly done using Circadian Rhythm(using temperature, biological tests) or sleep(using polysomnography (PSG), electroencephalography(EEG), actigraphy) or Psychomotor performance-based test(simple mental tasks and complex behavioural)[6].

- *Circadian rhythm* – is an endogenous oscillation with a period of approximately 24 hours [42]. It also is defined by National Institute of general medical sciences as – physical, mental and behavioural changes that follow a daily cycle and are mainly respondent to light and darkness of the environment around an organism[43]. According to [43], the characteristics of physiological processes as blood pressure, heart rate, the release of enzymes in an organism is controlled by circadian rhythms. According to [45] – clinical observations have shown that human beings' functions follow periodical variations regulated by the internal biological rhythms and when the period of the cycle is almost 24-Hrs it is qualified as circadian.

  Some of the modes of objective measurement of fatigue in the aviation industry[6] are briefly described below:

- *Polysomnography(PSG)* – it is a test done while you are asleep. In the process, a doctor will have you under observation whilst recording data based on brain waves, skeletal muscle activity, blood oxygen level, heart rate, breathing rate, eye movement and sleep pattern [56]. According to [57], PSG is used to investigate the relationship between changes in physiology, impact on sleep, and consequences of waking function, performance and behaviour. Data such as the sleep-wake history of individual and sleep logs depicting the pattern of sleep periods and naps are useful for PSG[57][58][59].
- *Electroencephalography(EEG)* – it is the recording of electrical brain activity[50] using electrodes attached[6] to the scalp when the subject [52] is resting or sleeping, after sleep-deprived, after hyperventilating[6][49]. According to [51], EEG is a physiological index that serves as an online continuous measure of cognitive load of a subject. As all activities in a person are mandated by the brain, hence the event-related potentials of the brain are considered a reliable method for accessing impaired

alertness[6]. EEG uses theta, alpha and delta band in consideration to determine mental workload and mental fatigue[6].

- *Actigraphy* – Actigraphy uses a portable device which might resemble a wristwatch that collects movement information(activity) over a period of time[48][17][6]. The important task of determining sleep and wake pattern is done by actigraphy.[48] Normally actigraphy data along with sleep diary log are taken in parallel to get the most appropriate readings needed[17].
- *Psychomotor Vigilance Task(PVT)-* Psychomotor skills are those which are primarily movement oriented[46] and in particular focuses on learning of organized activity which involves arms, hands, fingers and feet[47]. The evaluation of such psychomotor performance including the ability to sustain attention is carried out using PVT[6]. PVT is a reaction-timed task which measures the subject's response speed to a visual stimulus[17]. Research has shown that insufficient sleep is linked to many problems as problem-solving, decline in psychomotor skills and increased rate of wrong respond[17]. In a laboratory environment PVT is normally a 10 min test[17] but in a field, it can be reduced to 3 or 5 mins and can even be conducted in a noisy environment[6][17].
- *Critical Flicker-Fusion Frequency Test(CFF)* – it is the frequency at which a flickering light is perceived as continuous, is widely used for evaluating visual temporal processing[53]. It is a measure of visual processing speed[54] and also a neurophysiological method that measures the brain function[55]. It has been addressed by [53] that CFF reflects the basic temporal function of a visual system and hence can be a good measure for its performance.

2.8 Counter measures for fatigue

Formerly the research discussed fatigue symptoms, consequences and different methods of monitoring fatigue. Following that, it tries to shed some light on some countermeasures for fatigue or ways in which fatigue can be minimized/ mitigated to some extent or completely. As [13] demonstrate in their article, fatigue possesses a significant problem in modern aviation industry mainly because of the irregular work hours, long duty periods, circadian disruptions and inadequate sleep. According to [6] - with more understanding of fatigue causes, symptoms and consequences, changes have been happening in the aviation regulations and industry practices like – development of fatigue mitigating strategies based on subjective reports.

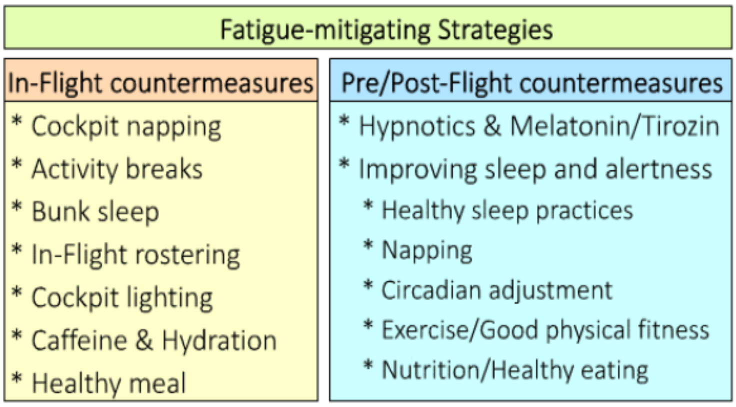

Figure 6: Fatigue mitigating strategies[6]

The figure above is a basic schematic for fatigue mitigating strategies documented by [6]. [13] has given a detailed analysis of these strategies in their paper. Briefly noting some key abstracts from their paper following details on the countermeasures are extracted:

Cockpit napping is most suitable when the amount of sleep is limited. Also, napping helps in restoring alertness without the use of any external substances. Usually napping is done in long haul flights or ultra-long flights to help the crew to be more refreshed and alert for their operations and duties. But this can only be done without hampering any other duties at hand.

Decreasing the monotonous environment of the flight deck, activity breaks helps in increasing the level of alertness. It might not be very effective as other measures but none the less, activity breaks help crew to get mild physical activity and feel refreshed. Activities can include change of posture, disengaging from flight task for pilots(during cruise portion), etc.

Bunk sleep is another type of countermeasure that is commonly used in Long Flights. This measure helps to address sleep loss and disruption in the circadian process whilst on duty for the crew. For this measure to work, sufficient crew member needs to be available as duties need to be conducted normally and ensure safety while some crew are taking rest. Upon good arrangement, this measure can ensure better alertness and more attentiveness of the crew.

Inflight rostering also can be taken as a countermeasure for fatigue as, assigning different jobs beforehand and then subsequently swapping duties later. This measure also works hand in hand with bun sleeping and one crew can be assigned to a station where another crew is taking a rest.

Light tends to have an acute effect on alertness of mood and performance impartial of circadian phase. Various reviews have shown that alerting effects of light has potential use during the night where conditions allow its use. Many suggest that light's alerting effect is due to the suppression of melatonin which is released in the late evening. Having the potential to mitigate alertness decrease, lightning can be used for the same purpose in the flight deck. The suggested luminescence of 100 – 200 lux.

On the other hand, post and pre-flight countermeasures discussed by [6] presents measures on getting better sleep in varying conditions by the crew. Mainly, the hypnotic measure is discussed when an individual has time for good sleep but is unable to attain it. Such a measure can be due to the disruption of the circadian rhythm and other work conditions. Some drugs also help in certain case of attaining sleep if other measure fails. Temazepam administration is affected by the time of intake as with most cases of drugs. This can help in improvement in sleep in many cases.

Nutrition and physical exercises also play a vital role in attaining sleep or managing the circadian process. This is due to a better lifestyle helps to build a better body and thus helps to regulate other bodily functions properly. Various strategies can be also applied for better sleep opportunities as – formulating a time schedule for going to bed and waking up, doing aerobic exercises before certain hrs of going to bed, having sleeping quarters silent, comfortable and totally absent of light sources during sleep time, avoiding caffeinated drinks prior to sleep, etc.

3 Artifact Development

This section builds upon the previous section of the research and discusses about different variables taken into consideration for the framework and how they need to be handled to assess fatigue in as individual. Details on the choice of variable and their roles are briefly explained in the following section. Concluding with a developed artefact at the end.

3.1 Current Measurement Application and tools for fatigue in aviation

With fatigue being underlined as a major factor for hazards and implications in the aviation industry there have been many models or applications that are under use currently. Some of these structures are highlighted in the section of the paper for a better understanding. These model structures are better explained in detail by CASA(Civil Aviation Safety Authority), from which the following information is gathered for inclusion in this paper. The main models that are discussed and compared are BAM, CAS, FAID, FRI, SAFE, SAFTE-FAST and SWP.

The main components in the model prescribed above are Homeostatic sleep drive, circadian process, sleep inertia, circadian phase adaptation, work type and time on a task[78]. The Civil Aviation Safety Authority of Australia has furthermore illustrated different comparisons of these models with varying factors which is exemplified below in a figure.

Figure 7 shows what sort of applications the models provide where the tick mark(✓) implies that an application is included in the model. Also, the numerical on the top of ✓ denotes that there are some specific criteria or needs for the application to work under that model. All this can be found in detail on the " Biomathematical Fatigue Models Guidance Document" published by CASA at https://www.icao.int/safety/fatiguemanagement/ArticlesPublications/biomathematical_fatigue_models.pdf

Model Applications	BAM	CAS	FAID	FRI	SAFE	SAFTE-FAST	SWP
Forward Scheduling	✓	✓	✓	✓[8]	✓	✓	✓
Non-scheduled / Irregular operations	✓	✓	✓	✓	✓	✓[9]	✓
Work / Rest cycles in augmented crew	✓	✓	✓[10]		✓	✓	
Evaluation of light exposure countermeasures	✓	✓					
Evaluation of napping countermeasures	✓	✓			✓	✓[11]	✓
Individual fatigue prediction	✓	✓			✓		✓
Training	✓	✓	✓	✓	✓	✓	✓
Safety Investigation	✓	✓	✓		✓	✓	

Figure 7 : Comparison of Model Applications[78]

Similar to the above comparison, CASA also does a brief component comparison among the various models which is illustrated in figure 8 below.

Model Components	BAM	CAS	FAID	FRI	SAFE	SAFTE-FAST	SWP
Homeostatic Sleep Drive	✓	✓	✓	✓	✓	✓	✓
Circadian Processes	✓	✓	✓	✓	✓	✓	✓
Sleep Inertia	✓	✓		✓	✓	✓	✓
Circadian Phase Adaptation	✓	✓	✓[13]		✓	✓	✓
Work Type	✓	✓		✓	✓	✓	
Time on Task	✓	✓	✓	✓	✓	✓	✓

Figure 8 : Model Component Comparison[78]

3.2 Datasets and variables identification

For the measurement of pilot fatigue there are various tools and applications for measuring a multitude of datasets; being subjective, objective, biomathematical as well as psychological. On the other hand for the assessment of cabin crew mainly subjective measurements determine the case of fatigue where sleep diaries and Flight time limitations play a vital role. With only datasets as these, it is not fully accurate if the person is fatigued or not, hence, some variables are identified that play role in a person's wellbeing for the better assessment of fatigue for the cabin crew. Few that are described and used in the literature are as follows:

- *Alcohol level/concentration in blood*

  Blood alcohol concentration(BAC) is directly proportional to the effects of alcohol in an individual. Although the effects of alcohol vary from person to person, the standards set on BAC is consistent for all.

  Everyone is aware of the impacts and effects alcohol has on the body but even then, someone might overestimate their capacity to handle it and this could result in physical or mental impairment. Because of these effects, BAC is taken in as a variable for the fatigue assessment of cabin crew.

- *Heart rate*

  Heartbeat is almost like a constant ticking clock in a person's body. It gives us various indications about a person, their wellbeing, and other factors relating to the body. The heart rate variation is dependent upon many factors as; physical exertion, mental exertion, medical illness, etc. All factors that are relating to heartbeat cannot be accounted for in one place as almost everything has some sort of an effect; that might be visible promptly or not. As cabin crew go through a multitude of experiences(both mentally and physically) on a flight, some irregularities in the heart rate can certainly be found if he/she is fatigued.

- *Sleep pattern*

  The research has already emphasized on this matter thoroughly, explaining how sleep plays a vital role in a person's fatigue level. As airline workers are subjected to various odd working hours and time changes during flight, it is almost certain that their sleeping habits will have been affected. Although previously mentioned in the paper, the circadian rhythm is the main culprit here. As every individual's body functions following this rhythm, sleeping and waking parameters are predetermined by this bodily function. It can be altered or manipulated to some extent but even then some level of fatigue can be seen on an individual after a period.

- *Blood pressure*

  As with heartbeat, blood pressure(BP) is also a factor and a variable here which will be discussed. Blood pressure is not directly related to the heartbeats but correlates to some extent to it. Blood pressure is the force exerted by blood on the arteries while the heart is pumping blood in the body. Various factors might have several effects on blood pressure of a person, but BP when not in its optimal range causes other numerous diseases and sickness in a person's body. These can result in a person being fatigued or show sign of fatigue. Thus BP is taken into account as a variable for the fatigue in cabin crew.

- *Flight time and off duty time*

  Flight time and rest time(off duty) play a vital role in the level of fatigue of any airlines personnel. As the duty time can vary depending upon different types of flights, the crew can be fatigued if this is not properly organized or scheduled. There are already many points discussed in this research about this issue and how the airlines have been dealing with it in different manners. There are already many applications that automatize the Flight time for an individual(when the duty roster are inputted) or reports and taken after flights (generally filled in by an individual); which help in determining the regular duty time and resting time(if needed) for a crew member. On top of that, ICAO and EAA have also depicted the various limitations on the duty hours to better manage the fatigue of a crew member. Having such concerning effect on the matter this is taken as one of the variables for the model as well.

- *Lifestyle during off duty*

  Everyone has a different way of lifestyle, the same applies to a crew member of the aviation industry. The lifestyle determines how refreshed or relaxed a person is to some extent. There are many issues in a person's lifestyle that determine multiple factors in a person; physically and mentally. Lifestyle can have constituents as nutrition intake, sleeping environment, recreational activity, relationship status, culture, religion, family pattern, etc. These sort of factors affect a person in a multi-dimensional way which might not be seen from observation alone. As they are prone to affect the mental and physical status of a person; lifestyle during off duty hours are also taken into consideration for a factor for fatigue in cabin crew.

- *Level of concentration or vigilance*

  Vigilance is a broad topic with varying meaning, but in the psychological definition- it is the ability to sustain attention to a task at or for a certain amount of time. Having attention means for the brain to be more active and well proficient in information processing. Hence the term being alert can be taken into consideration in this as well.

Vigilance of a person can be affected by varying factors as sleep deprivation, intoxication, through alcohol, medication, etc. And aviation crew who are needed to be refreshed and alert during their duty hours can be negatively affected by low vigilance or lower level of attentiveness. Due to such criteria, the level of vigilance is taken as a fatigue determining factor for cabin crew in this research.

- *Other general medical data*

  Everything cannot be measured and determined at a certain point in time so, some data need to be taken beforehand which can then be later incorporated within the system to determine the fatigue of an aviation personnel. Procedures such as general physical check-up, intermediate health check-ups(mental and physical) can be conducted and their data can be stored in the aviation database for future reference in determining fatigue. These mainly help in determining some long term fatigue state on the body which might be overlooked during immediate fatigue assessment methods. Mostly every organization has a quarterly or semi-annual medical check-ups for their personnel and the same case could be in application in the aviation industry. Such elements can reveal a repetitive pattern of fatigue factors or other disorder that might cause fatigue in personnel who have been working over a long period in the industry. Due to such varying and volatile state, these data have also been taken as variable in this research.

3.3 Means of test conduction

The tests that are required have to be precise and efficient, as well as taking the shortest time possible for the determination of fatigue. In regards to the data sets depicted in the earlier section of the research, the following test would be conducted for the best results and gathering of the required data(being time and resource-efficient)

- *Breathalyzer test for alcohol level*

  Breathalyzers have been in use for determining the level of alcohol in an individual's body in the road traffic for a long time. The way a breathalyser works is by taking in consideration of the ethanol present in the breath after alcohol consumption. As published in the whitepaper by Alcolizer technology(2013), the fuel cell in a breathalyser is linked to the battery in the device and measures minute voltage outputs(low millivolts)[72]. After the breath is taken a chemical reaction occurs inside the device and output is shown in the device, the reaction is short-lived thus the readings on the breathalyser returns to null again[72].

According to the Australian government, BAC and effects of alcohol are proportional but the effects do vary among individuals. The BAC calculation is the standard means of determining the extent of a person's alcohol impairment. Although expressed as a percentage in the unit, BAC is weight-per-volume measurement: grams of ethanol per 100 millilitres, or decilitres of blood[71]. The research done by [70] has found that Fuel cell Breathalyzers are reliable and consistent in measuring alcohol intoxication. Breathalyzers are advancing with the progression in technology, and in the future, there can be another type of device to replace the current one.

- *Wearables/ smartwatches for the heart rate and sleep patterns*

  In today's technological world smartwatches and other types of wearables have become a trend and almost everyone has one. These devices are packed with many functionalities in them which if used to their potential can have a great impact on a person's life. For the research objective, only functions as activity meter, heart rate(HR) measurement and sleep records are taken into focus. The wearable is a non-invasive way of gathering data. Through the data, it can be taken further and we can take the Heart Rate Variability(HRV), which can answer numerous questions about a person. According to an online article in Harvard Medical School's online portal - HRV in a simple sense is the amount of variation in time between each beat which is controlled by the Autonomous Nervous System(ANS)[79].

- *Blood pressure test with the portable unit or wearable*

  Just like heartbeat and HVR, blood pressure(BP) plays a vital role in the human body. Changes in BP of an individual can be triggered due to many different things – fatigue being one of them. It is quite hard to determine if the changes in BP is just due to fatigue but being one of the factors the paper looks into it as a variable. Testing BP of a person nowadays is not very hard as various equipment and devices are readily available. An individual does not need to visit his/her physician to know their BP now, they can use a portable device which can be self-administered. Even some wearables are available now that can give the BP of an individual at a certain time.

- *Sleep diaries and crew logs*

  Subjective measurements have always been in use in the aviation industry and it has been one of the baselines to measure fatigue. Although we can get various mathematically quantifiable data to measure fatigue, we still need the subjective data from the crew themselves to know more about the problem at hand. These will also help in cross-checking other data that might have been gathered by other means. For instance, sleep diaries can help to concretize the sleep data taken from wearables as some devices take resting phase as induced sleep as well. Also, other crew logs can be help determine an overview of a mental state of an individual(meaning reporting of some type of incident on-duty time that can cause fatigue). Logs also help to keep track of the duty roster and other manners of data which can be useful for the determination of fatigue.
- *Flight time data (in-house application or other application/logs)*

  The flight time is very crucial in the aviation industry. This determines the workload and duty period of an employee. The flight time can be calculated some application like the FTL app that is available on the market or any other inhouse application that the airlines use. These are just a time management tools used specifically for the aviation industry, but similar might be used in other organisations which gives a similar output. The other method of getting the data can be through the Crew Logs, which would be an online form-based tool that takes in input from the user to determine the total time of duty and off times in-between two consecutive work schedules. Such data of work time is essential as it gives an overview of how many hours is the crew member working at a time and helps to determine if they are prone to fatigue in near future as being awake for a prolonged period can have an impact on the physical and mental state of an individual. In case there have been too many additions of work hours suddenly, the individual can be registered as fatigued before the next consecutive duty.
- *Short mobile game/application for Vigilance concentration at a point*

  Level of concentration of an individual is vital in the aviation as while on duty the crew members are desired to perform many work tasks that require their full attention. Not being able to concentrate properly can lead to mistakes in the work and disturb the standard pattern of work schedule. Even the slightest of errors can sometimes lead to greatest of consequences, and aviation being one of the industries that work with a mass of customers at a time – such mistakes can not only hamper the industry but also the customers which can be very fatal at times. Every individual can have different levels of concentration thus to determine a standard level it is very difficult. But a generalised level to meet a basic standard can be achieved which can discover fatigue in an individual when this is cross-referenced with other factors and their results. An example can be, an application with flickering spots which the crew is supposed to tap on. This flickering pattern can be time-based and the shortest time would be more level of concentration and vice versa. To standardise, the flickers can be 10 times, each with one point, depending upon how many the crew member gets right and with other factors, the fatigued state can be determined for that time.

3.3.1 Test Data

The data that each of the required test listed above ranges from being mathematical to subjective. Here the research will discuss data that is outputted by each of the aforementioned tests successively and their basic readings.

The data/reading on a Breathalysers can be calibrated to measure the amount of ethanol present in the breath of an individual. Depending upon the organisation using the equipment the range can be altered or standardised per their need. While in the organisation like road traffic, in various countries the limit is .05 to .08, the aviation industry is stricter thus limiting the minimum to .04 reading on the breathalyser [20][21].

Wearables have become an accessory in this technological era, almost every person has some sort of gadget which they have on themselves. Similarly, the crew can have a specific wrist wearable with themselves which can measure their heartbeat and sleep pattern. The data here would be mathematical where the heartbeat would be in number and checked if it is within the normal range. This would later be cross-referenced with other data to finalise the results. The range is 60 - 80 for a normal adult where 75 beat is the most optimum. HVR standard for a normal adult varies in regards to the difference in the calculation method. The research takes into consideration the HRV method used by iPhone since that is the device used for the test conduction. In the device(iPhone) the HRV range from 40ms and higher.

Also according to various researchers, it is recommended that an adult have at least 6 hrs of sleep to be fully revitalised but this can differ from person to person because of their physical and mental status. The data that can be acquired from the wearable would include the REM sleep (deep sleep) and normal sleep with some movements. Although this data cannot be 100% accurate in all type of wearables as even resting phase without movement could trigger the device to take wrong input. But never the less the data would be very useful to again cross-reference other data to increase the efficiency of the result.

Blood Pressure(BP) which is taken as a variable is vital as well since different factors can alter this in an individual which can later be used to narrow down the data to the users need. Normally, the standard of BP according to medical personnel is 80/120. The BP readings are mainly the pressure exerted on the veins of an individual when the heart is pumping blood in the body. With the use of portable machines that are available, measuring BP of a person is very easy and less time-consuming. The gathered data then can be analysed alongside other factors to verify the finding's nature at that point in time. One of the latest creation and functionalities in a wearable is also a calculation of BP, where the measurements or data output is very much accurate to what a medical procedure would give.

Sleep diaries and crew logs are subjective measurements and mainly filled in by the crew themselves. The data here needs to be converted to a more mathematical form in regards to the data entered in the form. The form needs to be handled in such a manner that, a standardised or calculative form should be the output of the entered data in the form. One such calculative data could be the scale used for the circadian rhythm by various authors like the SSS or KSS which ranges from 1 -7 or 1-n(where n = upper threshold). With the help of such data, it would be easier to counter reference other data and get a definite answer at the end of the process. Also, the crew logs can be so set that the output of the form can be put into some range or numeric format.

Similar to other factors Flight time data for a crew can be gathered from the application or the logs for the flight time. The data here would be if there has been any abrupt schedules or extended duty time for the crew. The total flight time alongside the break the crew can get between consecutive work schedules is seen and depending upon their extent a scale can be made to get the appropriate data. Although the aviation industry itself has many regulations on these and there might hardly be any plausible data that might be acquired, the research still takes this into account due to the fact of long flights and abrupt scheduling of work schedules.

The vigilance or concentration data taken from a mobile application would give a definite number as an output but would need to be tallied with a self-made range for the concentration level. This would allow the system to determine the result status more efficiently. For the ease and comfort, the range of 10 flickers are taken, each having 1 point assigned. The mean being 5 flickers is taken as normal concentration level as a hypothesis for the experiment. Hence anything below 5 points will be regarded as fatigued, where fatigue level increases as the points get lower.

3.4 Test data prioritization

To get the best result most efficiently, this research constructs a prioritisation standard for the variable defined above. This will further help in determining fatigue in crew member when they are going for work. The prioritisation done is depicted in the table 8 below.

Table 8 : Variables and Prioritization

Variables taken	Priority level ascending
Alcohol concentration in blood	1
Sleep pattern	2
Flight time/ total duty time	3
BP and HRV	4
Concentration Level	5
Crew logs (other factors)	6
Previous medical history	7

Concerning the prioritisation illustrated, if the value for the 1st prioritised variable when analysing fatigue results higher then intended than all other variables are overlooked and the individual is promptly advised to take needed fatigue mitigation measures. Likewise, in the case of the other prioritisations which are portrayed, their mean value will correspond to determine if the examined individual requires fatigue mitigation tasks or not. The reason for this is that within the influence of alcohol(the no 1 priority on the list) an individual's physical as well as mental state will be deteriorated thus disabling them to perform the simplest of tasks. Further, intoxication or under the influence of alcohol results in other variables being affected or deteriorated as well - sleep, heart rate, blood pressure and level of vigilance all of these are affected simultaneously. The result is that the individual is fatigued.

All the results from the variable's own standards are modified to different points for the ease of calculation and interpretation. These modified points are taken as the base for the generation of result and are illustrated hereafter. For determining fatigue the paper has disclosed the rating of 0 to 1 and above for the final collaborated result of all the variables, where 1 and above are regarded as fatigued and below is taken as not fatigued. This is further elaborated below:

Table 9 : Blood Alcohol Concentration(BAC)

level	< 0.04 ml/dL	> 0.04 ml/dL
classifier	low	high
rating	0	1

Table 10 : Blood Pressure(BP)

Level	40/40 - 90/60	90/60 - 120/80	121/81 - 130/80s	131/81s - 139/89	140/90 - 179/120+
Classifier	low	normal	Prehypertension (moderate)	stage 1 hypertension (high)	stage 2 hypertension (critical)
Rating	0.9	0	0.3	0.6	0.9

Table 11 : Heart Rate Variability (HRV)

Level	30 ms and less	31 - 39 ms	40 - 50 ms or greater
Classifier	critical	moderate	normal
Rating	0.9	0.4	0

Table 12 : Heart Rate (HR)

Level	< 60	60-100	> 100
Classifier	High	Normal	High
Rating	0.8	0	0.8

Table 13 : Vigilence Level

Level	0-2	2-4	4-6	6-8	8-10
Classifier	critical	moderate	low	normal	excellent
Rating	0.9	0.8	0.5	0.2	0

Table 14 : Prior Sleep Amount

Level	0-2	2-4	4-5	>5
Classifier	critical	moderate	low	normal
Rating	0.9	0.7	0.2	0

In regards to the ratings depicted for the calculation of fatigue in crew member each listed variable's result is designated as - a, b, c, d and e respectively. For anyone to be entitled fatigued the result from the sum of these results needs to be 1 or greater. Some calculations of each reading are illustrated below for better understanding.

To be fatigued

a + b + c + d + e >= 1

taking the critical readings first for all the variables

a = 1; b = 0.9; c = 0.9 ; d = 0.9; e = 0.9

hence according to the aforementioned sum rule for fatigue, the result would be

4.6 which is a very high indication of the member being fatigued. Also, since for this calculation the BAC was taken into account the individual should be asked to take fatigue mitigation steps immediately.

Next, we take BAC level null and some other variables in the normal as well as a moderate form to see the result's consistency.

a = 0; b = 0.3; c = 0; d = 0.2; e = 0.2

In this case, the result amounts to 0.7 which entitles the individual to be not fatigued.

But there are some cases where additional observation might be needed to confirm the validity of the test. One such case could be - crew member has an elevated BP and moderated level HRV due to prior physical exertion while on the way to work. This could give falsified data but not to a greater variation. For example taking the variations as,

a = 0; b = 0.6; c = 0.6; d = 0; e = 0

In such a case the results output is greater than 1. While previously illustrated,

if result value > 1 = fatigued

or result value < 1 = not fatigued

The result here can be ambiguous hence the last call for such a result would depend upon the supervising officer present at the post and the explanation provided by the crew member.

The overall process of the assessment is portrayed by the model below:

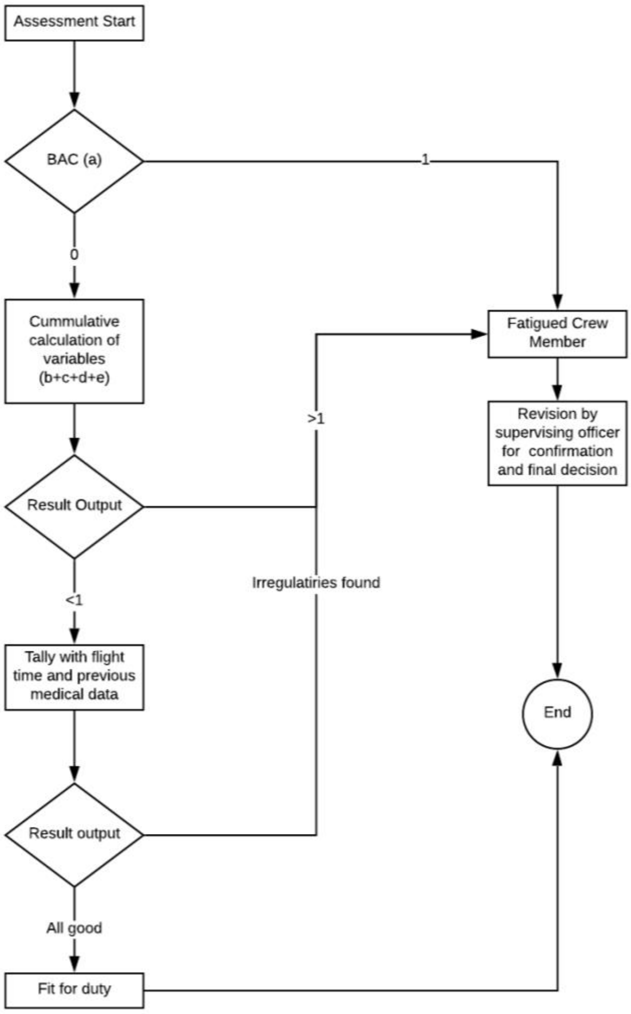

Figure 9 : Process of Assessment

Figure 9 details, the commencement of assessment takes place with BAC regulation check which follows through to the cumulative calculation of the variables. The result from this is combine with other data as medical and duty roster to concretize the output. The final result then gives the situation of an individual i.e. either fatigued or not fatigued. As there might be some irregularities, there is supervisor present to further evaluate the result. This final evaluation removes any irregularities and doubts which may have surfaced and helps to mitigate any risk on the industry due to fatigued personnel on job.

3.5 Process model

The following figure reveals the basic working structure of the process from when the crew member undergoes the fatigue test before work schedule. It takes into account various forms of data to properly give a result and characterize if the personnel is fit for the job or not(either fatigued or refreshed).

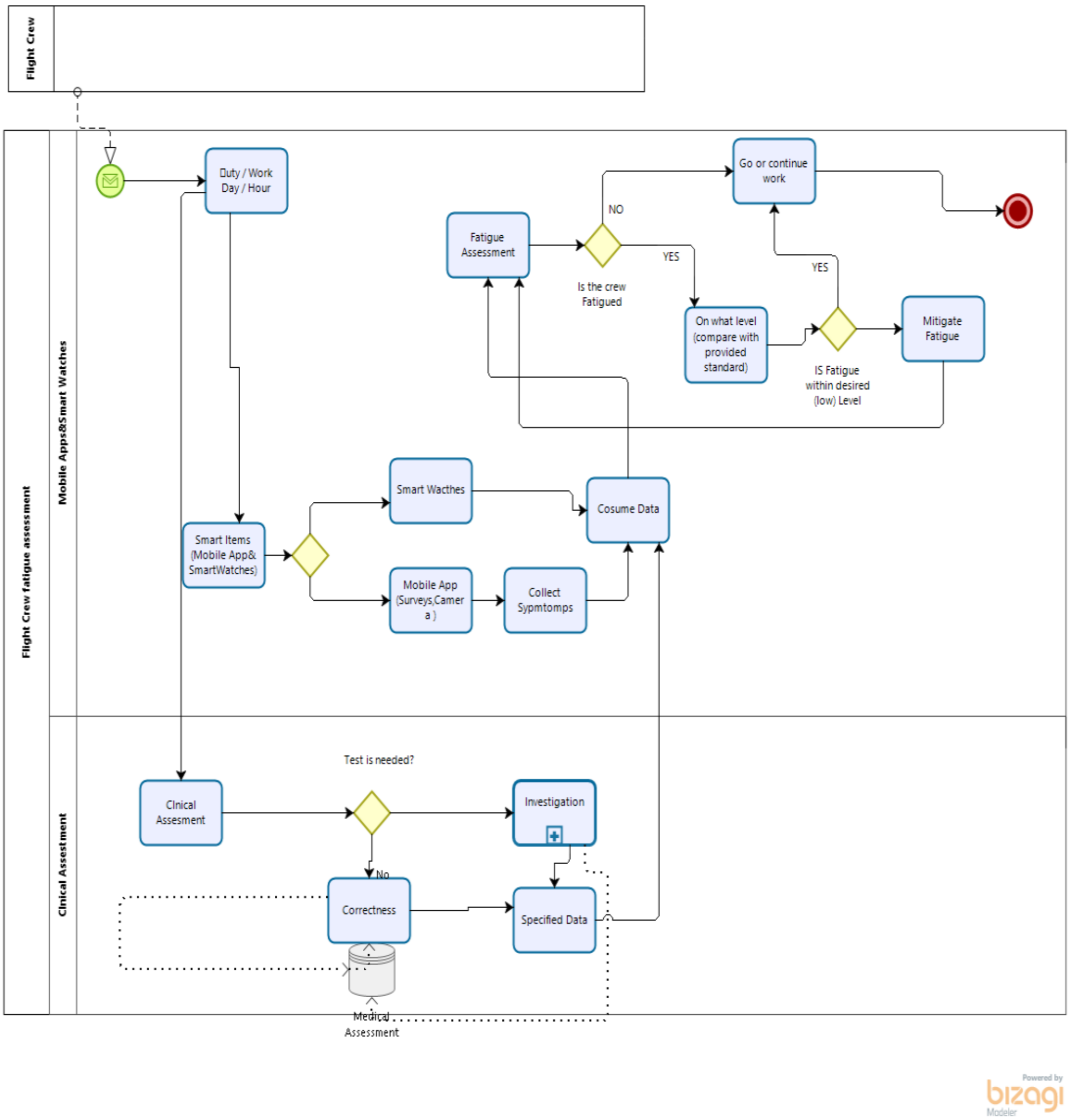

Figure 10 : BPM diagram representing FRMS method

4 Artefact/ process validation with case study

To validate the process presented in the above section a case study was done with 15 individuals. The researcher acted as evaluator which is presented in the process stated above. The purpose of acting as evaluator was to take into account the subjective input of the individuals whose data were taken into account.

During the procurement of the data, equipment that was available at hand was taken which were – apple watch and iPhone for the HRV data, self-administrable BP machine, sleep log(subjective data) from an individual, self-made flicker application for vigilance level, other subjective entries from a questionnaire. All the individuals who took part in the study were non-intoxicated with alcohol since as proposed in the model any high intoxication would mean taking immediate fatigue mitigation measures.

The acquired data was then put into a tabular form and their respective ratings were added into another table with results.

Table 15 : Data acquisition

Reading	BAC	BP	HRV	Vigilance Level	Sleep Amount
1	0	130/85	49	6-8	5+
2	0	130/90	32	6-8	4+
3	0	120/75	40	6-8	4+
4	0	130/80	55	6-8	6+
5	0	110/80	53	6-8	5+
6	0	130/90	52	6-8	5+
7	0	120/80	61	4-6	6+
8	0	140/90	24	4-6	<4
9	0	110/65	28	6-8	4
10	0	130/70	24	2-4	<4
11	0	120/70	32	6-8	4
12	0	130/70	26	6-8	4
13	0	120/80	45	6-8	5
14	0	120/80	40	6-8	5+
15	0	130/80	47	6-8	5+

The raw readings/data are given their respective ratings in the following table for the validation of the procedure. Along with these ratings the cumulative results, as well as the decision taken for each individual, is provided in the table below.

Table 16 : Data Ratings

No.	BAC Rating	BP Rating	HRV Rating	VL Rating	Sleep Rating	Cumulative Results	Decision
1	0	0.6	0	0.2	0	0.8	NF
2	0	0.3	0.4	0.2	0.2	1.1	F
3	0	0	0	0.2	0.2	0.4	NF
4	0	0.3	0	0.2	0	0.5	NF
5	0	0	0	0.2	0	0.2	NF
6	0	0.3	0	0.2	0	0.5	NF
7	0	0	0	0.5	0	0.5	NF
8	0	0.9	0.9	0.5	0.7	3.0	F
9	0	0	0.9	0.2	0.2	1.3	F
10	0	0.3	0.9	0.9	0.7	2.5	F
11	0	0	0.4	0.2	0.2	0.8	NF
12	0	0.3	0.9	0.2	0.2	1.6	F
13	0	0	0	0.2	0.2	0.4	NF
14	0	0	0	0.2	0	0.2	NF
15	0	0.3	0	0.2	0	0.5	NF

The table above shows the decisions that were based on the quantitative data gathered from various individuals during a certain time. For some of the data, it is better to have long term data which can be acquired from wearable devices used overnight. For the case study, short term data was taken and not all the individuals were in a resting phase state. This causes variation in data on a different level which can cause some data to be improper or slightly unfitting for accurate decision making. Due to such unwanted variation, the final decision in the conducted case study can have alterations. To further minimise the inaccuracies the final decision is examined by a supervisor(the researcher in this case) taking into account any random inconsistencies in the data or decision and other subjective details given by individuals on the matter of inconsistency.

Furthermore, alongside the quantitative validation, the research takes help from the W*H model developed by Dahanayake, A. and Thalheim, B.[80] for additional evaluation using a concept map. The concept map looks into the fatigue categories in different forms and presents elements that concern the categories in such a manner that various important details are highlighted such as:

- How the category is affected?
- Which symptoms are visible due to fatigue?
- What we need to measure and what sort of data is needed?
- What technology is available for measurement?
- When are the signs of fatigue seen on crew?

The concept map presented might not give us detailed quantitative results or data but the W*H model being a pre-established in the field, helps us generate a somewhat qualitative rationale to evaluate the result presented in the research. Details provided on the concept map has been taken from various researches and medical fields as well. The research and data details from [80][81][82][83][84][85][86][87][88][89][90][91] was taken to complete the concept map.

Table 17 : Concept Map using W*H model

Fatigue Categories	HOW: Influencing Factors	WHICH: Symptoms	WHEN: Indicators of Cabin Crew	WHAT: To Measure	WHAT: Data needed	WHAT: Technologies/tools available
Lifestyle	regular alcohol use	drowsy eyes, tiredness	less attentive	high blood pressure, irregular heartbeat	blood sample, urine sample, breath analysis	use of breathalysers, urine and blood test
	lack of physical activity	quick tiredness, physical pain	Quick exhaustion	muscular tension, breathlessness	electrical synapsis of the nerves	motor and sensory reflex test of muscles, self-reports
	emotional stress	mood swings, unstable mood	emotional breakdown	irregular brain/nerval activity	heart rate, breathing interval	different PDAs, use of ECG (electro cardio graph)
	overweight	body structure change,	prone to diseases, self-loathing	standard mass index to current state	body weight, height	BMI (Body Mass Index)
	physical exertion	tiredness, low interest	less attentive, quick exhaustion	self-report, other medical factors as heart rate, breathing status	electrical synapsis of the nerves, tension in muscles and ligaments	motor and sensory reflex test of muscles, self-reports
Physical Health conditions	anaemia	pale skin, insomnia, dizziness	tiredness, less attentive,	haemoglobin and iron count in blood	haemoglobin count, mean corpuscular volume, iron count	CBC (complete blood count) test
	arthritis	decreased range of motion, pain, stiffness	functionality, job duties hinderance, tiredness	swollenness of joints, loss of motion, blood test	physical deformity, motion data, blood test data	physical examination, x-ray, blood test
	eating disorder	rapid weight loss/gain,	prone to diseases, issues with self	eating attitude test, other psychological behaviour and tests	height, weight, heart rate, blood pressure, data on skin and nails	Rating of Anorexia and Bulimia (RAB) test, psychological aptitude test
	diabetic	frequent urination, blurry vision, extreme fatigue	prone to other diseases,	sugar level in blood, glucose tolerance	glucose and sugar level, BMI (body mass index)	blood test for sugar and glucose level, Glycated haemoglobin (A1C) test,
	allergies	rashes, irritation, shortness of breath	transferrable, causes hindrance in duties and work area	skin test, blood test	IgE (immunoglobulin E test) level, antibody count in body	blood and skin test
Mental Issue	anxiety	nervousness, hyperventilation, weakness	tiredness, breathlessness, emotional instability	self-report, psychometric data	reports, Q&A, characteristics of patients	mental and physical test, blood and urine test, behavioural aptitude test
	depression	fatigue, melancholy, sadness	emotional instability, trust issue	self-report, psychometric data	primary care/physician data, medications in use	mental/physical test, blood/ urine test, behavioural aptitude test
	Medication	nausea, upset stomach	various	contents of medication	prescriptions, dosage of use	standard dosage Vs prescribed dosage

5 Discussion and Limitation

The research presents a model to determine if a crew member is fatigued or not. The further work would be for the actual implementation of the model into an application to view the results in real-time.

Currently, there are many other applications which are in use, there also exist other models and frameworks which are under practise in the aviation industry for the assessment of fatigue alongside fatigue management guidelines. These, however, are based on the pilot mostly or ones that are based on both have more of a subjective data in them. Furthermore, the variables included in them are not adequate to precisely determine fatigue in a crew member – meaning most of the application, models, framework use often circadian rhythm (sleep data) and flight time for accessing fatigue along with some biomathematical data as polysomnography, psychomotor vigilance, etc for input. The model presented in the research looks into more variety of data to ensure better results.

Some of the widely used fatigue assessment models currently are:

- (Fatigue Avoidance Scheduling Tool) FAST
- (Fatigue Audit InterDyne)FAID
- (System for Aircrew Fatigue Evaluation) SAFE
- (Boeing Alertness Model) BAM

As briefly stated in the literature, FAST is a tool devised with SAFTE model which correlates to sleep, activity fatigue and task effectiveness model. The main idea of the model revolves around the data of - sleep acquired by a crew or how much sleep deprived is an individual. Concerning this, the model takes into consideration the circadian rhythm or sleep factor. This is further taken in to account in regards to duty time, the period of sleep, time zone changes.

FAID, on the other hand, is a tool that gives an expected fatigue score which is predetermined at a specific time. Although this might seem similar to the research proposed, this tool mainly uses each work period along with sleep and recovery data for projecting its data. Mainly, some airlines have been using this tool to better determine the work and rest schedules for its crews.

SAFE also is known as the System for Aircrew Fatigue Evaluation works in a similar way to the above tools/models. It includes into its data the influence of sleep, circadian rhythm, the working environment of the crew along with the rules and regulations constructed around it. some of the aviation industry are using this to autonomously assess flight schedules.

The BAM is yet another model which is used in the aviation industry by integrating into the FRMS. It is focused on the crew schedule planning as well as various work details planning on a day to day basis. The main positive side to this model is that it is configurable into the other management systems that might be in use already to better increase the efficiency of the tool or model. Taking into account different data as rostering and sleep data this model can provide an estimation of alertness in the form of a range.

When all such current models are taken and looked into, they all seem to perform what they are set out for but ultimately they cannot encompass all the variability that can alter the outcome in assessing the fatigue in a crew member. Stating this, the author is not proposing that the research provides all the needed variability in the research but focuses on the fact that the research takes in more variables in account to access fatigue in a cabin crew. In contrast to the already available tools and models, the research has covered the variables included in the currently available models/tools and more. Even this small amount of increase in variables can give a better assessment when it is developed into a tool or application for real-time use. As with more variability, we can have a better assessment of the problem at hand and the efficiency of better assessment can increase. To further elaborate, the research is mainly showcasing a different path that can be used to better evaluate fatigue and reveal other factors or characteristics that fatigue possesses. The risks are always immense when it comes to any problem within the aviation industry, as such is the case of fatigue that might give rise to hazards in operation.

Changes in technology are always happening and with demanding criteria, it is always best to keep changing for the better. The research encompasses the already included variables and adds more for better assessment of fatigue and to better understand its risks. The presented model is not standalone and would work alongside with the other regulations(training and FTLs) that are imposed by the various international organisations like IATA, ICAO, etc.

6 Conclusion

The research has gone through the process of showcasing what fatigue is and how it is a problem in the current scenario in the organisation. Mainly focusing on the matter of the aviation industry where slightest of mistakes causes and creates a huge impact of different magnitude. Using the process of systematic literature review the research dives deeper into the context at hand. A brief history of aviation reveals how aviation has been and is an enormous and integral part of civilization. The research further elaborates on the problems that have happened in the past in the aviation due to varying causes and try to relate them to fatigue where further it tries to narrow it down to the cabin crew members. A narrowed-down approach on the Risk management system reveals some of the hidden symptoms, causes and consequences of fatigue in the research. Diverse ways of monitoring and measuring fatigue in the current contexts are also seen in the literature which provides more insight on the topic. Lastly, the literature ends with some of the countermeasures that are prominent and in wide use for the elimination or mitigation of fatigue.

The question discusses in the research were:

1. What are the fatigue characteristics of the airline cabin crew?
2. What should constitute the framework for the identification of fatigue characteristics for FRMS?

The research tackles the first question by, looking at the different signs that are seen on an individual while looking at effects of the variables defined in the artefact development section of the research. Further, the research also incorporates the W*H model while doing the evaluation, this gives us varying details on the symptoms, indications, etc of fatigue. Using these ways the research looks into the different characteristics possessed by fatigue which can be seen on the airline cabin crew as well. The details for this are given in the section 3 and 4 of the research.

To answer the second question in the research, some variables have been defined and their ability to help in determining fatigued individual have be tested using a case study. This is elaborated in the artefact development phase of the research. Alongside this, an assessment model is also presented to briefly show the working mechanism.

We need to consider here that, everything that has been proposed in the research might be hard to put into live practice immediately but, the presented idea is viable and partial implementation and further testing can be done prior to full.

Although the research has proposed something different than what is available, without further development and practical implementation, the exact efficiency of the framework cannot be known. Also, as it is with all technological matter, evolution and change is inevitable, keeping this in mind by the time this research is completed others may have developed or proposed something similar.

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