IMPACT OF FATIGUE AS A HUMAN FACTOR IN AVIATION: A CONCEPTUAL MODEL DEVELOPMENT AND AN APPLICATION ON FLIGHT TRAINING STUDENTS.

A THESIS SUBMITTED TO

THE GRADUATE SCHOOL OF GRADUATES STUDIES

OF

UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION

BY

Alphonse NDAYAMBAJE

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTERS OF SOCIAL SCIENCE IN
AVIATION MANAGEMENT

JULY 2024

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I affirm that the information contained in this document adheres to academic standards and ethical principles. Furthermore, I confirm that, in compliance with these standards, I have included comprehensive citations and references for all materials and findings that are not original to this work.

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ABSTRACT

IMPACT OF FATIGUE AS A HUMAN FACTOR IN AVIATION: A CONCEPTUAL MODEL DEVELOPMENT AND AN APPLICATION ON FLIGHT TRAINING STUDENTS

Alphonse NDAYAMBAJE
Master of Science, Aviation Management
Supervisor: Assoc. Prof. Dr. Dursun Balkan

July 2024, 128 pages

Managing human factors is vital in the aviation management sector for ensuring flight safety and operational continuity. In this regard, one of the most critical human factors is fatigue, which involves physical, emotional, and mental fatigue due to factors like irregular sleep patterns, inadequate rest, and prolonged working hours. In this study, a conceptual and comprehensive framework is developed to combine all the factors that lead to decreased pilot fatigue levels, and a research model is created to assess the impact of pilot fatigue levels on decision-making performance based on key selected fatigue factors. The model is designed to assist in assessing, analyzing, and managing the fatigue levels experienced by student pilots during training and flight operations. Via this model, factors contributing to fatigue are investigated in three flight training schools (one European Union country and two in Türkiye), utilizing a survey-based approach. The survey is conducted with a total sample of 330 participants, and 179 provided responses. Data is collected using an online survey with random sampling. Gathered data is analyzed by applying Structural equation modeling hypothesis testing using Excel and analysis software. As per the findings, the survey revealed that lack of quality sleep , poor scheduling of academic classes, flying along-cross country and poor scheduling of academic activities appear as the most dominant factors leading to fatigue , thus impacting pilot decision making performance. This study is valuable by providing insights to enhance aviation safety, improve training programs and enable better preparation for the flight training students.

Keywords: aviation, human factor, fatigue, training students, structural equation modelling.

ÖZ

HAVACILIK YÖNETIMINDE İNSAN FAKTÖRÜ OLARAK YORGUNLUĞUN ETKISI: KAVRAMSAL MODEL GELIŞTIRME VE PILOTAJ ÖĞRENCILERI ÜZERINE BIR UYGULAMA

Alphonse NDAYAMBAJE
Yüksek Lisans, Havacılık Yönetimi
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Temmuz 2024, 128 sayfa

Havacılık Yönetimi sektöründe uçuş emniyetinin ve operasyonel sürekliliğin sağlanması açısından insan faktörünün yönetilmesi hayati önem taşımaktadır. Bu bağlamda en kritik insan faktörlerinden biri, düzensiz uyku düzeni, yetersiz dinlenme, uzun çalışma saatleri gibi faktörlerden kaynaklanan fiziksel, duygusal ve zihinsel yorgunluğu içeren yorgunluktur. Bu çalışmada, pilot yorgunluk seviyesine yol açan tüm faktörleri bir araya getiren kavramsal ve kapsamlı bir çerçeve geliştirilmiş ve seçilen temel yorgunluk faktörlerine dayanarak pilot yorgunluk seviyesinin karar verme performansı üzerindeki etkisini değerlendirmek için bir araştırma modeli oluşturulmuştur. Model, öğrenci pilotların eğitim ve uçuş operasyonları sırasında yaşadıkları yorgunluk seviyelerinin değerlendirilmesine, analiz edilmesine ve yönetilmesine yardımcı olmak üzere tasarlanmıştır. Bu model aracılığıyla biri Avrupa Birliği ülkesinde, ikisi Türkiye'de olmak üzere üç uçuş eğitim okulunda yorgunluğa katkıda bulunan faktörler ankete dayalı bir yaklaşımla araştırılmaktadır. Toplam 330 kişilik örneklemder ankete 179 katılımcı yanıt vermiştir, ve veriler rastgele örneklemeli çevrimiçi bir anket kullanılarak toplanmıştır. Toplanan veriler, Excel ve analiz yazılımı kullanılarak yapısal Esitlik modelleme ve hipotez testleri uygulanarak analiz edilmiştir.Bulgulara göre anket, kaliteli uyku eksikliğinin, akademik derslerin kötü programlanmasının, ülke çapında uçmanın, akademik faaliyetlerin kötü programlanmasının yorgunluğa yol açan ve dolayısıyla pilot karar verme performansını etkileyen en baskın faktörler olarak göründüğünü ortaya çıkardı. Bu çalışma, havacılık emniyetini artırmaya, eğitim programlarını geliştirmeye ve uçuş eğitimi öğrencilerine daha iyi hazırlanmaya yönelik bilgiler sağlaması açısından değerlidir.

Anahtar kelimeler: Havacılık, İnsan faktörü, yorgunluk, eğitim öğrencileri, yapısal Esitlik modelleme.

DEDICATION

This dissertation is dedicated to my wife, Jane INGABIRE and my son, Nolan ISHEMA whose unwavering support, encouragement, and motivation have been indispensable to me during this entire journey. I also dedicate this work to all my friends who are currently student pilots at different universities, one in a European Union country and the others in Türkiye.

In addition, I extend heartfelt appreciation to the piloting students from our university. The consistent support and priceless feedback you offered have been integral in guiding the development of my thesis. The depth of your insights and contributions has truly elevated the quality of this work.

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In conclusion, I am deeply grateful to all piloting students who participated in this research survey. Their invaluable contributions were essential in the completion of my study.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURES

LIST OF TABLES

TABLES

LIST OF ABBREVIATIONS

BAC	Blood-Alcohol Concentration
CMD	Conceptual Model Development
DSS	Decision Support System
EASA	European Union Aviation Safety Agency
ECA	European Cockpit Association
ERSO	European Road Safety Observatory
NASA	National Aeronautics and Space Administration
NBAA	National Business Aviation Association
NTSB	National Transportation Safety Board
PVT	Psychomotor Vigilance Test
RCA	Root Cause Analysis
SEM	Structural equation modeling
WOCL	Window of Circadian Low

CHAPTER 1

INTRODUCTION

1.1 General Background

The origin of the word "fatigue" can be traced back to the Latin word "fatigare," which means "to tire out" or “to exhaust." from Latin, it was adopted into old French as "fatiguer," retaining the same meaning. Eventually, it made its way into Middle English as "fatigue" during the 17th century. From that day on, fatigue is still useful in its spelling and pronunciation and has remained relatively unchanged in its spelling since then.

According (Robert , 2013), One of the challenges in scientifically researching fatigue is that ‘‘the term appears to have institutionalized meaning among scientific groups like psychologist, physiologists , Sociologists, engineers and so on.

From a psychological perspective, fatigue has been defined as a state of weariness related to reduced motivation (Lee, Hicks & Nino, 1991). Psychological fatigue is characterized by difficulties in concentration, decreased cognitive performance, slowed reaction time, increased irritability, physical symptoms, sleep disturbances, lack of motivation, memory impairment, and difficulty making decisions, and heightened emotional sensitivity. Managing it typically involves rest, stress management, and maintaining a healthy lifestyle. Stress and other powerful emotional events have been linked to psychological tiredness, which can accompany depression and anxiety.

Fatigue is described as functional organ failure from a physiological perspective (Berger, 1991) Such organ failure generally is attributed to excessive energy consumption and can be characterized by the depletion of hormones,

neurotransmitters or essential substrates of physiological function Physiological fatigue connected with infection, fever, anemia, sleep disturbances and pregnancy.

The given physiological fatigue example in endurance exercise, like running a marathon, results from factors such as glycogen depletion, metabolic byproduct accumulation, electrolyte imbalance, central nervous system changes, muscle damage, dehydration, hormonal fluctuations, and increased core body temperature. These factors collectively contribute to a temporary decline in physical performance.

Fatigue, from an engineering perspective refers to the physical and mental weariness experienced by individuals working in the field of engineering. This can result from various factors and may have significant implications for both individuals and the projects they are involved in. Here are some key aspects related to fatigue in engineering personnel, such as long working hours, high workloads, project pressures, mental strain, inadequate sleep, physical demands, monotonous tasks, poor work-life balance, environmental factors, and a lack of social support.

To mitigate fatigue, organizations can implement strategies such as workload management, flexible work arrangements, training and support, regular breaks, and health and wellness programs. Addressing fatigue is crucial not only for the well-being of engineering personnel but also for the overall success and safety of engineering projects.

When you run out of energy to spend on yourself and others, this is referred to as social fatigue or social exhaustion (Gullot, 2023). Sociological fatigue can manifest in a variety of ways. One manifestation of these phenomena could be burnout because of constant engagement with critical societal concerns. For example, social justice scholars and advocates may become emotionally exhausted after lengthy exposure to the terrible realities they aim to understand and change.

On the other side, sociological fatigue can also refer to a feeling of overload caused by the field's extensive web of theories and concepts. Students who are traversing the complexities of sociological frameworks may become exhausted as they battle with varied perspectives and strive to reconcile seemingly contradicting notions.

Whether it's the emotional toll of confronting societal problems or the academic struggle of understanding complicated ideas, sociological tiredness emphasizes the importance of a healthy work-life balance.

Recognizing these characteristics is crucial for understanding and managing fatigue effectively because it can take different forms and can affect individuals physically, mentally, and emotionally. Physically, it presents as an overwhelming sense of weariness, often accompanied by muscle weakness and a lack of energy, making routine activities difficult. Mentally, fatigue induces cognitive fog, hampering concentration, memory, and decision-making abilities. Emotionally, it triggers irritability, mood swings, and a general sense of frustration that needs treatment. Most of the time fatigue can be traced to one or more lifestyle issues, such as poor sleep habits or lack of exercise and so on.

In aviation, pilots contend with three main types of fatigue: transient, cumulative, and circadian (FAA, 2012). Transient fatigue emerges abruptly from severe sleep deprivation or extended wakefulness over 1-2 days. Cumulative fatigue results from repeated mild sleep restriction or prolonged wakefulness across consecutive days. Circadian fatigue denotes reduced performance during nighttime hours, particularly within the "window of circadian low" (WOCL) from 2:00 a.m. to 05:59 a.m. Identifying these types, helps tailor strategies for managing fatigue, whether through lifestyle changes, seeking medical advice, or practicing relaxation techniques to restore balance and well-being (Percy, 1920).

Fatigue can be attributed to three primary categories of causes: Individual or personal factors (such as age and domestic responsibilities), Environmental factors (like ambient temperature and noise levels), and work-related factors (such as work schedules and prolonged working hours. Fatigue can arise from various factors, including inadequate sleep, poor diet, stress, lack of physical activity, medical conditions, medications, dehydration, excessive caffeine intake, and environmental factors (Barhum, 2021).

Symptoms of the fatigue vary with mental, physical, and emotional manifestations including sleepiness, apathy difficulties in concentrating, attention lapses, decreased vigilance, increased reaction time, task fixation, slowing of higher-level mental functioning, miscommunication, and lack of motivation, irritability and emotional sensitivity to increased errors while performing tasks especially during divergent processing (knowledge-based, innovative, creative problem solving) (Göker, 2018).

The consequences of fatigue in aviation can be severe and affect various aspects of flight operations: decreased cognitive performance, impaired judgment, increased errors, reduced alertness and vigilance, physical impairment, and may contribute to serious accidents. Fatigue impairs cognitive and physical abilities, necessitating proper crew rest and duty schedule management. Insufficient resources can compromise safety. Lack of assertiveness, Pressure, lack of awareness, stress, and acceptance of unsafe practices can also contribute to accidents.

Based on data from accident statistics, fatigue is emerging as a growing concern in aviation operations, feedback from pilots, and operational flight studies. Sleep deprived people move and think more slowly, make more mistakes, and have memory problems than well-rested people. An NBAA survey published on May 13, 2019, revealed that 54% of operators regard fatigue as a serious concern. Data from NASA's Aviation Safety Reporting System indicates that approximately 21% of reported aviation incidents are attributed to fatigue. The NTSB finds that 88 percent of aircraft mishaps are caused by fatigue.

We cannot talk about fatigue in aviation without talking about 12 dirty dozen in aviation where fatigue comes from Gordon Dupont introduced the "Dirty Dozen" concept in 1993 during his time at Transport Canada. It was subsequently integrated into fundamental training modules aimed at enhancing Human Performance within the transportation industry. It refers to twelve common human factors or behaviors that can contribute to accidents and errors in aviation. These factors highlight the role of human error, communication breakdowns, teamwork issues, and decision-making challenges in aviation safety.

While the specific factors may vary in different discussions, the "Dirty Dozen" acts as a prompt to underscore the significance of addressing these human factors to enhance safety and prevent accidents in the aviation industry. In aviation, the concept of the "Dirty Dozen" encapsulates twelve critical human factors that significantly contribute to accidents and incidents within the industry. These factors encompass a range of issues, including lack of communication among crew members or with air traffic control, complacency stemming from routine operations leading to overlooked safety protocols, lack of knowledge or application of procedures, and distractions that divert attention from crucial tasks. Additionally, issues like lack of teamwork, fatigue, lack of awareness, pressure to perform within time constraints, lack of resources, lack of awareness, stress, reluctance to assert safety concerns, difficulty adapting to changes, and organizational norms tolerating unsafe practices round out this comprehensive list.

Identifying and actively addressing these factors through targeted training, awareness campaigns, and improved operational strategies is essential to fortifying aviation safety protocols and preventing avoidable accidents (Prieto, 2021).

According to reports published by Business Aviation Insider on May 13, 2019, both long and short-distance missions, contribute to fatigue. Extended flights can keep flight crews awake for over 20 hours, while shorter flights involving rapid turnarounds and multiple legs can be physically draining. Research indicates that attempting to function after being awake for 18 hours is comparable to having a blood alcohol content of 0.5 percent, a level deemed unacceptable for ground transport, flying, or aircraft maintenance. More complex round-the-clock aviation operations can push flight and ground crews to their physical and mental limits.

Aviation fatigue is a major concern in the aviation business, affecting the safety and performance of pilots, crew members, and even ground crew. The aviation sector faces significant challenges due to factors such as disruptions to circadian rhythms, long working hours, and unpredictable schedules. Fatigue poses a substantial risk in aviation due to its detrimental impact on cognitive abilities, decision-making, and performance, heightening the potential for catastrophic errors. Strict regulations by

aviation authorities mandate compliance with fatigue-related guidelines, ensuring safety and preventing legal repercussions.

Various regulatory authorities, such as the Federal Aviation Administration (FAA) in the United States and the European Union Aviation Safety Agency (EASA), have implemented standards and limitations on duty hours to combat aviation fatigue. These regulations aim to ensure that flight crew members have sufficient rest periods between flights and adequate time for recuperation. Efforts to mitigate aviation fatigue involve strict regulations, comprehensive fatigue risk management systems, and the implementation of strategies like controlled rest periods, adequate scheduling practices, and education on sleep hygiene. Airlines and aviation authorities continually refine policies and procedures to address this issue, emphasizing the importance of crewmembers being well-rested before and during their flights.

1.2 Significance of the Study

This study concentrates on examining how fatigue affects student pilots, enhancing aviation safety, and improving training programs. It helps develop better training methods, optimize performance, and ensure regulatory compliance. Understanding fatigue's effects on physical and mental health can lead to better well-being strategies.

This research also provides aspiring pilots with a realistic view of career challenges and equips them to prepare for the aviation profession. By understanding fatigue's effects, the aviation industry can reduce pilot fatigue, improve operational efficiency, contributing to overall safety, and propose strategies for the prevention and management of fatigue, with the ultimate goal of enhancing the quality of pilot training, improving safety, and promoting the well-being of future aviators. To achieve this objective, a conceptual and comprehensive framework is developed to combine all the factors that lead to pilot fatigue level, and a research model is created to assess the impact of pilot fatigue level on decision-making performance based on key selected fatigue factors. This model is informed by various readings, and

innovative ideas. After developing the model, we chose to focus on one aspect: examining the relationship between fatigue levels and factors related to training, workload, lifestyle, and decision-making performance of student pilots, rather than addressing the entire framework.

1.3 Research Questions and Hypotheses

The aim of this study is to answer the subsequent research questions:

1. How does training, workload, and lifestyle factors collectively influence the fatigue level of student pilots?
2. How does the fatigue level affect the decision-making performance of student pilots in aviation?

1.4 Statement of the Problem

The problem of fatigue among flight training students in aviation is a multifaceted issue with several critical aspects. Flight training is known for its rigorous demands, including extensive flight hours, complex theoretical knowledge, and the need for precision, which can lead to stress, burnout, and fatigue among students. The fatigue has serious safety implications, as it may lead to decreased alertness, slower response times, and impaired decision-making, potentially resulting in accidents and incidents.

The absence of standardized regulations for student pilots' rest and duty hours further the risk of fatigue. Additionally, psychosocial factors such as stress, anxiety, and performance pressure play a significant role in student pilot fatigue and require a better understanding.

Moreover, fatigue among student pilots hampers flight training program efficiency and contributes to the shortage of pilots issue in the aviation industry. There's a pressing need for evidence-based, comprehensive strategies that encompass

workload management, psychological support, and education to address this issue effectively.

1.5 Scope of the Study

In this study, fatigue is going to be considered in the aviation sector and the scope involves student pilots candidates in one European Union Country and Türkiye in order to understand whether flight students are fatigued. This study investigates factors influencing fatigue in student pilots through a comprehensive questionnaire, exploring the interplay of training, workload, and lifestyle to understand their collective impact on fatigue levels and subsequent effects on decision-making performance, how to mitigate it, and consequences if not complied with.

This thesis is structured into seven sections, each meticulously crafted to investigate student pilot fatigue in aviation. The Introduction sets the stage, providing an overview of the research landscape, including the problem statement, significance, and research questions. Chapter II delves into existing literature on fatigue, drawing from various disciplines to enhance understanding. In Chapter III, attention shifts to the development of a framework and research model, to aid decision-making in the cockpit amidst fatigue. Chapter IV outlines the methodology and data processes used in the study. Chapter V presents findings and analysis derived from empirical data, shedding light on the impact of fatigue on student pilots. Chapter VI explores the implications of these findings (Discussions) across the aviation industry and beyond. Finally, Chapter VII concludes the thesis with insights that rise above challenges and suggests future research directions for ensuring the safety of student pilots and limitations.

CHAPTER 2

LITERATURE REVIEW

Fatigue remains a prominent concern in the aviation industry, significantly affecting the operational performance, safety, and overall well-being of flight crews and personnel. In the previous chapter, we discussed the background, providing context; the problem statement, which identifies the issue; the significance, which underscores its importance; and the research questions, which illuminate the path forward. In this chapter, we focus on the previous researchers' contributions to understanding fatigue in aviation and their effects on student pilots.

2.1 Conceptual background of fatigue

The history of fatigue, from 1838 when Wilhelm Albert wrote the first known article on metal fatigue, to the present, is described in detail, with special emphasis on the German contribution in the years 1920–1945 (Schlitz & Walter, 1996) .The initial investigations into fatigue began within the industrial sector, focusing on its impact on productivity.

Research on pilot’s fatigue began during World War II in the 1940s, prompted by the demands of wartime aviation. Various countries, including the United States, the United Kingdom, Germany, Japan, and others, undertook crucial studies to understand the effects of prolonged flight operations on pilots' performance and well-being. The urgency of mitigating fatigue to ensure pilot safety and mission success drove these efforts, laying the foundation for subsequent research in aviation medicine and human factors. Since then, global efforts have continued to advance our understanding of pilot fatigue, aiming to develop effective strategies to manage fatigue-related risks and enhance pilot well-being and performance.

After World War II, there was a shift in scientific comprehension, delving into the physiological, psychological, and occupational aspects of fatigue. There are several up-to-date studies on fatigue listed below in table 1.

Table 1: Summary of related studies

Author	Subject	Contribution
(ECA, 2012)	Pilot fatigue Barometer	Evaluates the fatigue levels of European pilots
(Australian Civil Aviation Safety Authority, 2012)	Fatigue Management Strategies for Aviation Workers: A Training & Development Workbook	Aims to enhance aviation safety by effectively addressing fatigue-related risks within the aviation industry
(Alwin van Drongelen, 2016)	Risk factors for fatigue among airline pilots	Determines fatigue risk factors for pilots in aviation
(Mendonca, 2019)	Fatigue Identification and Management in Flight Training: An Investigation of Collegiate Aviation Pilots	Evaluates collegiate aviation students' self-awareness of their fatigue issues; to investigate possible causes of fatigue afflicting collegiate aviation students; and investigates the lifestyle of collegiate aviation students and their views on personal strategies for managing fatigue.
(Branislav Kandera, 2019)	The Consequences of flight crew fatigue on the safety of civil aviation	Establishes an objective measure for fatigue, focusing on evaluating sleep, a critical aspect of fatigue.
(Matthew, 2020)	Fatigue in Collegiate Flight Training	Enhances our comprehension of the effects of fatigue on students within a collegiate flight training environment.
(Craig & al, 2023)	Prevalence of fatigue among commercial pilots	Determines the level of subjective fatigue reported by short-haul pilots and compare the experiences between low-cost and scheduled airline pilots.
(Julius, 2022)	Understanding Factors Underlying Fatigue among Collegiate Aviation Pilots in the United States	Explores fatigue as a multifaceted phenomenon and to evaluate potential associations among these factors using proposed measurement models.
(Mustafa, 2022)	An exploration of the causes and effects of flight attendant fatigue in Turkish aviation	The origins and consequences of fatigue among flight attendants employed by a Turkish airline company, utilizing a self-administered questionnaire.

Table 1: Summary of related studies (Continued)

Author	Subject	Contribution
(Lucia et al., 2022)	The relationship between workload, performance and fatigue in a short-haul airline.	Establishes the correlation between pilot workload, performance, subjective fatigue, sleep duration, number of flight sectors, and flight duration in short-haul operations.
(Craig & al, 2023)	Factors contributing to self-reported student pilot fatigue	Explores whether flight students encounter fatigue, the factors influencing their inadequate sleep, and the extent to which time management contributes to this phenomenon.
(Rõbinkov, 2003)	Perspectives on pilots' fatigue risk management in Estonian short-haul passenger airlines	Investigates the causes of fatigue among pilots in Estonian short-haul passenger airlines. It seeks to highlight concerns related to fatigue risk management and provide recommendations to improve flight safety in this specific sector of the aviation industry.
(Teo, 2020)	An analysis of collegiate aviation pilots and fatigue	Explores the causes and symptoms of fatigue among collegiate aviation students, investigate the statistical association between enrollment status and willingness to fly fatigued, and assess the predictive value of age and flight hours in determining this willingness.
(Sun Jun-Ya, 2023)	Pilot fatigue survey: A study of the mutual influence among fatigue factors in the "work" dimension	Examines the interconnectedness of factors influencing fatigue within the "work" dimension in analyzing the causes of pilot fatigue.
(simmons, 2023)	A fatigue survey of European Pilots	Proactively identifies fatigue signs and contributors before the summer peak, sharing results publicly to aid industry improvement. This includes informing National Aviation Authorities (NAAs) and supporting European Union Aviation Safety Agency (EASA)'s standardization efforts.

Based on the above summary table research conducted in the aviation industry, particularly focusing on pilots, there has indeed been a comprehensive examination

of various dimensions of fatigue. Researchers have delved into pilot fatigue, strategies for managing it, and its impact on flight safety. Notable contributions include studies that specifically analyze the fatigue levels of European pilots and identify risk factors unique to airline pilots.

Through a deep understanding of the underlying causes and the development of targeted interventions, researchers strive to minimize fatigue-related risks, thereby ensuring the safety and well-being of both pilots and passengers. These concerted efforts underscore a dedicated approach to tackling flight crew fatigue and fostering a safety-oriented culture within the aviation profession.

A significant focus within this body of research lies on collegiate aviation students, who face unique challenges in managing fatigue. Studies in this area explore students' self-awareness of fatigue issues, investigate underlying causes, and propose strategies for effective fatigue management. Additionally, proactive initiatives aimed at sharing research findings publicly and supporting standardization efforts highlight the industry's dedication to addressing fatigue-related risks. By disseminating knowledge and implementing best practices, researchers seek to enhance safety measures and promote continuous improvement in fatigue management practices, ultimately contributing to safer flight operations and improved well-being for aviation personnel and passengers alike.

In the 21st-century transportation sector, there have been developments enabling 24/7 operations, affecting working hours. Many incidents in civil aviation have been linked to fatigue as a significant factor. It is widely recognized that fatigue stands out as the primary cause of accidents. While plane crashes can be attributed to various factors, it has been established that fatigue ranks among the foremost reasons for such incidents.

There is no universally recognized definition of fatigue that is accepted across all contexts because different fields have different definitions and have something to contribute to fatigue as an overarching, diffuse and multidimensional concept. However, because of the specific pastimes of researchers and the desire to

operationalize fatigue for particular sorts of studies, the maximum definitions so far may also have been narrow, effectively defining and measuring only a part of the equal fatigue.

FAA defines fatigue as a physiological state in which there is a decreased capacity to perform cognitive tasks and an increased variability in performance as a function of time on task. Fatigue is also associated with tiredness, weakness, lack of energy, lethargy, depression, lack of motivation, and sleepiness (FAA, 2016).

In the same manner, The International Civil Aviation Organization (ICAO) defined fatigue as a physiological state of reduced mental or physical performance capability resulting from sleep ,circadian phase, loss or extended wakefulness, 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 (ICAO, 2020).

2.1.1 Sleep Quantity and Quality as Fatigue Factors

Sleep quantity refers to the number of hours an individual sleeps and how consistently they maintain this pattern. For adults, the recommended sleep duration typically falls between 7-9 hours per night. Consistently obtaining less sleep than this recommended amount can lead to a cumulative sleep debt, resulting in heightened fatigue and decreased alertness.

Moreover, irregular sleep patterns, such as frequent changes in sleep-wake times or inconsistent sleep schedules, disturbances to the body's natural biological clock, commonly referred to as the circadian rhythm, can directly impact the quality of sleep. These disruptions can contribute to fatigue and impaired cognitive function. Overall, maintaining a consistent sleep schedule within the recommended duration range is crucial for minimizing sleep debt and promoting better alertness and cognitive performance.

The law of sleep is processed with the beneficial useful resource of the usage of the homeostatic body form of the circadian rhythm, the sleep/wake cycle. These daily

patterns are connected with specific brain wave activities, hormone releases, cellular regeneration, and other biological processes. Without this internal circadian clock, humans would struggle to optimize energy usage and internal bodily functions (Sujana, 2023).

Several pieces of advice from scientists state that improving sleep quality and quantity is crucial for overall health and well-being. Consistently adhering to a regular sleep pattern, aiming for 7-9 hours of sleep nightly, is crucial for alleviating fatigue. Implementing a calming bedtime routine, such as reading or enjoying a warm bath, helps signal the body to relax. Moreover, enhancing the sleep environment by ensuring a comfortable, cool, and dark setting can significantly improve sleep quality (Xinbo Xu, 2023).

Avoiding screens, heavy meals, caffeine, and alcohol intake before bedtime remains crucial, directly influencing the quality of sleep experienced. Simultaneously, engaging in regular exercise earlier in the day positively contributes to improved sleep quality. By adopting these practices, individuals can foster an environment conducive to better sleep, steering clear of disruptive factors like large meals, stimulants, and activities that hinder relaxation at bedtime. This comprehensive strategy not only promotes longer and more restful sleep but also actively combats factors that often lead to disrupted or restless nights, ultimately contributing to overall well-being and reduced fatigue (Kohyama, 2022).

2.1.2 The Physical Effects of the Atmosphere and Fatigue

The atmospheric conditions within an aircraft significantly influence a pilot's mental and physical state, potentially leading to fatigue. Environmental factors like noise, temperature variations, and pressure changes directly affect a pilot's comfort and concentration during flight. High noise levels in the cockpit can contribute to stress and hinder a pilot's ability to maintain focus, leading to increased fatigue over time.

Variations in cabin pressure and temperature can cause discomfort and bodily stress, impacting a pilot's overall well-being during long-haul flights. Furthermore, limited

oxygen levels in the cockpit may contribute to feelings of tiredness and diminished cognitive abilities, amplifying fatigue. Diminished oxygen levels in high-altitude environments or areas with poor air quality lead to hypoxia. This condition arises when the body doesn't receive adequate oxygen to sustain normal bodily functions. Hypoxia symptoms include shortness of breath, confusion, rapid heart rate, and fatigue, showcasing the body's vulnerability to oxygen deficiency.

Exposure to excessive solar radiation, particularly without proper protection, can cause sunburn, dehydration, and heat-related exhaustion, all of which contribute to physical fatigue.

Furthermore, wind and air movement, while refreshing in moderation, can be exhausting if strong or carrying irritants like dust or allergens, impacting respiratory health and overall energy levels. Some medical conditions such as chronic fatigue syndrome, fibromyalgia, anemia, or thyroid disorders can result in ongoing fatigue, disrupting everyday activities. Additionally, poor nutrition and inadequate hydration play a role in fatigue, reducing energy levels and impacting bodily functions, further amplifying feelings of tiredness (Mark, 1998).

Understanding atmospheric factors and their impact on the body is pivotal in managing fatigue-related issues. Awareness of air pressure changes and reduced oxygen levels at higher altitudes helps individuals prepare for altitude sickness, mitigating symptoms like headaches and fatigue. Knowledge about extreme temperatures and humidity empowers people to take precautions to prevent heat-related exhaustion and weakness. Recognizing the relationship between physical exertion, mental stress, and fatigue assists in adopting strategies to minimize their effects, ensuring adequate rest and stress management. Additionally, comprehending the role of sleep deprivation, medical conditions, and nutrition in fatigue enables individuals to make informed lifestyle adjustments, prioritizing quality sleep, seeking medical guidance, and maintaining a balanced diet to combat persistent tiredness.

2.1.3 Motivation and performance, as well as mental fatigue

Motivation is a driving force that influences human actions at all times, leading them to engage in specific behaviors to fulfill their requirements. It stands as a crucial factor in attaining success, particularly in professional endeavors. Motivation originates internally within individuals, representing a strong inclination to accomplish tasks. It encompasses the various forces associated with individuals' thoughts, aspirations, convictions, in essence, their desires, needs, and anxieties.

Motivation and mental fatigue are significantly correlated. While opinions may vary regarding the degree of motivation's influence on performance, it is generally acknowledged that achieving high levels of performance becomes difficult in the absence of motivation.

The connection between motivation and performance is most effectively demonstrated in educational environments. Numerous academically talented students fail to complete college each year because they either neglect to attend classes, fail to study, or simply become too distracted to fulfill their academic responsibilities (Hall, 2003). In the process of education, the individual's attitude towards learning and their level of motivation are paramount for success. The degree of motivation an individual possesses during the educational journey also profoundly impacts their cognitive perception and understanding (Harun, 2022).

Lately, researchers have been conducting the impact of alcohol intake and fatigue on performance. Although the risks of alcohol intoxication in driving and aviation are well-known, the effects of fatigue are not as well known or understood. Studies employing specific performance evaluations conducted by researchers have explored this issue (Australian Civil Aviation Safety Authority, 2012) has revealed that:

a) Staying awake from 7 a.m. until midnight can result in performance deficits akin to those experienced when one's blood alcohol content (BAC) reaches 0.05%, a threshold that represents the limit that is legal to drive in several different countries.

b) If an individual wakes up at 7:30 a.m. the following day, their overall performance impairment would be equivalent to that of someone with a blood alcohol concentration (BAC) of 0.10%, which is double the legal limit for fully licensed drivers.

Research involving twenty-four airline pilots examined the impact of early starts and extended duty hours, including multiple take-offs and landings over two consecutive days, on fatigue. The results indicated that the workload from frequent take-offs and landings significantly increased fatigue levels throughout the duty period (Honn et al., 2016). The performance of cockpit crew indicated heightened fatigue over duty period spanning five days compared to a single workday on the psychomotor vigilance test (PVT) (Brezonakova, 2017) .

The study examined how the European Aviation Safety Agency implemented new flight time limitations within the legal framework. The author identified potential risks arising from overwhelming and high demands on the job, resulting in heightened pilot fatigue. Factors such as frequent changes in time zones, early start times for duties, and extended duty hours often contribute to fatigue among cockpit and cabin crew members, leaving insufficient time for rest and recuperation. Due to the safety-sensitive nature of aviation, symptoms of fatigue and burnout can markedly impair performance in critical tasks, marked by prolonged reaction times.

Effective team performance largely depends on coordination, whereas stress significantly impairs the effectiveness of team members. An analysis of several injury-causing incidents revealed a total of 212 mistakes. Of these, thirty errors were due to inadequate and improper communication, and thirty-six were related to the inability to effectively manage conflicting task demands (NASA, 2015).

Furthermore, thirty-six errors occurred due to unintentional neglect of essential tasks and actions. These analyses highlight key elements concerning the proficient performance of pilots, indicating their vulnerability to interruptions, emergencies, and other high-stress scenarios.

The study examined how mental fatigue affects behavior. Participants were involved in a task that demanded sustained attention for prolonged periods (Boksem et al., 2006). They were incentivized with a coin reward for accurate task performance, emphasizing both speed and accuracy. Participants had the option to prioritize either speed or accuracy in their performance improvement efforts. Fatigued participants, when motivated, demonstrated adequate task monitoring by sacrificing response speed. These findings highlight a significant motivational aspect in mental fatigue processes. However, participants were unable to enhance their performance in both aspects simultaneously, suggesting that fatigue entails more than just a balance between rewards and effort. Instead, it necessitates adaptive strategies to maintain performance levels amidst adverse conditions.

The study examined the relationships among cockpit crew workload, duration of sleep, performance, subjective fatigue, and flight duty time. Ninety pilots were involved in the research, completing assessments including the NASA Task Load Index, the Samn-Perelli fatigue scale, and the Psychomotor Vigilance Task prior to each flight. Significant correlations were found between workload and other variables. Increased fatigue was associated with higher reported workload by cockpit crews, leading to poorer objective performance (Arsintescu, 2020).

The research sought to address errors stemming from intellectual fatigue without relying on medication. In the study, the author examined cognitive cues as a means to enhance cognitive recall and improve medical documentation quality during episodes of acute mental fatigue, without turning to pharmaceutical interventions. Findings showed that non-sleep-deprived individuals demonstrated enhanced recall when cognitively fatigued. The author suggests that it's feasible to reduce errors related to fatigue without resorting to pharmacological interventions (Flindall, 2015).

Performance, motivation, and fatigue have complex relationships that interact in ways that have a profound effect on an individual's wellbeing. High performance expectations often require sustained effort and dedication, potentially leading to physical and mental fatigue over time. Similarly, motivation acts as a driving force, influencing the amount of effort individuals invest in their endeavors.

While high motivation can inspire diligence and persistence, it can also inadvertently contribute to fatigue when individuals push themselves excessively without adequate rest. Striking a balance between performance and motivation is essential to manage fatigue effectively. Properly managing these factors involves establishing realistic goals, mindful self-regulation, and creating environments that support breaks and work-life balance.

2.1.4 Fatigue and Stress Relationship

Stress is when you feel pressure or worry about things happening in your life. It makes you feel tense, anxious, or overwhelmed. Stress can come from work, personal problems, or unexpected events. It can cause headaches, tense muscles, and make you feel upset or moody. Stress impacts human beings in many categories of life.

This tendency frequently results in adverse outcomes, including reduced productivity among personnel and a deterioration in the quality of products and services provided by the organization. Stress triggers the body's fight-or-flight response, prompting the release of hormones like cortisol and adrenaline (Justin, 2019). While these hormones are beneficial in short bursts, chronic stress can lead to an overproduction, resulting in increased fatigue. Prolonged stress disrupts sleep patterns, leading to inadequate rest and contributing to exhaustion and fatigue.

Fatigue is feeling very tired, like your body or mind has run out of energy. It happens when you have been working a lot, are not getting enough rest, or have too much to do. You might feel weak and sleepy and find it hard to focus.

Stress and fatigue share commonalities in their effects on our well-being. Both can drain our energy, leaving us feeling physically and mentally exhausted. Stress, caused by various pressures, can disrupt sleep and contribute to fatigue. Similarly, ongoing fatigue can make it harder to cope with stress, creating a loop where one worsens the other. They both can affect our mood, making us feel irritable or anxious,

and impact our ability to concentrate or make decisions. Physical symptoms like headaches or body aches can be linked to both stress and fatigue.

In literature, stress and fatigue are often used interchangeably, but it's crucial to recognize that they represent distinct phenomena. Stress can have both positive and negative impacts, whereas fatigue lacks such ambiguity. Continuous stress can lead to heightened anxiety, depression, and ultimately fatigue (Price et al., 1992).

Effectively handling stress and fatigue involves incorporating diverse practical approaches to restore balance and improve overall health. Start by incorporating regular physical activity into your daily routine, as exercise helps alleviate stress and boosts energy levels. Prioritize a balanced diet comprising nutritious foods to nourish your body and steer clear of excessive caffeine and sugar intake, particularly before bedtime, to improve the quality of sleep.

Creating a consistent sleep routine and practicing calming activities before bed can significantly improve your sleep quality. Incorporate stress-relief techniques such as deep breathing exercises, meditation, or yoga to help calm your mind and alleviate tension. Learn to manage your time effectively by organizing tasks and setting achievable goals while taking breaks to prevent burnout. Engaging in hobbies or activities you enjoy provides a mental break and a sense of fulfillment. It is crucial to recognize when stress becomes overwhelming and seek support from friends, family, or professionals. Prioritizing self-care, setting realistic expectations, and finding a balance between work and relaxation are pivotal in effectively tackling stress and fatigue.

2.1.5 Relationship Between Fatigue and Organization Success

Workers typically possess a set of knowledge, skills, and abilities that serve as the basis for their job performance within an organization. These qualities are generally considered to form a reliable foundation for their contributions to the organizational goals. However, fatigue can greatly diminish an individual's capacity to effectively utilize their knowledge, skills, and abilities.

Fatigue does not just impact the individual; it also extends to those in their vicinity and the organization to which they belong, thus affecting the economy, social interactions, and cultural landscape of the nation. This essential aspect requires significant attention.

Fatigue within an organization may lead to various outcomes, as observed (Dorrian, 2012):

a) Tasks may be neglected or slowed down.
b) There could be an increase in the need for permissions and reports.
c) Customers or service recipients may be neglected.
d) Levels of customer dissatisfaction may rise.
e) Pressure within professional relationships may increase.
f) Error frequencies may elevate.
g) Talented personnel may leave their positions.
h) Productivity in tasks may decrease.
i) Skilled employees may attrite.
j) Organizations may encounter systemic issues stemming from declining work disciplines.
k) The influence of workplace interruptions can be quantified.

Furthermore, fatigue can contribute to increased absenteeism, higher turnover rates/dropouts, and a negative impact on student pilots morale. Such consequences can disrupt team dynamics, hinder collaboration, and erode the organizational culture, ultimately affecting the company's success and bottom line.

When student pilots feel extremely exhausted, it can make it tough for them to perform their job effectively. Their mistakes might increase, they could get sick more often, and they might struggle to think clearly. This can slow down the company's progress and make it harder for it to do well. Also, if workers often feel very tired, they might not want to stay at the company for a long time.

Recognizing the profound effects of fatigue, organizations must prioritize initiatives that promote a healthy work-life balance, support student pilots well-being, and

create an environment conducive to optimal performance. Creating an environment conducive to optimal performance goes hand-in-hand with Student pilots well-being. It involves establishing a culture that values open communication, provides avenues for feedback, and fosters a sense of purpose among employees. Leaders who prioritize this environment see a more engaged workforce, resulting in higher levels of motivation and dedication. Student pilots who feel supported in managing their professional responsibilities alongside personal obligations tend to exhibit higher job satisfaction, reduced stress levels, and increased dedication to their roles.

2.2 Fatigue in Transportation Industry

Fatigue in the transportation industry presents a pervasive challenge that extends across various sectors such as aviation, trucking, shipping, and railway operations. This issue stems from multiple factors, including the demanding work schedules that often involve long and irregular hours, leading to chronic sleep deprivation among workers. The nature of transportation jobs, characterized by monotonous tasks and prolonged periods of driving, flying, or operating machinery, contributes significantly to mental and physical exhaustion.

Environmental factors, such as constant noise, vibrations, and extreme temperatures, further exacerbate fatigue levels among workers. Undiagnosed sleep disorders among employees can also intensify the problem, heightening the risk of fatigue-related accidents and compromising overall operational efficiency.

Personal responsibility also plays a vital role. Transportation workers must take ownership of their health and well-being by prioritizing sufficient sleep, maintaining a healthy lifestyle, and recognizing their limitations when fatigued. This involves being vigilant about their own alertness levels and knowing when it's necessary to take breaks or seek assistance to prevent fatigue-related incidents.

By combining regulatory measures, technological advancements, education, supportive workplaces, and individual accountability, the transportation industry can

effectively combat fatigue and enhance overall safety for both workers and the public they serve.

2.2.1 Fatigue in Ground Transportation

Fatigue is a significant concern in ground transportation, affecting various modes of travel, including car, truck, bus, and train operators, and can reduce driving performance efficiency. It poses serious risks to both the drivers and passengers as well as others on the road. Driver fatigue findings from road traffic activity in an environment of five basic elements: road traffic, driver, vehicle, road and its environment.

It's estimated that driver fatigue contributes to around 15 to 20% of serious accidents, though exact figures may vary among studies. This percentage is even higher for accidents involving trucks, fatal incidents, and those occurring on highways. Driving while fatigued substantially raises the likelihood of a crash. According to a meta-analysis of 14 studies, Fatigued drivers are at a 29% increased risk of being involved in a crash compared to non-fatigued drivers (ERSO, 2021).

Fatigue in ground transportation is a serious problem that needs attention. By understanding why it happens, seeing its effects, and finding ways to fix it, we can make things safer. Taking care of drivers, following rules, and using new technology can help prevent accidents caused by tiredness. It is important to work together to make ground transportation safer for everyone.

2.2.2 Fatigue in Aviation Industry

Fatigue poses challenges for transportation enterprises, especially in the aviation sector, which operates under 24/7 conditions. However, the aviation sector differs from other transportation industries due to distinctive elements. The circadian rhythms of aviation workers affect their alertness, performance, and well-being.

Additionally, economic factors within aviation influence the fatigue levels of flight crews. Below are the factors that initiate fatigue (Engin, 2021):

a) Reducing the number of aircraft personnel due to economic factors increases the workload of the flight crew, thereby contributing to fatigue.
b) Organizations often fail to recognize the significance of fatigue adequately, resulting in a lack of serious attention given to the issue.
c) The existing safety regulations and laws are not enough in adequately safeguarding against fatigue.
d) Inadequate effectiveness of work and recreational programs contributes to increased fatigue.
e) The loneliness experienced in the working environment aboard the aircraft, along with feelings of isolation, contributes to an increase in fatigue.

The aviation industry has long recognized specific fatigue symptoms among flight crew members (Ono, 1991). Furthermore, it has been recognized that such symptoms can significantly impair an individual's performance and reliability. Specific symptoms or conditions may arise in individuals as a result. Fatigue affects the human body, cognitive function, and emotions. Key signs and symptoms of fatigue within the aviation industry include:

a) Memory lapses,
b) Deficient ability to make decisions,
c) Delayed response time ,
d) Drowsiness ,
e) Communication difficulties ,
f) Moody disturbance ,
g) Micro-sleep and,
h) Lack of interest and strength.

2.2.2.1 Fatigue in the Cockpit and Cabin Crew

Fatigue among cockpit and cabin crew poses a significant concern in aviation, given its capacity to hinder performance and compromise flight safety. Irregular schedules, jet lag from time zone changes, high workload, and sleep disruptions contribute to crew fatigue. Throughout flight operations, the cabin crew plays a pivotal role in passengers' evaluation of service quality, consequently influencing the success of the airline.

In recent years, the increasing number and frequency of flights, especially long-distance and overnight flights have presented increased challenges for cabin and cockpit crews. The significant requirements and anticipations set by company management impose notable pressure on cabin crews, amplifying their workload and stress levels. The heightened pressure can cause both physical and emotional fatigue, ultimately resulting in emotional exhaustion, which is a significant element of burnout. As a coping strategy, cabin and cockpit crews may gradually develop insensitivity as a defensive response.

Fatigue management regulations for operators are outlined in Annex 6: Operation of Aircraft, Part I: International Commercial Air Transport (Aircraft). These regulations mandate that states implement guidelines based on scientific principles for managing fatigue. This can be accomplished by voluntary laws pertaining to fatigue risk management systems (FRMS) or by required regulations imposing restrictions on flight duration, duty duration, flight time, and rest periods of time. Members of the cabin crew and flight crew are subject to these regulations (ICAO, 2016).

2.2.2.2 Fatigue Risk Management System (FRMS)

It serves as a manual intended to help air operators develop a fatigue risk management system (FRMS) that complies with the ICAO's standards and recommended practices (SARPs). According to ICAO, The FRMS has been defined by ICAO as ”A data-driven means of continuously monitoring and managing

fatigue-related safety risks, based upon scientific principles providing both knowledge and practical expertise to guarantee that the appropriate personnel are operating at sufficient levels of alertness (Carina & al, 2010).

Fatigue Risk Management System (FRMS) represents a comprehensive framework embraced by diverse sectors to tackle the significant challenge of employee fatigue. At its core, an FRMS is a strategic approach aimed at identifying, evaluating, and mitigating the risks associated with fatigue-induced impairments. Industries such as transportation (aviation, trucking, maritime), healthcare, manufacturing, and others with round-the-clock operations recognize the detrimental impacts of fatigue on performance, safety, and overall productivity.

Firstly, FRMS involves a thorough assessment of factors contributing to fatigue, encompassing long work hours, irregular shifts, sleep deprivation, and disruptions to natural circadian rhythms. Identifying these elements allows organizations to comprehend the scope and potential risks associated with fatigue among their workforce. Subsequently, FRMS focuses on mitigating these risks by implementing tailored strategies. These strategies often encompass adjustments to work schedules, provision of adequate rest breaks, education on sleep hygiene practices, and training programs aimed at raising awareness about the dangers of fatigue.

Monitoring and assessment form another crucial component of an FRMS. Organizations regularly collect data on fatigue-related incidents, conduct fatigue assessments, and seek employee feedback to gauge the effectiveness of implemented measures. By analyzing these data, they can identify patterns, areas for improvement, and the overall success of their fatigue management strategies. This continual assessment enables organizations to adapt and improve their FRMS, ensuring it remains relevant and effective in addressing evolving challenges and industry-specific needs.

In industries where safety is paramount, such as aviation, healthcare, and manufacturing, FRMS holds significant importance in ensuring the safety of employees and the general public. Regulatory bodies often provide guidelines or

mandates for implementing FRMS in these sectors, underscoring its importance in managing fatigue-related risks. Overall, An FRMS goes beyond being just a static set of instructions but a dynamic, flexible system designed to proactively manage fatigue, promote safety, and enhance overall operational efficiency in high risk industries.

2.2.2.2.1 Components of an FRMS

An FRMS goes beyond being a mere collection of tools; it embodies a managerial philosophy based on organizational policies and procedures, implementing a comprehensive approach to managing fatigue. This "systems approach" involves an interconnected network of individuals and resources engaged in activities aimed at reducing fatigue within the operational setting. The intricacy of these systems will vary based on the size and diversity of the operational environment.

a. FRMS Policy

The FRMS policy will be integrated into the company's overarching fatigue management policy, which delineates the following:

a) The FRMS Organizational structure encompasses diverse personnel and job functions, including crew scheduling, labor relations, marketing, human resources, operational safety, training, and research and analysis of human factors.
b) Scheduling policies ensure compliance with all relevant FAA flight and duty time regulations, potentially incorporating additional constraints established by the organization to mitigate fatigue in specific situations, sometimes established through collective bargaining agreements.
c) Employees are obligated to report for duty in a state of fitness, ensuring they are adequately rested to perform their tasks safely. Likewise, individuals must notify the organization if they are not sufficiently rested, and the organization must have policies in place to substitute fatigued employees with well-rested counterparts.

d) Fatigue is a complex problem necessitating thorough training for all crew members to grasp its origins, optimize rest intervals, employ fatigue alleviation tactics, and meet their obligation to report fit for duty to ensure safe task performance.

e) Policies should outline processes for reporting errors and incidents linked to fatigue, including instructions for instituting a non-punitive fatigue reporting system, commonly referred to as "Just Culture." (James, 1997).

f) According to the organization's complexity and size, this policy will outline different approaches for gathering impartial information about fatigue and its impact on performance.

g) Because the FRMS is a Continuous Improvement Process (CIP), it requires a set of policies that outline how fatigue data are used to enhance fatigue management over time. In essence, these mechanisms allow the system to be flexible and self-adjusting, allowing it to adjust to changing situations that could otherwise lead to fatigue.

h) Policies should clearly define the roles and responsibilities of managers and employees in managing fatigue, encompassing guidelines for addressing fatigue both during work and between assignments. This involves making sure that there are enough breaks in between duties and requiring individuals to report fit for duty, which confirms that they are rested and prepared for work.

b. Education and awareness training program

Comprehensive education and awareness-raising initiatives are essential to building a solid foundation and understanding of fatigue management and mitigation in operations covered by FRMS (Fatigue Risk Management System) permission. It is imperative that the holder of the certificate customize their educational and training plans to emphasize the particulars of the FRMS authorization and relevant flight crew protocols. The training and awareness programs must be tailored to each FRMS authorization's specific needs because each authorization is unique. To guarantee clarity and effectiveness, the certificate holder should also explicitly state the training

components connected to each of their various FRMS authorizations, if they have any.

c. Fatigue analysis and reporting system

The methods that are necessary to recognize, report, and look into cases of fatigue risk that result from both external and internal sources are outlined in this section. It entails developing and assessing both proactive and reactive strategies targeted at reducing the risk of fatigue by using objective operational data and procedures. These procedures include crew scheduling, relaxation periods, and trip scheduling tactics. The fatigue implications of particular flight routes or schedules can be evaluated by applying methods such as biomathematical models of tiredness. The two primary parts of this approach are the assessment of the potential implications of the fatigue risk and the evaluation of the fatigue risk related to the schedule or trip. Proactive corrective measures can be put in place to reduce the risk in light of this research. Additionally, the technique for reporting fatigue may indicate that particular.

d. Monitoring fatigue among flight and cabin crew members

This function focuses on individual crewmember fatigue reports, much like the fatigue analysis and reporting system. These reports offer feedback to the certificate holder regarding factors believed to contribute to fatigue.

a) **To be able to ensure the effectiveness of these reports,** it is imperative to establish procedures for gathering all the essential data. This means recording information about the crew member's prior schedule, attempts to rest, subjective and objective signs of fatigue, potential aggravating or contributing environmental factors to fatigue, pertinent health or medical conditions, specific incidents or actions associated with the event, and communication prior to and during the incident. Protecting employee privacy and putting in place safeguards to protect staff members from unfavorable outcomes that would discourage them from reporting fatigue should be the top priorities of corporate policies.
b) **Technological advancements** aimed at monitoring sleep and performance among crewmembers can enhance self-reported fatigue data. While continuous

utilization of these technologies may not be feasible, periodic assessments of actual sleep (using actigraphs or logbooks) and fatigue (via performance metrics and subjective evaluations) can be highly advantageous for accurately evaluating fatigue levels across various operations and identifying key factors contributing to fatigue (Hursh , 2010).

The person who holds the certificate to improve the FRMS's investigative and predictive capacities can use the results of these evaluations. This makes it easier to evaluate any prospective fatigue in operations that are coming up, like a suggested new schedule.

e. Incident Reporting Process

Reports of adverse events, which could be wholly or partially attributed to fatigue, resemble crew reports and can function as a means of gathering all pertinent information regarding fatigue's role in the incident. Ideally, corporate policies would delineate how adverse events are evaluated for potential fatigue involvement and establish a methodology for conducting thorough Root Cause Analyses (RCAs). While detailed guidelines for RCAs are available elsewhere (refer to the current edition of AC 120-59, Internal Evaluation Programs), the incident investigation and reporting process should, at the very least, gather all necessary information to ascertain the root cause of the incident, particularly regarding the potential level of fatigue and the circumstances contributing to the fatigue-related event. The FRMS regulations should incorporate a clause to protect privacy and enforce measures to safeguard employees from adverse consequences that might discourage them from reporting and related conditions.

f. Performance Evaluation

An FRMS operates as a self-improving system that involves evaluating past monitoring, analysis, training, and mitigation efforts. Policies and procedures, informed by the assessment of outcomes and the FRMS's effectiveness in addressing fatigue, offer feedback to continually enhance system performance.

The Continuous Improvement Process (CIP) comprises the subsequent elements:

a) An evaluation and reporting mechanism to gauge the efficiency of the FRMS, with reports accessible to the regulator.
b) A process where assessment findings guide the FRMS program in adapting and enhancing itself.
c) A framework for periodic external assessment of the FRMS to ascertain its effectiveness in mitigating fatigue-related risks. While not mandatory, establishing a process for capturing the economic benefits and costs of the program could be advantageous.

2.2.2.2.2 The continuous FRMS Process

Referring to an FRMS as a "process" implies that it involves a sequence of activities that are rooted in corporate policies, organizational structures, and procedures. It goes beyond being static guidelines, evolving into a dynamic system where certificate holders actively identify and respond to the influence of fatigue on their operations. Employees play a crucial role in executing specific tasks to implement established policies and procedures within their organization. The FRMS process comprises four fundamental steps, which are continually revisited, promoting continuous enhancements in performance and reductions in fatigue-related risks. Each step in this iterative process relies on one or more tools for effectively managing fatigue.

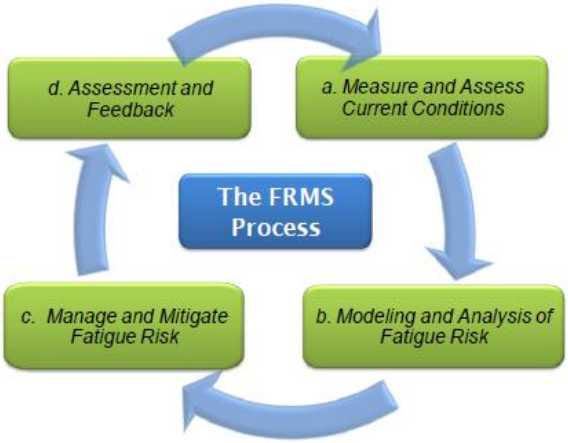

Figure 1: The fatigue risk management system process (FAA Advisory Circular, 2013)

a. Measurement and assessment of current conditions

In the initial stage, the emphasis is on measuring and assessing the degree of fatigue risk associated with existing schedules and operations. This involves gathering information on crewmember reports of errors and accidents due to fatigue, as well as schedules prior to these reported occurrences. Developing a thorough grasp of the organization's current circumstances is essential for formulating a robust mitigation strategy.

b. Modeling and analysis of fatigue risks

In this next phase, the primary objective is to determine the underlying cause of fatigue by analyzing work schedules and assessing the related fatigue risk. This stage is critical in the process as it employs scientific principles regarding fatigue, potentially incorporating computer modeling, to pinpoint the particular operational and crew-related factors that may lead to substantial performance variations due to fatigue. Through thorough analysis, this step aims to provide a more profound understanding of the origins of fatigue within the organization's operations. (Hursh , 2010) . This step is critical for managing and mitigating fatigue because it entails measuring fatigue risk and identifying the conditions (fatigue drivers) that contribute to this risk. Analysis of fatigue risk can be segmented into two primary components:

the likelihood of a specific level of fatigue occurring and the severity of the consequences should fatigue occur (Hursh , 2010).

For example, flight operations conducted between midnight and 05:59 am invariably coincide with the Window of Circadian Low (WOCL), a period characterized by diminished alertness and performance. Assessing this performance decline in connection with the tasks scheduled during this timeframe is crucial; elevated fatigue levels are particularly concerning if they coincide with critical flight maneuvers.

c. Management and mitigate fatigue risk

This third stage goes beyond the assessment and examination of elements that contribute to fatigue. Management must be actively and continuously engaged in reviewing the preliminary data and working with all stakeholders to develop solutions that address the underlying causes of fatigue.

d. Assessment and feedback

The fourth stage of this procedure involves collecting evidence of success in the form of updated policies, better training, better scheduling, more opportunities for rest, and objective data proving that these modifications have successfully reduced weariness. Less complaints of errors linked to fatigue, proof of better sleep patterns, or predictive modeling showing higher performance and decreased risks associated with fatigue are all examples of evidence of decreased fatigue.

This phase is essential to the process' ongoing improvement. It's possible that certain interventions won't reduce fatigue as anticipated, requiring additional changes. In addition, new routes, higher service needs, labor turnover, and schedule changes might provide additional difficulties that raise the risk of weariness. This stage enables continuous modifications to improve ongoing operations and successfully manage upcoming changes.

2.2.3 The Benefits of Managing Fatigue in Aviation

Managing fatigue in aviation offers numerous important advantages that impact safety, operational efficiency, regulatory compliance, and overall well-being. Foremost, fatigue management significantly enhances flight safety. Well-rested pilots and crew members are better equipped to respond swiftly and accurately during critical situations, reducing the likelihood of errors or accidents that can compromise safety. By addressing fatigue-related impairments in cognitive abilities and reaction times, aviation professionals ensure safer flights for passengers and smoother operations for airlines.

Moreover, effective fatigue management contributes to improved operational performance within the aviation industry and aids in reducing the number of crew absences linked to fatigue. When individuals are adequately rested, they exhibit better decision-making abilities, maintain higher levels of alertness, and handle complex tasks more efficiently. This optimized performance translates to more reliable and punctual flights, minimizing disruptions, and enhancing overall operational efficiency for airlines.

Adhering to regulations concerning fatigue management is crucial. Compliance with established rules not only ensures safety standards are met but also safeguards against potential legal issues. Airlines that prioritize and follow these regulations demonstrate a commitment to safety protocols, thereby fostering a culture of responsible aviation practices and maintaining industry standards.

Moreover, managing fatigue is not solely about professional obligations; it significantly impacts the health and well-being of aviation professionals. Mitigating fatigue contributes to lowering the likelihood of chronic health conditions like sleep disorders and stress-related illnesses among pilots and crew members. This promotes better physical and mental health, leading to a more positive work environment and increased job satisfaction among aviation professionals.

Additionally, effective fatigue management contributes to building trust and confidence among passengers. Airlines that prioritize safety by managing fatigue

instill confidence in travelers, promoting loyalty and a positive reputation. While initial investments in fatigue management strategies may incur costs, the long-term benefits, such as reduced accidents and smoother operations, lead to substantial cost savings for airlines.

In summary, managing fatigue in aviation is crucial for ensuring safety, enhancing operational efficiency, complying with regulations, promoting well-being among aviation professionals, and building trust with passengers. Prioritizing fatigue management is key to creating a safer, more reliable, and resilient aviation industry.

2.2.4 The Consequences of Fatigue in Aviation

Fatigue in aviation can have profound implications due to the critical nature of tasks carried out by pilots and aviation personnel. The impact of fatigue in this industry can lead to:

a) **Impaired decision-making:** Fatigue can hinder a pilot's capacity to promptly and precisely make decisions, impacting their judgment during crucial flight stages like takeoff, landing, and emergencies.
b) **Reduced alertness and performance**: Fatigue can significantly reduce alertness and cognitive performance, leading to slower reaction times, decreased situational awareness, and diminished ability to focus on critical tasks.
c) **Errors and accidents**: Fatigue is a known factor contributing to aviation incidents and accidents. Pilots experiencing fatigue are more prone to making errors, which can lead to serious safety risks for passengers, crew, and aircraft.
d) **Decreased communication**: Fatigue can hinder effective communication among crew members, air traffic control, and ground personnel. Miscommunication or misunderstanding instructions due to fatigue-related issues can lead to potentially dangerous situations.
e) **Physical and mental health Risks**: Continuous fatigue result to physical health issues, such as exhaustion, muscle fatigue, and compromised immune function.

It can also have significant mental health implications, including increased stress, anxiety, and mood disturbances.

f) **Regulatory and compliance issues**: Aviation regulatory bodies have strict guidelines and limitations on duty hours and rest periods to mitigate the risks associated with fatigue. Violating these regulations can lead to legal and regulatory consequences for aviation personnel and organizations.

g) **Long-term health effects**: Chronic fatigue among aviation professionals can lead to long-term health issues, affecting overall well-being and potentially forcing individuals to reconsider their career in aviation.

To minimize the impact of fatigue on aviation safety, various strategies are employed, including implementing strict duty hour limitations, providing adequate rest periods between flights, creating fatigue risk management systems, promoting sleep hygiene and healthy lifestyles among aviation personnel, and conducting fatigue awareness training. Ensuring adequate rest, proper scheduling, and adhering to regulations designed to manage fatigue are crucial to maintaining safety and minimizing the risks associated with fatigue-related impairments in the aviation industry.

2.2.5 Fatigue Countermeasure in Aviation

Fatigue countermeasures involve approaches aimed at minimizing or mitigating the effects of fatigue across a range of situations, such as driving, working, or participating in physical activities. Some effective fatigue countermeasures include:

a) **Napping:** Napping is a natural fatigue-fighting technique that has been proven effective in reducing performance impairments resulting from sleep deprivation, restricted sleep, and prolonged working hours. A brief nap, typically lasting 20-40 minutes, can enhance a pilot's alertness and cognitive function. This is especially beneficial during long-haul flights or when pilots face fatigue due to irregular schedules or shifts in time zones.

b) **Caffeine:** Caffeine serves as a potent fatigue-fighting tool, providing temporary boosts in alertness and postponing the onset of sleepiness. It comes in diverse formats, including coffee, tea, energy drinks and over-the-counter tablets.

c) **Technology:** Technological advancements like Optalert offer an objective means to detect initial indications of fatigue and provide continuous real-time feedback on fatigue levels, assisting drivers or pilots and their supervisors in managing fatigue more effectively (Christer, 2010)

d) **Shift work and sleep scheduling:** Adjusting work schedules and sleep patterns can help combat fatigue, especially for those working in shift work environments.

e) **Organizational considerations:** Organizations might improve employee fatigue management and sleep health by implementing strategies to mitigate fatigue risk management systems (FRMS) or fatigue risk management programs (FRMP).

f) **Bunk sleep:** In the context of aviation, bunk sleep specifically refers to the designated rest areas or sleeping compartments on long-haul aircraft where flight crew members, including pilots and sometimes cabin crew, can rest or sleep during extended flights.

g) **In-flight rostering:** involves the strategic scheduling and assignment of pilots to flights, considering factors like crew availability, legal regulations, qualifications, and individual preferences. The process aims to create balanced schedules that ensure safety, adequate rest, compliance with regulations, and efficient flight operations.

h) **Cockpit lighting:** This serves as an additional method to heighten alertness levels in the cockpit during nighttime (Cajochen, 2007). Light exposure suppresses the secretion of melatonin, causing changes in circadian rhythms and promoting alertness. In particular, short-wavelength light pulses, especially those around 420 nm, have been proven to improve subjective alertness, as evaluated using a 9-point visual analogue scale (Victoria, 2006).

i) **Healthy meal:** Ensuring a balanced diet comprising lean proteins, complex carbohydrates, healthy fats, and sufficient hydration is vital for reducing fatigue. Incorporating these dietary components into your daily meals provides your body with essential nutrients and energy for optimal functioning. Lean proteins such

as poultry, fish, tofu, and legumes supply amino acids necessary for muscle repair and energy production. Complex carbohydrates from whole grains, fruits, and vegetables offer a sustained release of energy, guarding against energy dips. Healthy fats sourced from avocados, nuts, seeds, and olive oil support brain function and hormone balance. Adequate hydration through regular water intake is also critical for sustaining energy levels and preventing dehydration-related fatigue. Prioritizing a balanced diet rich in these nutrients and hydration can effectively combat fatigue and promote overall well-being.

j) **Exercise:** can be used as a countermeasure for fatigue in aviation, particularly for pilots who experience sleep loss or long duty periods. Studies examining how exercise influences fatigue within aviation have indicated that engaging in short periods of physical activity can alleviate some of the rises in drowsiness and weariness connected to lack of sleep.

k) **Circadian adjustment:** Adjusting your circadian rhythm involves several strategies: Firstly, establish consistent sleep-wake times to regulate your schedule. Secondly, ensure exposure to natural light during the day while minimizing evening light to signal sleepiness. Thirdly, engage in early-day exercise to help regulate your body's internal clock. If natural light is unavailable, consider using bright artificial lights to help realign your circadian rhythms.

l) **Consider melatonin supplements:** To aid in altering your sleep timing, allowing for earlier or later sleep patterns as needed. These methods collectively assist in recalibrating and managing your circadian rhythm effectively (Keuren, 2021).

According to the literature, previous researchers have made significant contributions to understanding fatigue in aviation. They have extensively studied the physiological, emotional, and mental impacts of fatigue on pilots, shedding light on how fatigue impairs crucial bodily functions such as reaction times and alertness, leading to increased errors during critical flight operations. Emotionally, fatigue contributes to heightened stress levels, irritability, and mood swings, while mentally, it results in a decline in cognitive functions, including memory, attention, and

situational awareness. Researchers have also explored the influence of circadian rhythms, noting that disruptions caused by irregular flight schedules, crossing time zones, and night flights significantly decrease pilot alertness and performance. To combat these issues, various fatigue management strategies have been assessed, including regulatory measures like limiting flight duty periods, optimizing crew schedules to better align with natural circadian rhythms, and implementing controlled rest periods during flights. Additionally, the adoption of fatigue risk management systems, cockpit alertness monitors, and fatigue detection software, alongside training programs for pilots on recognizing and managing fatigue, underscore the importance of a comprehensive approach to enhancing pilot safety and performance.

These studies have laid a strong foundation for recognizing the critical role that fatigue plays in aviation safety and performance. For this reason, our research aims to develop an innovative framework tailored to aviation training institutions, based on both empirical evidence and established theoretical models of fatigue management. This framework will incorporate advanced data analytics to process information from various sources such as sleep patterns and training schedules. Real-time monitoring will enable the framework to provide immediate feedback and recommendations, helping trainers and trainees make informed decisions about workload, rest periods, and training intensity. Furthermore, the framework is designed to adapt to individual needs, offering personalized strategies that take into account each trainee's unique needs.

Consequently, our research is dedicated to creating a specialized system explicitly tailored to tackle these challenges and implement mitigation strategies at strategic, tactical, and operational levels. In the forthcoming chapter, we will delve into its development journey, detailing the innovative features it encompasses and underscoring the substantial advantages it offers to aviation training. Our framework operates much like a mirror, providing student pilots and institutions with a reflective tool to assess fatigue levels and determine appropriate mitigation strategies. Similar to the process of self-reflection, this framework enables proactive fatigue

management tailored to the unique security and safety needs of both individuals and organizations. Through continuous assessment and adaptation, it serves as a dynamic mechanism for promoting well-being and optimizing performance in aviation settings.

CHAPTER 3

FRAMEWORK AND RESEARCH MODEL DEVELOPMENT

In this chapter, a conceptual and comprehensive framework has been created to integrate all the factors contributing to pilot fatigue. Additionally, a research model has been developed to evaluate how pilot fatigue influences decision-making performance, focusing on key selected fatigue factors. It draws upon a wealth of knowledge, including insights from various books, lessons learned from our university studies, and innovative ideas.

The primary objective of this framework is to assist in evaluating, analyzing, and managing the fatigue levels encountered by student pilots throughout their training and operational flights. It commences by exploring fundamental aspects of fatigue, including its various types, underlying causes, and identifiable symptoms. This thorough investigation lays a strong groundwork for comprehending the intricate dynamics of fatigue in aviation settings.

Subsequently, the framework offers a diverse array of mitigation strategies during both training and actual flight operations. By tailoring interventions to specific contexts, it aims to proactively address fatigue-related issues and enhance overall safety and performance while also addressing potential consequences that may arise if these mitigations are not followed.

The chapter is divided into three distinct parts, each addressing specific facets of fatigue management. Firstly, it explores the nuanced impact of fatigue on student pilots, covering the various types of fatigue, their underlying causes, and the tools available for accurate measurement. This comprehensive examination provides a solid foundation for implementing effective fatigue management strategies.

The second part of the chapter delves into actionable strategies aimed at reducing fatigue for student pilots. It takes into consideration various factors such as workload dynamics, environmental conditions, and training modalities. By examining fatigue management strategies across strategic, tactical, and operational levels, the

framework ensures a holistic approach to mitigating fatigue within the aviation training context.

Lastly, the chapter outlines the potential consequences of neglecting the proposed fatigue management strategies. It emphasizes the vital necessity of following these measures, not just for the welfare of student pilots, but also for the overall efficiency of training organizations and practices in managing workload. This comprehensive approach emphasizes the urgent need for proactive fatigue management measures across all levels of aviation training.

3.1. Systematic Representation

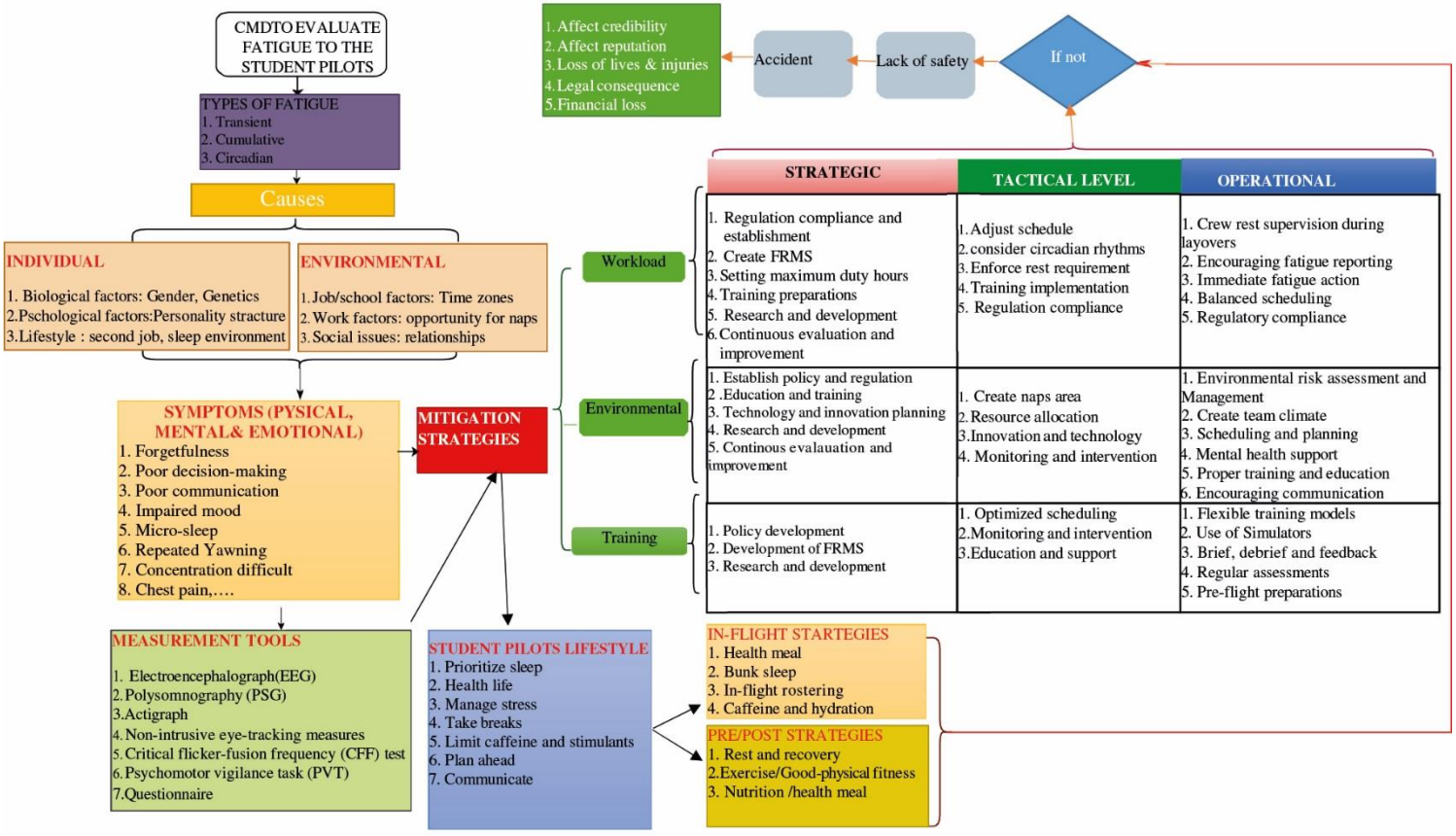

Figure 2: Conceptual framework to evaluate the student pilots' fatigue (Developed by the author).

This figure includes types and causes of fatigue, symptoms, related measurements tools and mitigation strategies at operation, tactical and strategic levels. This model is a unique and comprehensive synthesis of the author based on the literature review findings related to these figure components. The following subsections describe the model components:

3.1.1 Types, Causes and Symptoms of Student Pilot Fatigue

In aviation, student pilots encounter three specific forms of fatigue: transient fatigue, cumulative fatigue, and circadian fatigue (FAA, 2012):

a. **Transient fatigue:** Arises as a result of severe sleep deprivation or extended periods of wakefulness within a short timeframe, typically spanning 1 or 2 days.

b. Cumulative fatigue: Occurs due to recurrent mild sleep deprivation or prolonged wakefulness over consecutive days

c. Circadian fatigue: This describes a decrease in performance commonly observed during nighttime hours, particularly within the individual's "window of circadian low" (WOCL), typically occurring between 2:00 a.m. and 05:59 a.m.

Student pilot fatigue originates from two key categories: Individual and Environmental causes. Individual factors involve biological aspects like gender and genetics, psychological elements such as stress coping mechanisms, and lifestyle choices like secondary employment or inadequate sleep environments. Environmental causes encompass job/school demands impacting circadian rhythms, work conditions affecting rest opportunities, and social factors including personal/professional relationships contributing to emotional stress.

The symptoms of fatigue encompassing physical, mental, and emotional indicators such as forgetfulness, poor decision-making, poor communication, micro-sleep, impaired mood, and concentration difficulties, repeated yawning , mood disturbances, chest pain and so on. According to (Caldwell, 2009) there are various measurement tools:

- **Electroencephalography (EEG)** Measuring brain electrical activity, particularly event-related potentials (ERPs), is considered the benchmark for assessing reduced alertness. However, its use is limited in operational settings due to its intrusive nature, requiring electrodes and technical expertise. Increased theta wave amplitude and decreased alpha wave amplitude indicate high mental workload and mental fatigue (Klimesch, 1999).
- **Polysomnography (PSG)** detects brain activities during sleep using EEG, electrooculography (EOG), and electromyography (EMG) but necessitates electrodes on the head/face and technician expertise. It can identify micro-sleep and eye movements, offering insights into sleep quantity, structure, quality, and alertness. (Göker, 2018)
- **Actigraphy:** Actigraphy is a method that measures your activity using a watch-like device called an actigraph. It can identify patterns in your sleep-wake cycle, helping to detect health issues like sleep disorders, and typically requires wearing it for up to two weeks. (Mashaqi, 2003)
- **Non-intrusive eye tracking:** Non-intrusive eye-tracking methods are those that allow the measurement of eye positions and movements without requiring the user to wear any special equipment or restricting their head movement. (Z. Zhu, 2004)
- **The Critical Flicker-Fusion Frequency (CFF):** The test evaluates visual response efficiency by measuring retinal modulation frequency, typically falling within the range of 25 Hz to 55 Hz (Natalia, 2022).
- **The Psychomotor Vigilance Task (PVT):** The Psychomotor Vigilance Test (PVT) assesses how fatigue impacts alertness due to factors like lack of sleep, staying awake too long, disruption of the body's internal clock, and the duration of tasks. However, the usefulness of the usual 10-minute PVT is often doubted in real-life situations (Mathias Basner, 2011).

It's important to understand how a person's body is doing to help them perform their best, especially during long or uneventful tasks. This involves looking at different things like their face, eyes, and brain activity, as well as their muscles, wrists, head

position, and how much their eyes close. These clues give us an idea of how focused and alert they are, and if they might be getting tired. By keeping an eye on these signs, we can take steps to help them stay sharp and avoid getting too worn out, making sure they can keep doing their job well.

When it comes to keeping track of how our bodies are doing, looking at different factors gives us a complete picture of someone's physical condition. By combining things like facial expressions, eye movements, and brain activity, we can understand how much mental effort someone is putting in and where their attention is focused. At the same time, watching things like muscle tension and how much someone's eyes close can show us if they're getting tired or relaxed. Using this information, we can target ways to help them feel better and stay focused during long periods of work. Taking this multi-dimensional approach to monitoring helps organizations take proactive steps to manage fatigue, making sure everyone stays safe and performs at their best.

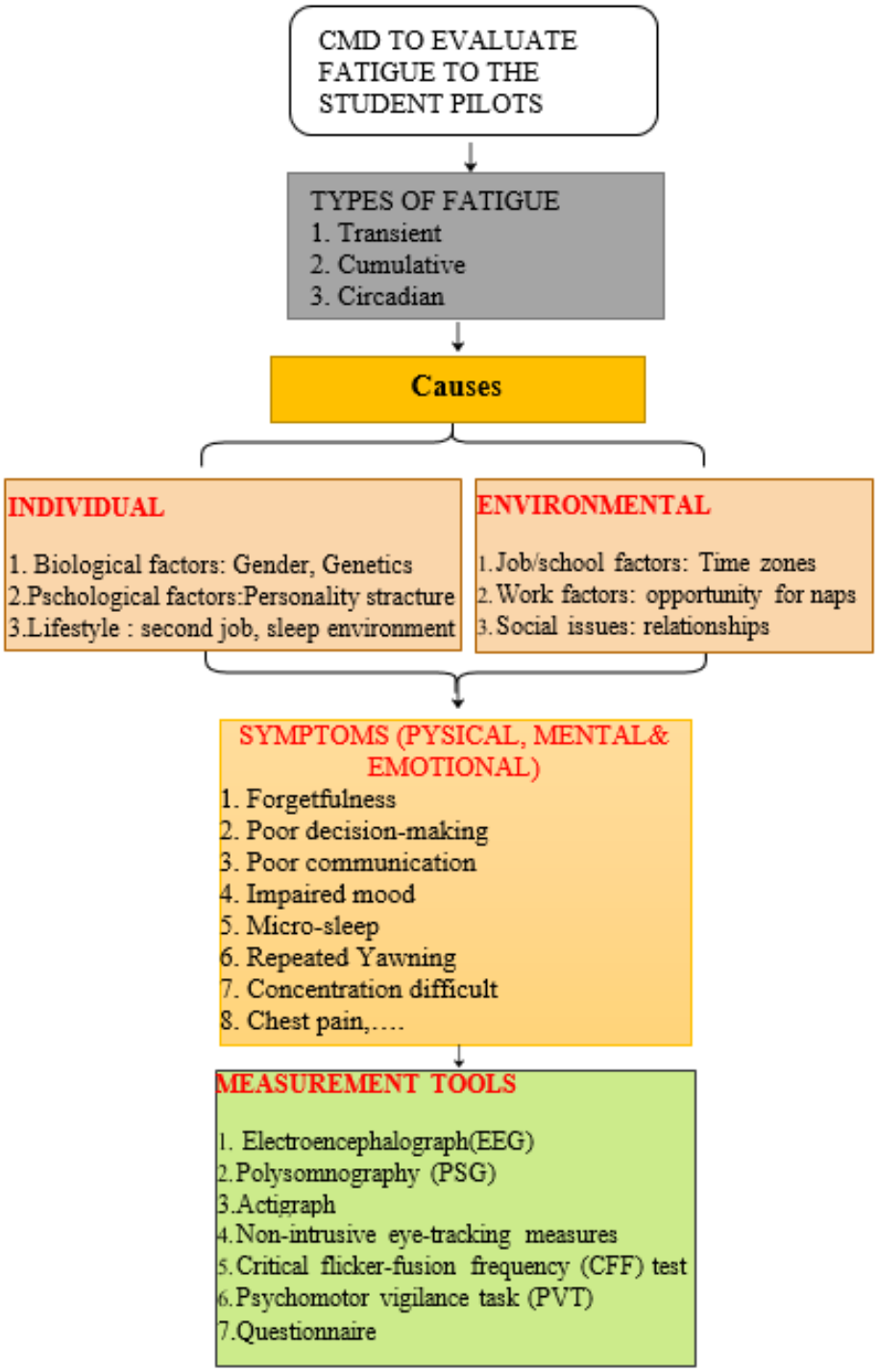

Figure 3: General information about fatigue (Developed by the author).

3.1.2 Mitigation Strategies

3.1.2.1 The Student Pilot Lifestyle

Managing fatigue is crucial for student pilots as it directly impacts their ability to make sound decisions and operate an aircraft safely.

- **Prioritize Sleep:** Adequate sleep is fundamental for pilots. It directly impacts cognitive function, reaction time, decision-making abilities, and overall alertness. Consistency in sleep patterns is essential to mitigate the effects of jet lag and irregular flight schedules.
- **Healthy Lifestyle:** A balanced diet and regular exercise support physical health and mental acuity. Proper nutrition provides the necessary energy levels, while physical fitness enhances endurance, strength, and resilience, which are crucial during long flights or emergencies.
- **Manage Stress:** Piloting aircraft inherently induces stress, underscoring the critical importance of effective stress management for student pilots. Methods like deep breathing, mindfulness, and meditation serve to regulate stress reactions, fostering clarity of thought and sustained focus, even in high-pressure situations.
- **Take Breaks:** Aviation can be demanding, both mentally and physically. Regular breaks allow for relaxation and recovery, preventing burnout, maintaining peak performance levels during flights, and training sessions.
- **Limit Caffeine and Stimulants:** While caffeine can provide temporary energy boosts, excessive intake can lead to jitteriness, anxiety, and disrupted sleep patterns. Moderation ensures its benefits without detrimental effects.
- **Plan Ahead:** Thorough planning is critical in aviation. Pilots should meticulously plan flights, considering weather conditions, potential challenges, and alternate routes. This preparation minimizes risks and enhances safety during flights.
- **Communicate and develop:** Effective communication within the cockpit and with others in the aviation community is essential. Continuous learning and

seeking feedback help pilots improve their skills, stay updated with advancements, and enhance their overall proficiency.

3.1.2.2 Workload Mitigations

Within the flight training school, the different levels should be involved. Strategic, tactical, and Operational. The leadership roles at various levels within a flight training school are structured hierarchically, from strategic decision-making to tactical management and operational execution.

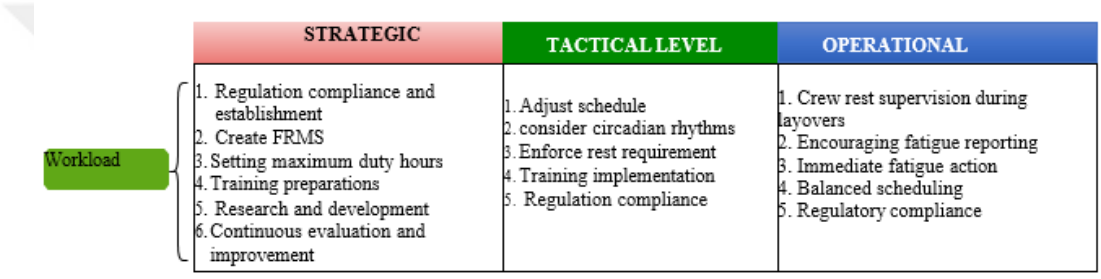

Figure 4: Workload mitigations at all levels (Developed by the author)

3.1.2.2.1 Workload mitigation at strategic level

Fatigue mitigation at a strategic level involves implementing various measures and strategies to effectively manage and minimize fatigue-related risks in a given context. Here's an overview of how each point contributes to fatigue mitigation

a) **Regulation compliance and establishment:** This involves adhering to existing regulations from ICAO, EASA and FAA or creating new ones that address fatigue management. Regulations can set standards for rest periods, maximum working hours, shift scheduling, and other related factors to ensure compliance across the organization or industry.
b) **Create FRMS (Fatigue Risk Management System):** The initiation of the FRMS involves developing a structured approach to identifying, evaluating, and

addressing fatigue risks within an organization. This encompasses policies, procedures, training, and tools to systematically manage fatigue.

c) **Setting maximum duty hours*:*** Establishing and enforcing maximum duty hours is essential for managing fatigue. This means placing restrictions on how long individuals can work during a specific period to avoid excessive tiredness.
d) **Training preparations:** Providing comprehensive training to student pilots is essential. This training should cover aspects such as recognizing signs of fatigue, understanding its impact on performance and safety, implementing effective coping strategies, and adhering to policies and procedures outlined in the FRMS.
e) **Research and development:** Continuous research and development are necessary to stay updated with the latest scientific findings, technologies, and methodologies related to fatigue management. This allows organizations to adopt innovative approaches and tools for better fatigue mitigation.
f) **Continuous evaluation and improvement:** Regularly assessing the effectiveness of implemented fatigue mitigation measures is crucial. Continuous evaluation helps identify areas for improvement in the FRMS, training programs, scheduling practices, or other aspects of fatigue management. It allows for adjustments and enhancements to better address fatigue-related risks.

Implementing these strategic measures requires collaboration between management, regulatory bodies, employees, and possibly external experts. It involves a multi-faceted approach that combines regulatory compliance, policy implementation, education, and ongoing evaluation to effectively mitigate fatigue risks in a sustainable manner.

3.1.2.2.2 Workload Mitigation at Tactical Level

In the context of tactical-level fatigue management in aviation, especially for pilots, here's how each of these strategic activities can be adapted to address workload mitigation and fatigue:

a) **Adjust schedule:** To mitigate fatigue among student pilots, tactical leadership should ensure balanced training schedules with adequate rest periods, rotate training tasks to manage workload, regularly monitor fatigue levels, and educate students on the importance of rest and time management.

b) **Consider circadian rhythms:** To consider circadian rhythms when mitigating fatigue among student pilots, tactical leadership should strategically schedule training, prioritize rest periods, manage lighting, promote proper nutrition and hydration, optimize sleep environments, educate on circadian rhythms, and allow for flexibility and adaptation.

c) **Enforce rest requirement:** Ensuring sufficient rest periods for pilots is essential for mitigating fatigue and maintaining safety in the cockpit. This involves adhering to regulatory guidelines that dictate maximum duty times and minimum rest periods between flights. Additionally, fostering a culture that prioritizes rest and encourages pilots to proactively manage their fatigue by taking adequate breaks and prioritizing sleep is crucial.

d) **Training implementation:** The implementation of training on rest requirements for pilots, originating from regulatory bodies, aviation organizations, or flight training institutions, involves delivering engaging sessions, incorporating practical exercises, assessing understanding, fostering a culture of safety, and continuously improving the training program to ensure compliance and enhance aviation safety standards.

e) **Regulation compliance:** Regulation compliance ensures that all training programs adhere to the guidelines and standards set forth by relevant aviation regulatory bodies, promoting safety and professionalism within the industry.

3.1.2.2.3 Workload Mitigation at Operational Level

When considering workload mitigation at the operational level for pilot students, it's crucial to address their workload and stress factors, ensuring their well-being, performance, and learning experience. Here's how these strategies might apply:

a) **Crew rest supervision during layovers:** For pilot students involved in training or educational programs, ensuring adequate rest during breaks or layovers is essential. Supervision and facilitation of suitable rest environments and accommodations are necessary to support their learning, rest, and overall well-being between training sessions or flights.
b) **Encouraging fatigue reporting:** Fostering an open and non-punitive environment for reporting fatigue is especially important for pilot students. Encouraging them to report feelings of fatigue during training helps instructors and program administrators understand potential stressors and adjust training schedules or methods accordingly.
c) **Immediate fatigue action:** Establishing protocols to address reported fatigue promptly is crucial for pilot students. Instructors and training personnel should have procedures in place to respond swiftly to signs of fatigue, potentially adjusting training schedules, providing additional breaks, or modifying the training workload to ensure student safety and learning effectiveness.
d) **Balanced scheduling:** Creating balanced training schedules is vital for pilot students' workload management. This involves spacing training sessions effectively, avoiding excessive consecutive flight hours, and considering optimal learning periods to prevent overload and exhaustion during training.
e) **Regulatory compliance:** Ensuring compliance with regulatory guidelines related to student pilot training is fundamental. This includes adhering to stipulated duty/rest hour limitations, following guidelines on training duration, and maintaining a safe and regulated learning environment in accordance with aviation regulatory standards.

3.1.2.3 Environmental Mitigation

Environmental mitigation for fatigue at strategic, tactical, and operational levels involves addressing fatigue-related issues across different organizational layers.

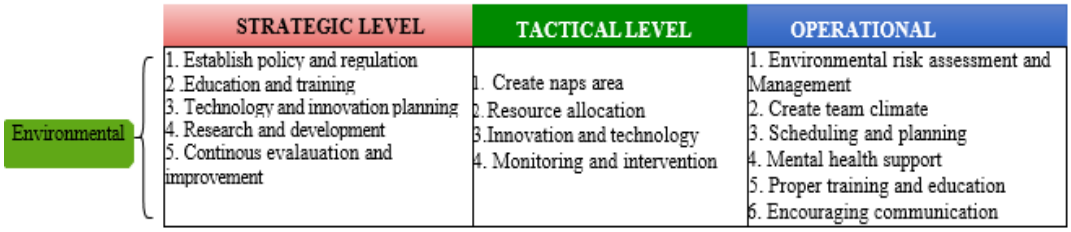

Figure 5: Environmental mitigations at all levels (Developed by the author).

3.1.2.3.1 Environmental Mitigation at Strategic Level

a) **Establish policy and regulation:** Setting up policies and regulations related to work hours, breaks, and environmental conditions is essential. This could include guidelines on maximum work hours, mandatory break periods, and standards for a conducive working environment to minimize physical and mental fatigue caused by environmental factors.

b) **Education and training:** Delivering education and training programs for employees and students can improve awareness about fatigue-inducing environmental factors and ways to mitigate them. This may include educating workers about the importance of proper rest, nutrition, hydration, and the impact of environmental factors like noise, temperature, and lighting on fatigue.

c) **Technology and innovation planning:** Employing technology and innovative solutions can aid in creating a more comfortable and conducive work environment. For instance, using ergonomic tools, automated systems to monitor environmental conditions, or implementing technology that adjusts lighting or temperature can help reduce fatigue-inducing factors.

d) **Research and development:** Supporting research and development initiatives can yield novel technologies or methodologies that more efficiently alleviate fatigue induced by environmental factors. Research into better materials,

workspace design, or technologies that reduce noise and enhance air quality can significantly contribute to a healthier work environment.

e) **Continuous evaluation and improvement:** Regularly assessing the work environment, gathering feedback from employees and analyzing data on fatigue-related incidents can help in identifying areas for improvement. Continuous improvement strategies enable organizations to adapt, refine, and implement changes that mitigate fatigue-inducing environmental factors effectively.

3.1.2.3.2 Environmental Mitigation at Tactical Level

Fatigue mitigation strategies for environmental factors at the tactical level involve addressing various aspects to ensure personnel remain alert and effective. Here's a breakdown of each strategy:

a) **Create Napping Areas:** Establish designated areas where personnel can take short naps to combat fatigue. These areas should be designed to facilitate quick and effective rest periods, promoting alertness and combatting fatigue.

b) **Resource Allocation:** Ensure proper distribution of resources such as manpower, equipment, and supplies. Adequate staffing levels and appropriate equipment can reduce the physical and mental strain on individuals, minimizing fatigue.

c) **Innovation and Technology:** Leverage innovative solutions and technology to streamline tasks and reduce the workload. Automation, advanced tools, and updated equipment can help in completing tasks more efficiently, minimizing the strain on personnel and reducing fatigue.

d) **Monitoring and Intervention:** Implement systems for continuous monitoring of fatigue levels among personnel. This can include wearable devices, regular check-ins, or fatigue assessment tools. Intervene promptly when signs of fatigue are detected, such as providing breaks or redistributing tasks.

3.1.2.3.3 Environmental Mitigation at Operational Level

Mitigating fatigue at the operational level involves addressing environmental factors that can impact a team's performance and well-being. Here's a breakdown of strategies to tackle these issues:

a) **Environmental Risk Assessment and Management:** Conduct thorough assessments of the operational environment to identify potential fatigue-inducing factors. Manage and mitigate these risks through proactive measures, such as adjusting work conditions, safety protocols, and workload distribution.

b) **Create Team Climate Foster** a positive team culture that emphasizes support, collaboration, and mutual respect. Encourage teamwork, camaraderie, and a sense of belonging, which can help alleviate stress and mitigate the impact of environmental stressors.

c) **Scheduling and Planning:** Develop well-thought-out schedules that consider rest periods, adequate breaks, and reasonable workloads. Ensure that plans are realistic and allow flexibility to accommodate unforeseen challenges while preventing excessive fatigue accumulation among team members.

d) **Mental Health Support:** Ensure that mental health resources, counseling services, and stress management programs are readily available. Encourage open discussions about mental well-being and cultivate a supportive culture where individuals feel empowered to seek help when needed.

e) **Proper Training and Education:** Equip team members with the necessary skills and knowledge to manage stress, recognize signs of fatigue, and employ coping strategies effectively. Training sessions on sleep hygiene, resilience, and stress reduction techniques can be beneficial.

f) **Encouraging Communication:** Establish open channels for communication within the team. Encourage individuals to voice their concerns, share workload challenges, and communicate their needs for support. Effective communication can help in identifying and addressing issues promptly.

3.1.2.4 Training

Addressing fatigue through training and mitigation strategies at different organizational levels involves considering the distinct responsibilities and focus areas inherent in each level.

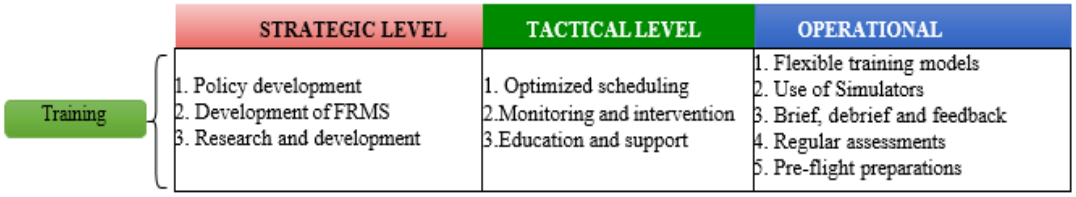

Figure 6: Training mitigations at all levels (Developed by the author).

3.1.2.4.1 Training at Strategic Level

At the strategic level, the focus on training and mitigation involves several key element:

a) **Policy Development:** Developing comprehensive policies is crucial for effective risk management and mitigation. Policies should outline guidelines, procedures, and standards for addressing various risks within the organization. This includes policies related to safety, security, compliance, ethics, and crisis management. Regular review and updates to policies are essential to adapt to evolving threats and industry changes.

b) **Development of Fatigue Risk Management Systems (FRMS:** Integrating Systems to mitigate fatigue risks is crucial in industries where fatigue can significantly impact safety and performance. FRMS involves understanding, assessing, and mitigating the risks associated with employee fatigue. Strategies may include analyzing work schedules, providing adequate rest periods, offering fatigue awareness training, utilizing technology for monitoring fatigue levels, and implementing policies to manage fatigue-related risks.

c) **Research and Development (R&D**: Distribution of resources towards research and development (R&D) is crucial for maintaining a proactive stance in identifying and mitigating emerging risks. Research initiatives encompass

studying industry trends, analyzing incident data, exploring new technologies for risk mitigation, and devising innovative strategies to bolster organizational resilience. Collaboration with academic institutions or industry experts can facilitate the exchange of knowledge and foster innovation.

3.1.2.4.2 Training at Tactical Level

Mitigating fatigue at a training school, especially at the tactical level, involves implementing specific measures to address fatigue-related risks among personnel.

a) **Optimized Scheduling:** Tactical-level mitigation of fatigue often begins with scheduling strategies. This includes designing work or training schedules that consider circadian rhythms, adequate rest periods, and avoiding excessively long shifts or training sessions. Rotating schedules, allowing sufficient recovery time between sessions, and planning breaks are vital in mitigating fatigue.
b) **Monitoring and Intervention:** Implementing monitoring systems to track signs of fatigue is crucial. This might involve using fatigue assessment tools, wearable devices, or observation methods to identify individuals at risk. Upon identification, intervention strategies should be in place, which could include allowing rest breaks, providing access to relaxation areas, or modifying tasks to reduce fatigue.
c) **Education and Support:** Providing education on fatigue management is essential at the tactical level. This involves training personnel on recognizing signs of fatigue, understanding the importance of sleep and rest, and adopting healthy lifestyle practices. Moreover, offering support services such as access to counseling sleep hygiene education, or stress management workshops can help individuals better cope with fatigue-related issues.

3.1.2.4.3 Training at Operational Level

Mitigating fatigue at the operational level within a training school involves implementing various strategies tailored to minimize fatigue-related risks among personnel. Here are specific mitigation approaches:

a) **Flexible Training Models:** Introducing flexible training models allows for adaptable scheduling, which considers individual needs and circadian rhythms. Offering options for flexible hours or training sessions enables personnel to participate in training at times that align better with their optimal alertness and reduces the likelihood of fatigue.

b) **Use of Simulators:** Simulators are invaluable tools in training environments. They offer realistic training scenarios while providing a controlled environment that can adjust factors to suit the learning pace and comfort of individuals. This reduces the physical and mental strain often associated with high-stress or high-demand practical exercises.

c) **Brief, Debrief, and Feedback Sessions:** Implementing structured briefings before training sessions and debriefings afterward is essential. Briefings ensure clarity of objectives and expectations, while debriefings allow personnel to discuss their experiences, share insights, and receive feedback. This communication loop aids in addressing concerns, adjusting strategies, and improving training effectiveness while minimizing stress.

d) **Regular Assessment and Monitoring:** Continuous assessment and monitoring of personnel's well-being and performance are critical. Regular check-ins, surveys, or fatigue assessments help in identifying trends, recognizing early signs of fatigue, and implementing necessary interventions promptly.

e) **Pre-flight Preparations (if applicable):** In aviation or similar contexts, thorough pre-flight preparations are essential. This includes checklist reviews, ensuring adequate rest for pilots or crew, verifying equipment functionality, and conducting safety briefings. Adequate preparation minimizes stress during high-stakes situations and reduces the likelihood of fatigue-related errors.

3.1.3 The Consequences of Non-Compliance With Mitigation Strategies

Failing to comply with mitigation strategies related to student pilots, environmental conditions, training, and workload management can have severe consequences impacting safety and various other aspects:

a) **Credibility:** When mitigation strategies specifically designed for student pilots' safety are disregarded, it undermines the credibility of the training institution. Stakeholders expect tailored safety measures for student pilots, and failure to provide these erodes trust in the institution's commitment to student well-being and safety.

b) **Reputation:** A training institution's reputation heavily relies on its ability to ensure the safety and proper training of student pilots. Non-compliance with tailored safety measures can lead to incidents or accidents that tarnish the institution's reputation, affecting its attractiveness to potential students and partnerships within the aviation industry.

c) **Loss of Lives and Injuries:** Neglecting to implement appropriate mitigation strategies for student pilots directly endangers their safety and well-being. This negligence can lead to accidents causing injuries or fatalities among student pilots or instructors, creating a significant impact on individuals and reflecting poorly on the institution's safety protocols.

d) **Legal Consequences:** Failure to comply with safety measures for student pilots and other related aspects can result in legal repercussions. Regulatory bodies may impose severe sanctions, revoke licenses, or initiate legal proceedings against the institution for accidents caused by inadequate safety measures, leading to legal expenses and operational setbacks.

e) **Financial Loss:** Incidents arising from non-compliance with safety strategies for student pilots and related factors can result in substantial financial burdens. Legal fees, compensations, potential loss of accreditation or partnerships, increased insurance premiums, and operational disruptions contribute to significant financial losses for the training institution.

Adherence to tailored and effective mitigation strategies addressing the safety of student pilots, environmental concerns, training quality, and workload management is paramount for any training institution. Ensuring compliance not only prioritizes the safety of student pilots and staff but also serves to uphold credibility, protect reputation, avoid legal consequences, and safeguard financial stability within the aviation education sector. By implementing and enforcing these strategies, training institutions demonstrate their commitment to maintaining the highest standards of safety and quality in aviation education. This fosters trust and confidence among students, parents, regulatory bodies, and the broader aviation community.

It also reflects positively on the institution's reputation, enhancing its competitive edge and positioning it as a preferred choice for prospective students and industry partners.

Moreover, adherence to mitigation strategies mitigates risks associated with accidents, incidents, and regulatory non-compliance, thereby reducing potential liabilities and financial losses. This proactive approach not only safeguards the institution's financial stability but also contributes to long-term sustainability and growth.

In summary, compliance with tailored and effective mitigation strategies is essential for training institutions to ensure the safety of student pilots, maintain credibility, protect reputation, and secure financial stability in the dynamic and highly regulated aviation education sector.

3.2 Conceptual Model Development

In the context of this thesis, our attention is directed towards specific components of the conceptual model given in Figure 2. This model is designed to assist in assessing, analyzing, and managing the fatigue levels experienced by student pilots during training and flight operations, as well as to propose mitigation strategies.

Rather than conducting an exhaustive analysis of the entire framework, our study adopts a more targeted approach. We concentrate on examining the interplay between fatigue levels and specific factors pertaining to student pilot training, workload, and lifestyle. Furthermore, we delve into the intricate relationship between fatigue levels and decision-making performance, as shown in Figure 7.

By narrowing our focus in this manner, we aim to gain a deeper understanding of how fatigue impacts crucial aspects of student pilot training and operational readiness. Through our investigation, we seek to uncover nuanced insights into how variations in workload, training activities, lifestyle choices, and other related factors influence fatigue levels among student pilots. Additionally, our examination of the relationship between fatigue and decision-making performance is essential for identifying potential areas of concern and developing targeted interventions to mitigate the impact of fatigue on pilot safety and performance.

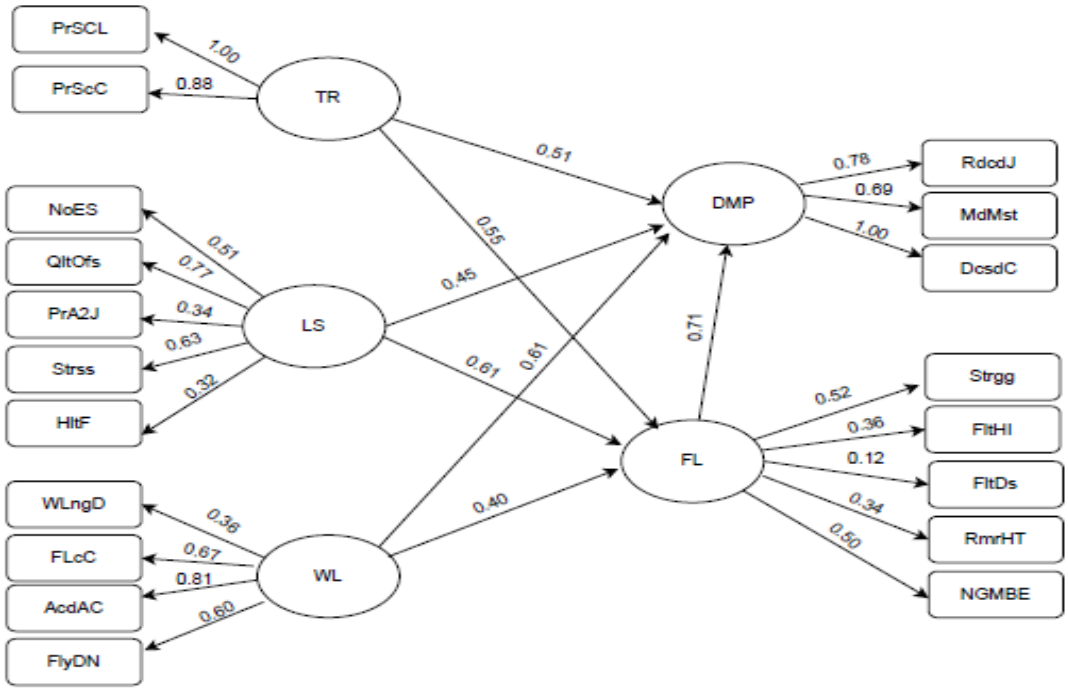

Figure 7: Research model (Developed by the author).

In Figure 7 above, the parameters are categorized as follows: Training-related factors (TR) include poor scheduling of flight lessons (PrSCL) and poor scheduling of

classes (PrScC). Lifestyle-related factors (LS) encompass stress (Strss), personal activities or other commitments/second job (PrA2J), quality of sleep (QltOfs), not enough sleep (NoES), and health or fitness (HlthF).Workload-related factors (WL) involve working a long day (WLongD), flying long cross-country (FLcC), academic activities (AcdAc), and flying during night (FlyDN). Decision-making performance (DMP) factors include reduced judgment (RdcdJ), making mistakes (MdMst), and decreased concentration (DcsdC).

There are also factors affecting fatigue levels such as struggling to stay awake during a flight (Strgg), remarking (out loud or to myself) about how tired I was but proceeding with the flight anyway (RrmHT), feeling disinterest during flight activities because of fatigue (FltDs), not giving my best effort due to fatigue (NGMBE), and feeling heightened irritation during a flight because of fatigue (FltHI). These coefficients underscore the interconnected nature of the variables, highlighting how factors like training, leadership, work-life balance, decision-making, and flight operations mutually influence each other within the studied model.

In the structural equation model developed, several significant relationships among latent variables have been identified. Training (TR) shows strong associations with PrSCL (1.00) and PrScC (0.88), highlighting their substantial influence. Leadership (LS) exhibits notable connections with QltOfs (0.77) and Strss (0.63), alongside moderate influences from PrA2J (0.34), HltF (0.32), and NoES (0.51). Work-Life Balance (WL) is significantly linked to FLcC (0.67), AcdAC (0.60), and FlyDN (0.60), with a moderate relationship to WLngD (0.36). The Decision-Making Process (DMP) is influenced by LS (0.55) and TR (0.51), and strongly affects MdMst (1.00), RdcdJ (0.78), and DcsdC (0.69). Flight (FL) is influenced by LS (0.61), DMP (0.71), and WL (0.40), and in turn impacts Strgg (0.52), RmrHT (0.50), and FltHI (0.36), with moderate relationships to FltDs (0.34) and NGBME (0.34).

The author seeks to investigate several specific relationships: Training Related Factors (TR) to Fatigue Level (FL), Training Related Factors (TR) to Decision-Making Performance (DMP), Lifestyle Related Factors (LS) to Fatigue Level (FL),

Lifestyle Related Factors (LS) to Decision-Making Performance (DMP), Workload Related Factors (WL) to Fatigue Level (FL), Workload Related Factors (WL) to Decision-Making Performance (DMP), and the interrelationships between Fatigue Level (FL) and Decision-Making Performance (DMP). We also draw a connection between our analysis and the validated questionnaire previously developed and tested by other researchers for data collection on fatigue in aviation, as provided in Appendix A.

In line with the research questions developed, various hypotheses have been formulated for testing, as outlined below:

H1: Training-related factors of fatigue significantly contribute to the fatigue levels experienced by student pilots.
H2: Training-related factors of fatigue affect the decision-making performance of student pilots.
H3: Lifestyle-related factors of fatigue significantly contribute to the fatigue levels experienced by student pilots.
H4: Lifestyle-related factors of fatigue affect the decision-making performance of student pilots.
H5: Workload-related factors of fatigue significantly contribute to the fatigue levels experienced by student pilots.
H6: Workload-related factors of fatigue affect the decision-making performance of student pilots.
H7: The fatigue levels experienced by student pilots affect their decision-making performance.

These relationships are further explored in subsequent chapters, where we analyze and delve deeper into the gathered data. Through detailed statistical analyses, we aim to uncover significant patterns and insights, providing a clearer understanding of how these factors impact fatigue levels and decision-making performance among aviation professionals.

CHAPTER 4

METHODOLOGY AND APPLICATION STUDY

To complement the model established in the preceding chapter, a data-driven study employing an online survey questionnaire is conducted. This chapter delves into the research design, study area, population, sample selection, sampling technique, data collection instrument, questionnaire validation, administration process, and data analysis methods.

4.1 Research Design

This study utilizes a quantitative research design. Through the collection of numerical data that can be statistically examined, quantitative research can provide a thorough understanding of the relationship between variables and enable the drawing of impartial conclusions.

4.2 Research Approach

Deductive research methodology is used for this investigation. It entails putting theories to the test and looking at how various factors relate to one another in light of previous theories and written works. Specific research questions can be developed using the deductive technique, and anticipated hypotheses can be tested.

4.3 Questionnaire Development

In our study, a questionnaire is developed to support the research model as given in chapter 3 figure 7. The questionnaire is based on proven, reliable, and valid studies of (Julius, 2022) and (Matthew, 2020). The reliability of a questionnaire refers to its consistency in accurately measuring intended concepts or variables, ensuring that responses are stable and dependable across diverse conditions and over an extended

period of time. This reliability is crucial for the author aiming to produce trustworthy findings that contribute valuable insights to their field of aviation fatigue; the validated questionnaire is utilized as a key component of our research methodology. To ensure the ongoing validity of the questionnaire, we conducted a rigorous reliability analysis of the data collected. This finding assures us that the items in the questionnaire reliably measure the same underlying construct or variables, thereby enhancing the reliability of the data collected for subsequent analysis. By maintaining high reliability standards, we strengthen the credibility and robustness of our research outcomes, ensuring that our findings are meaningful and impactful in advancing knowledge within our area of study.

The questionnaire was grouped into sections. Section one gathered demographic information, while section two have two questions, for question one : ***"Please rank the accuracy of each statement describing contributing factors that may have led to fatigue during flight activities".*** This question had a subscale consisting of eleven items. This question answered the questions related to the training, workload and training factors to the contribution to the fatigue level.

For question number two of this section two: ***"Please rank the accuracy of each statement describing your overall experience during all of your flight activities?"*** .This question had a subscale consisting of eight items. By relying on a questionnaire with a solid track record of validation, we can be more confident in the accuracy of the data we gathered. The questions have been tested and proven to be trustworthy, which adds credibility to our study. This way, we ensure that the information we're collecting is reliable and can be trusted for our research. The survey questionnaire is attached to the appendix A.

4.4 Population and Sample Size

The study's target audience is flight training schools in one European Union country and two in Türkiye. Additional criteria that could be taken into account during the selection process include enrollment in a specific flight training school and being a

student pilot. During this process the data sampling method was random sampling because each member of population has an equal chance of being selected.

According to the population of student pilots published by the Council of Higher Education in Türkiye, there is 7,355 student pilots (YOK, 2024). Additionally, statistics published by Statista indicate that the total number of registered student pilots in Italy in 2023 is 2,131 (statista, 2024). The total population of student pilots is approximately 9,486. Using a sample size calculator on the SurveyMonkey website, the required sample size for this research was determined to be 148 student pilots, with a 95% confidence level and an 8% margin of error. The actual collected sample size of 179 student pilots from three flight school programs exceeds this requirement, ensuring that the sample size is adequate for drawing reliable conclusions.

The main tool used for data collection is a structured questionnaire. To collect quantitative information about student pilot, the questionnaire will have both closed-ended and Likert-scale questions. The survey was conducted online via Google Forms, running throughout March 1, 2024, during the spring semester. It remained accessible electronically to respondents for a duration of thirty days.

Before collecting data, approval from the ethics committee was obtained, as seeking ethical permission from the institutional review board is a crucial step to ensure ethical standards in the research process (Appendix B is attached for reference).

4.5 Data Analysis

To maintain the integrity of the research, the researcher conducted a thorough review of the survey to mitigate any potential biases in both the study's execution and data analysis. This thorough investigation aimed to bolster the validity and reliability of the results, ensuring they accurately depicted the relationship between the variables under study and their outcomes. Subsequent to data collection, a comprehensive statistical analysis was conducted.

Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize the research variables. Additionally, structural equation modeling analysis was employed to investigate the relationships among these variables.

In the data analysis process, a combination of tools was employed, including Microsoft Excel and analysis software. Excel served as the primary tool for preliminary data cleaning and basic descriptive statistics, offering a user-friendly interface conducive to efficient data organization. Meanwhile, other software, recognized for its advanced statistical functionalities, was utilized for conducting more complex analyses such as structural equation modeling (SEM). This dual-tool approach not only allowed for a thorough examination of the data but also facilitated the derivation of results essential for rigorous hypothesis testing.

By combining Microsoft Excel for initial data cleaning and basic descriptive statistics with analysis software for more advanced analyses, researchers ensure a comprehensive exploration of the dataset. This methodological strategy enabled researchers to delve deeply into the data, uncovering patterns, relationships, and trends that contributed to the testing of hypotheses.

Moreover, it empowered researchers to draw insightful conclusions from the study, providing valuable insights into the factors influencing fatigue levels among student pilots. Overall, this approach enhanced the robustness and credibility of the research findings, contributing to a more nuanced understanding of the phenomenon under investigation.

CHAPTER 5

ANALYSIS AND FINDINGS

The prior chapter covered data collection and methodology used. This chapter will focus on analyzing it to derive insights and present results. Using structural equation modeling analysis is employed to explore relationships between variables, while data visualization methods will be used to present findings visually. Ultimately, this analysis will provide a clear understanding of the data and contribute to answering the research questions.

5.2 Demographics Statistics and Cross Tabulation

The purpose of demographic statistics and cross tabulation is to analyze and understand the characteristics of a population and the relationships between different variables, particularly categorical ones. It helps researchers gain insights into patterns, associations, and dependencies within a population, and it is helpful for decision-making.

5.2.1 Demographic Statistics

Demographic data, such as age, gender, enrollment status, and total logged flight time, were gathered through the survey. All participants were associated with flight training institutions in Southern Europe and Asia, with a total of 179 respondents. 67.6% of the participants identified as male, whereas approximately 29.1% identified as female ,***and 3.4% preferred not to say. Among the enrolled students, 35.2% were freshmen, 39.1% were sophomores, 13.4% were juniors, and 11.7% were seniors. According to age, 42.5% were between 18-22, 41.3% were between 23-27, and 16.2% were between 28-32.***

In the "Frequencies of approximate total logged flight time" table, the majority of respondents have logged between 50 to 100 hours of flight time, representing 40.8%

of the total. Additionally, 37.4% have logged less than 50 hours, while 11.2% and 10.6% have logged 101-250 hours and 251-500 hours, respectively.

In the "Frequencies of Institution" table, Institution 1 has the highest representation among respondents at 46.4%, followed by Institution 2 at 38.0%, and Institution 3 at 15.6%. These percentages provide insights into the distribution of respondents across different institutions.

Table 2: Summary of Participant's Demographics

Frequencies of Age

Age	Counts	% of Total	Cumulative %
18-22	76	42.5 %	42.5 %
23-27	74	41.3 %	83.8 %
28-32	29	16.2 %	100.0 %

Frequencies of Gender

Gender	Counts	% of Total	Cumulative %
Male	121	67.6 %	67.6 %
Female	52	29.1 %	96.6 %
Other	6	3.4 %	100.0 %

Frequencies of Institution

Institution	Counts	% of Total	Cumulative %
Institution 1	83	46.4 %	46.4 %
Institution 2	68	38.0 %	84.4 %
Institution 3	28	15.6 %	100.0 %

Table 2: Summary of Participant's Demographics **(Continued)**

Frequencies of Enrollment

Enrollment	Counts	% of Total	Cumulative %
Freshmen	63	35.2 %	35.2 %
Sophomore	71	39.7 %	74.9 %
Junior	24	13.4 %	88.3 %
Senior	21	11.7 %	100.0 %

Frequencies of Total Flight time

Flight time	Counts	% of Total	Cumulative %
Less than 50hrs	67	37.4 %	37.4 %
50-100hrs	73	40.8 %	78.2 %
100-250hrs	20	11.2 %	89.4 %
251-500hrs	19	10.6 %	100.0 %

5.1.2 Cross Tabulation

In the gender * enrollment cross-tabulation, the data highlights a notable concentration of male students in the sophomore enrollment level equal to 51 , comprising the highest count within this category. Turning to the age * gender cross tabulation, it becomes evident that the 18-22 age group accounts for the largest portion of both male and female students, suggesting a predominant presence of younger individuals within the student body. Moreover, a consistent trend of higher male enrollment across all age groups emerges from the data.

In the age * institution cross tabulation, Institution 1 emerges as the primary choice across all age brackets, particularly among students aged 18-22 and 22-27, while Institution 3 exhibits the lowest total count, potentially indicating a smaller student population or a specialized program focus.

Lastly, Flight time * Institution cross tabulation, the table indicates that Institution 1 has the highest total enrollment with 83 students, followed by Institution 2 with 68 students, and Institution 3 with 28 students. Among the flight time categories, freshmen are the most numerous across all institutions, with a total count of 67 students in Institution 1, 38 in Institution 2, and 4 in Institution 3. Sophomores also exhibit significant enrollment, with 73 students in total, distributed as 31 in Institution 1, 24 in Institution 2, and 18 in Institution

In contrast, both Junior and senior categories have lower enrollment numbers across all institutions, with the Junior category having 20 students in total and the Senior category having 19 students in total.

Table 3: Summary of cross tabulation Statistics

Gender * Enrollment cross tabulation

		Enrollment				Total
		Freshmen	Sophomore	Junior	Senior	
Gender	Male	42	51	9	19	121
	Female	20	20	11	1	52
	Prefer not to say	1	0	4	1	6
Total		63	71	24	21	179

Age * Gender Cross tabulation

		Gender			Total
		Male	Female	Prefer not to say	
Age	18-22	52	20	4	76
	23-27	50	23	1	74
	28-32	19	9	1	29
Total		121	52	6	179

Flight time * Institution cross tabulation

		Institution			Total
		Institution 1	Institution 2	Institution 3	
Flight time	Less than 50hrs	25	38	4	67
	50-100hrs	31	24	18	73
	101-250hrs	13	4	3	20
	25-500hrs	14	2	3	19
Total		83	68	28	179

Age * Institution cross tabulation

		Institution			Total
		Institution1	Institution2	Institution3	
Age	18-22	42	21	13	76
	23-27	38	23	13	74
	28-32	3	24	2	29
Total		83	68	28	179

Table 4: Descriptive Statistics

	N	Min	Max	Mean	Std. Deviation
FlyingDuringNight	179	1	3	1.46	.583
FlyingAlongAcross-country	179	2	5	3.96	.920
Working a long day	179	1	5	3.94	1.113
StressCausedByFamily	179	1	5	3.78	1.124
PoorSchedulingOfLessons	179	1	5	3.85	1.092
PoorSchedulingOfClasses	179	1	3	1.80	.720
LackOfHealthOrFitness	179	1	5	4.03	1.052
PersonalActivities (Second Job…)	179	1	5	3.95	1.082
AcademicActivities	179	1	5	3.37	1.469
QualityOfSleep	179	1	5	2.45	1.522
NotOfEnoughSleep	179	1	4	2.32	1.436
StrugglingToStayAwake	179	1	4	2.57	1.386
RemarkedHowTiredIWas	179	1	3	1.70	.710
ReducedJudgementduetofatigue	179	1	3	2.03	.807
FeltdisinterestedDueToFatigue	179	1	4	2.50	1.338
NotGivenMyBestEffort	179	1	5	3.41	1.130
MadeMistakesDueToFatigue	179	1	4	2.29	1.355
FeltHeightenedIrritation	179	1	3	1.72	.727
ConcentrationDecreased	179	1	5	2.21	1.288
Valid N (listwise)	179				

The descriptive statistics, gathered from 179 participant responses, provide quantitative insights into the factors impacting student pilots. They reveal both the prevalence of these factors and the diversity of experiences among student pilots. For instance, "Flying during Night" has a mean value of 1.46, suggesting it's not a frequent occurrence and likely has limited impact on student pilot fatigue. In contrast, "Lack of Health/Fitness" and" Flying a long cross country" have much higher mean values of 4.03 and 3.96 respectively, indicating they are more prevalent and impactful. These differences in mean values highlight the varying significance of these factors within the student pilot community. Additionally, the standard deviations of 0.583 for "Flying during Night" and 1.522 for "Quality of Sleep" indicate considerable variability around these means, emphasizing the diverse experiences student pilots encounter.

Before proceeding with the collected data, although we were confident in its validity, we assessed its reliability. This means the items are consistently measuring the intended constructs, allowing us to confidently use the questionnaire for our study and trust the stability and accuracy of the collected data.

5.1.3 Structural Equation Modeling

Structural Equation Modeling (SEM) is chosen in research for its ability to delve deeply into complex relationships among variables. By allowing simultaneous analysis of multiple variables and incorporating both measurement and structural models, SEM enables researchers to test intricate hypotheses and theoretical models rigorously. Its capacity to integrate qualitative and quantitative data within a single framework enhances the depth of analysis, accommodating diverse study designs. SEM's reliance on fit indices ensures the validity of models by assessing how well they align with observed data, thereby offering robust insights into multivariate relationships.

To ensure the appropriateness of data in Structural Equation Modeling (SEM), it is essential to subject it to several assumptions, including normality, linearity,

homoscedasticity, outliers, and multicollinearity (Marwan, 2024). These assumptions are detailed as follows:

a) **Normality** (Multivariate normality): refers to the assumption that the data or residuals of the model follow a multivariate normal distribution. This assumption is important because many statistical tests and estimators used in SEM rely on the assumption of multivariate normality for accurate parameter estimation and model fit assessment.
b) **Linearity**: Relationships between variables should be linear, demonstrated graphically through scatterplots. This ensures that the data's distribution pattern aligns with straight-line relationships.
c) **Homoscedasticity**: The variance of the dependent variable should be consistent across the range of the independent variable. This can be assessed using tests like p-value greater than 0.05 indicates that there is no significant evidence to reject the null hypothesis of equal variances across groups or conditions. Alternatively, visual assessment through scatterplots ensures equal variance across data points.
d) **Independence of residual**: The independence of residuals in SEM means ensuring that errors in the model are not correlated. To check this, plot residuals against predicted values and use the Durbin-Watson test for autocorrelation.
e) **No Multicollinearity**: This occurs when independent variables are highly correlated with each other, potentially inflating standard errors and causing significant variables to appear insignificant. Multicollinearity can be detected using metrics like the Variance Inflation Factor (VIF) and Tolerance. A VIF greater than 10 indicates high correlation among independent variables, indicating multicollinearity. Similarly, Tolerance values below 0.1 also signal multicollinearity issues.

With the aid of Excel and analysis software, the data were coded, cleaned, and scored. There were 95% stated confidence intervals. Scatter plots were used to evaluate homoscedasticity and autocorrelation, and QQ plots and density histograms were utilized to evaluate the normality assumptions. Variance inflation factors (VIFs) were used to evaluate multicollinearity.

Table 5: Summarized table for all analysis assumptions

VARIABLES	NORMALITY	LINEARITY & HOMOSCEDASTICITY	INDEPENDENCE OF RESIDUAL D/W (BETWEEN 1.5 AND 2.5_	NO MULTICOLLINEARITY (VIF) (1 > 1.020 and 1.281 < 5)
Poor scheduling of flight lessons	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.810	Satisfied with the range of VIF
Poor scheduling of flight classes	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.508	Satisfied with the range of VIF
Stress	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.899	Satisfied with the range of VIF
Personal activities	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.742	Satisfied with the range of VIF
Quality sleep	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.820	Satisfied with the range of VIF
Not of enough sleep	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.710	Satisfied with the range of VIF
Poor health or fitness	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.710	Satisfied with the range of VIF
Working a long day	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.702	Satisfied with the range of VIF
Flying long cross- country	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.653	Satisfied with the range of VIF
Academic activities	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.733	Satisfied with the range of VIF
Flying during night	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.973	Satisfied with the range of VIF
Reduced judgement due to fatigue	Satisfied	Satisfied	Satisfied because is Durbin Watson is 2.045	Satisfied with the range of VIF
Making mistake due to fatigue	Satisfied	Satisfied	Not Satisfied because is Durbin Watson is 1.483	Satisfied with the range of VIF
Reduced concentration due to fatigue	Satisfied	Satisfied	Satisfied because is Durbin Watson is 1.663	Satisfied with the range of VIF

This table summarizes the assessment of each factor regarding normality, linearity, homoscedasticity, Independence of residuals, and multicollinearity based on your evaluation criteria. Given that the data are normally distributed and there is linearity

for all variables tested, the primary concern lies with the outliers in poor scheduling of academic classes and making mistakes due to fatigue. The values indicating positive autocorrelation in the residuals, such as a Durbin-Watson statistic of 1.483, suggest a violation of the independence assumption. Detailed verification of assumptions results can be found in Appendix C.

The structural equation modeling (SEM) was used to test the relationship between training related factors and fatigue level, training related factors and decision-making performance, lifestyle related factors and fatigue level, lifestyle related factors and decision-making performance, workload related factors and fatigue level, workload related factors and decision-making performance, and the interrelationships between fatigue level and decision-making performance.

Confirmatory Factor Analysis (CFA) is a statistical technique used in Structural Equation Modeling (SEM) to validate measurement instruments by examining how well observed variables (indicators) align with the latent constructs (factors) they are intended to measure. By confirming the structure of latent constructs hypothesized in a theoretical model, CFA ensures that the relationships among variables are accurately represented. It assesses the validity of measurement instruments, verifies the construct validity of the model, and evaluates overall model fit using various statistical indices. The model's fit was assessed, and adjustments were made by considering modification indices, which highlight correlations among observed variables exceeding 10. Relationships were removed if their parameter estimates fell below 0.50, either based on significant improvement in fit indices or authors' informed judgment.

CFA within SEM is essential for establishing the reliability and validity of research measures, providing a robust foundation for further analysis. In our data he SEM primarily uses fit indices (e.g., RMSEA, CFI, TLI) to evaluate how well the hypothesized model fits the observed data, considering both measurement and structural aspects of the model. The structural equation model shows good fit with Chi-square (χ^2) = 858, degrees of freedom (df) = 816, p = 0.02, Root Mean Square Error of Approximation (RMSEA) =0.05, Standardized Root Mean Square Residual

(SRMR) = 0.08, Comparative Fit Index (CFI) 0.95, Tucker-Lewis Index (TLI) =0.91, and Goodness of Fit Index (GFI)) =0.95.

Table 6: Measurement model

				95% Confidence Intervals				
Latent	**Observed**	**Estimate**	**SE**	**Lower**	**Upper**	**β**	**Z**	***p***
TRA	PrSCL	1.000	0.00	1.000	1.000	1.00		
	PrScC	0.844	0.210	0.433	1.224	0.88	2.02	<0.001
LS	NoES	1.000	0.175	0.657	1.342	0.51	2.71	0.039
	QltOfs	1.662	0.310	1.052	2.271	0.77	1.36	<0.001
	PrA2J	1.226	0.268	0.699	1.752	0.34	2.57	0.032
	Strss	0.618	0.240	0.147	1.088	0.63	1.57	<0.001
	HltF	0.342	0.193	0.162	1.211	0.32	1.77	0.021
WORK	WLngD	1.000	0.199	0.609	1.390	0.36	2.03	0.031
	FLcC	1.027	0.293	0.452	1.601	0.67	2.50	0.023
	FlyDN	2.376	0.153	0.076	2.675	0.81	0.54	<0.001
	AcdAC	2.200	0.429	1.359	3.408	0.60	2.13	0.051
DMP	RdcdJ	1.000	0.633	0.359	1.641	0.78	2.28	0.006
	MdMst	2.00	0.345	0.324	2.675	0.69	1.12	<0.051
	DcsdC	1.854	0.000	0.000	0.000	1.00		
FL	Strgg	1.000	0.123	0.759	1.241	0.52	1.13	0.081
	RmrHT	1.805	0.633	0.564	3.004	0.36	2.85	0.011
	FltDs	1.507	0.213	0.231	1.923	0.12	0.07	0.031
	NGMBE	1.478	0.156	0.156	1.798	0.34	2.49	0.091
	FltHI	1.984	0.235	0.235	2.445	0.50	2.45	0.041

Table 6 presents the measurement model employed in this study's Structural Equation Modeling (SEM) analysis, which evaluates the relationships between latent variables and their observed indicators. The model encompasses several key

constructs essential to understanding factors influencing pilot fatigue. For instance, Training Related Factors (TRA) are represented by indicators like PrSCL and PrScC, where PrSCL shows a perfect estimate of 1.000, indicating precise measurement, and PrScC demonstrates a significant estimate of 0.844 ($p < 0.001$). Lifestyle Related Factors (LS), including QltOfs and Strss, exhibit strong estimates (1.662 and 0.618, respectively) with p-values < 0.001, underscoring their reliability in capturing lifestyle influences. Workload Related Factors (WORK), Decision-Making Performance (DMP), and Fatigue Level (FL) are similarly analyzed, each revealing crucial insights into their respective indicators' contributions to the overall model. The inclusion of estimates, confidence intervals, β coefficients, z-values, and p-values in Table 7 provides a comprehensive framework for assessing the model's validity and the robustness of its findings in understanding pilot fatigue dynamics.

Another step is to test the reliability of latent variables to evaluate the internal consistency and reliability of the latent variables (constructs) being measured by the observed variables (indicators). Reliability indices such as Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE) are commonly used in SEM to evaluate these aspects.

Table 7: Reliability indices of the SEM latent variables

Variable	α	ω1	ω2	ω3	AVE
TR	0.750	0.653	0.653	0.624	0.310
LS	0.723	0.723	0.723	0.723	0.566
WL	0.761	0.774	0.774	0.774	0.635
FL	0.736	0.694	0.694	0.710	0.364
DMP	0.718	0.712	0.812	0.745	0.523

Table 7 displays the reliability indices and average variance extracted (AVE). The reliability metrics for all latent variables are strong, indicating solid internal consistency. This confirms that the observed variables reliably measure their respective constructs in a coherent manner. In Structural Equation Modeling (SEM), parameters like estimates, standard errors, confidence intervals, standardized coefficients (β), z-values, and p-values are critical. They quantify relationships

between variables, assess their significance, and help validate hypotheses, ensuring the model accurately reflects real-world data and theories.

Table 8: Parameters estimates

				95% Confidence Intervals				
Dep	**Pred**	**Estimate**	**SE**	**Lower**	**Upper**	**β**	**z**	**p**
TR	FL	0.55	0.10	0.354	0.746	0.55	1.50	0.013
TR	DMP	0.51	0.08	0.353	0.667	0.51	2.38	0.023
LS	FL	0.61	0.12	0.375	0.845	0.61	2.08	0.031
LS	DMP	0.45	0.09	0.274	0.626	0.45	0.67	0.001
WL	FL	0.40	0.07	0.263	0.537	0.40	1.71	0.003
WL	DMP	0.61	0.10	0.414	0.808	0.61	2.10	0.023
FL	DMP	0.71	0.11	0.494	1.006	0.71	2.10	0.011

Table 8 summarizes the results of hypothesis testing in SEM, displaying the relationships between various latent variables and their statistical significance. Each row corresponds to a specific hypothesis regarding the relationship between two latent variables, providing key metrics to interpret the strength and significance of these relationships.

CHAPTER 6

DISCUSSION

In the previous chapter, the results were thoroughly explored, and the dataset collected through the Google Forms survey analyzed. In this chapter, the overall discussions are provided, along with their implications for the government, training institutions, regulatory bodies, and the student pilots themselves.

Based on the findings presented in Table 7, the analysis of structural relationships among latent variables in the SEM model reveals several significant associations. Firstly, there is a statistically significant positive relationship observed between TR (Training Related Factors) and FL (Fatigue Level), as indicated by an estimate of 0.55 ($p = 0.013$) and a β coefficient of 0.55, highlighting the strong influence of TR on FL. Similarly, TR also demonstrates a significant positive impact on DMP (Decision-Making Performance), with an estimate of 0.51 ($p = 0.023$) and a β coefficient of 0.51, underscoring its role in affecting DMP.

Moreover, the relationship between LS (Lifestyle Factors) and (Fatigue level) FL is notably strong, with an estimate of 0.61 ($p = 0.031$) and a β coefficient of 0.61, suggesting that lifestyle factors (LS) significantly influences FL. Additionally, LS shows a significant positive impact on DMP, with an estimate of 0.45 ($p = 0.001$) and a β coefficient of 0.45, indicating its contribution to DMP outcomes.

Furthermore, WL (Workload Factors) exhibits a significant positive relationship with FL (estimate = 0.40, $p = 0.003$, $\beta = 0.40$) and DMP (estimate = 0.61, $p = 0.023$, $\beta = 0.61$), highlighting its role in influencing both constructs. Lastly, FL demonstrates a significant positive impact on DMP, with an estimate of 0.71 ($p = 0.011$) and a β coefficient of 0.71, indicating FL's substantial effect on DMP outcomes.

These findings provide empirical support for the hypothesized relationships within the SEM, indicating the direction, strength, and statistical significance of relationships between the latent variables examined in the study.

Table 9: Summary table of hypotheses

HYPOTHESES	SUPPORTED
$H_{1.}$ Training-related factors of fatigue significantly contribute to the fatigue levels experienced by student pilots.	Yes
$H_{2.}$ Training-related factors of fatigue affect the decision-making performance of student pilots.	Yes
H3: Lifestyle-related factors of fatigue significantly contribute to the fatigue levels experienced by student pilots.	Yes
H_4. Lifestyle-related factors of fatigue affect the decision-making performance of student pilots.	Yes
H_5. Workload-related factors of fatigue significantly contribute to the fatigue levels experienced by student pilots.	Yes
H_6. Workload-related factors of fatigue affect the decision-making performance of student pilots.	Yes
H_7. The fatigue levels experienced by student pilots affect their decision-making performance.	Yes

Based on Table 9, it is evident that all hypothesized relationships between various factors and outcomes related to fatigue and decision-making performance among student pilots are supported. This includes the significant contributions of training-related, lifestyle-related, and workload-related factors to fatigue levels, as well as their subsequent effects on decision-making performance. These findings underscore the multifaceted nature of factors influencing pilot fatigue and highlight their critical implications for aviation safety and performance.

Understanding fatigue factors is essential for student pilots, who must recognize elements like poor scheduling, stress, and sleep quality and how they impact performance. A balanced schedule is key to avoiding fatigue from poorly coordinated classes and flight lessons. Effective stress management is vital for controlling fatigue levels and ensuring top performance during training. Prioritizing quality sleep is critical for reducing fatigue and improving learning and flight performance. Developing strong time management skills enables students to allocate time effectively for study, practice, rest, and seeking support when necessary,

fostering a comprehensive approach to fatigue management throughout their training journey.

Training institutions should utilize the framework developed in this thesis because it provides a helpful strategy to mitigate fatigue among student pilots, based on the findings. To effectively address fatigue, institutions should implement balanced schedules, integrate stress management programs, prioritize promoting quality sleep, support students in developing time management skills, and offer flexible learning options such as using simulators, staying updated on industry standards, supported by leadership's commitment to clear policies and a strong safety culture and stay updated on industry standards, supported by leadership's commitment to clear policies and a strong safety culture. By prioritizing fatigue management, institutions enhance the learning experience and promote student well-being. Additionally, school leadership should implement structured scheduling practices and offer fatigue management training at all levels (tactical, operational, and strategic), along with developing comprehensive education programs to shape the learning environment for student pilots.

Governments play a vital role in shaping the regulatory landscape and promoting fatigue management in aviation training through legislation and policy development. By enacting laws and regulations that prioritize fatigue management, governments create a framework for regulatory bodies to enforce standards effectively. Interagency collaboration is essential to ensure a coordinated approach across different government departments responsible for aviation oversight, health, labor, and education. Moreover, governments can facilitate public awareness campaigns and educational initiatives to educate stakeholders about the risks associated with fatigue and the importance of adopting effective mitigation strategies. International collaboration efforts also allow governments to contribute to the development of global standards for fatigue management, promoting consistency and safety in aviation training worldwide.

Regulatory bodies like EASA and ICAO among others, hold a pivotal role in ensuring the safety and effectiveness of flight training programs by enforcing

policies related to fatigue management. Rigorous enforcement of existing regulations, including scheduling practices and rest periods, is paramount to safeguarding student pilots from the adverse effects of fatigue. Through regular audits and inspections, regulatory bodies can identify areas of non-compliance and take corrective measures to mitigate fatigue-related risks. Additionally, establishing robust systems for data collection and analysis enables regulatory bodies to monitor trends, assess risks, and develop evidence-based interventions to improve fatigue management practices. Collaborating with industry stakeholders and providing support for research into fatigue management further strengthens regulatory efforts in enhancing safety within the aviation training sector.

Fatigue is a complex issue requiring collective responsibility from various stakeholders, including government bodies, regulatory authorities, training institutions, and the broader environment. Addressing it involves creating and enforcing effective policies, regulations, and training programs, as well as promoting awareness and well-being within the aviation industry. Recognizing fatigue as a shared responsibility allows stakeholders to work together to reduce its impact and ensure safe, effective aviation operations.

Based on the framework provided, here's how flight training schools can translate it into actionable policies to manage fatigue among student pilots by:

a) Integrating into training programs and regular informational sessions for pilots and staff to ensure that everyone understands how these factors can impact fatigue levels. By increasing awareness and knowledge, companies can proactively manage fatigue risks, enhance pilot well-being, and maintain high safety standards in aviation operations. To effectively address fatigue among student pilots, it's crucial to develop a policy that educates personnel on the different types of fatigue, their root causes, symptoms, measurement tools, and the consequences if they fail to comply.
b) Prioritizing the implementation of regular fatigue assessments utilizing tools such as EEG, PSG, Actigraphs, and questionnaires to effectively monitor pilot well-being. Implementation efforts should include establishing clear protocols

for conducting assessments, ensuring robust data handling practices, and fostering an environment that encourages pilots to report symptoms openly and without fear of repercussions. Confidentiality of data must be strictly maintained throughout the process. Using insights gained from these assessments, companies can make informed decisions to optimize schedules and implement targeted interventions aimed at mitigating fatigue risks and enhancing overall safety in aviation operations.

c) Providing clear guidelines and training sessions for all personnel involved in flight operations. Regularly review and update policies based on feedback from pilots, research findings, and evolving industry standards to continuously improve fatigue management practices and enhance safety in aviation. At the strategic level, prioritize developing a policy that ensures strict adherence to aviation regulations governing pilot duty and rest requirements. At the tactical level, optimize pilot schedules to include sufficient rest periods between flights, designate quiet nap areas at airports or bases, and offer continuous fatigue management training for pilots and crew members. Implement operational policies focusing on monitoring crew rest periods effectively, promoting a culture of open fatigue reporting among pilots, supporting mental well-being, and ensuring fair workload allocation.

CHAPTER 7

CONCLUSION, FURTHER RESEARCH SUGGESSION AND LIMITATION

This chapter will discuss the study's conclusions; limitations encountered during the thesis, and provide suggestions for further research.

The previous researchers have made a tremendous contribution; yet, there existed a gap in the development of the conceptual framework. After identifying this gap, efforts were made to develop it in this thesis. The conceptual framework serves as a mirror, enabling the recognition of fatigue. Once identified, the conceptual framework proposes effective mitigation strategies to training organizations for fatigue management. It is put forward that factors contributing to fatigue are diverse and complex. Our findings suggest avenues for further research and intervention development to address student pilot well-being.

Through developed conceptual framework, the stakeholders are able to identify that there is fatigue and apply mitigations provided, serving as a guiding beacon for aspiring pilots, offering them a transparent understanding of the challenges inherent in an aviation career while equipping them with the knowledge and preparedness necessary to excel in the profession. This study not only fosters a realistic perspective but also empowers future aviators to navigate the complexities of the industry with confidence and proficiency.

The findings of this study play a pivotal role in advancing the overall safety and effectiveness of aviation practices. By enhancing training programs and refining methodologies, the research facilitates the acquisition of the comprehensive knowledge and skills essential for success in aviation. By optimizing performance metrics and ensuring adherence to regulatory standards, this study addresses critical facets of pilot training and operational protocols, thereby laying a robust foundation for safer skies and operations that are more efficient.

Furthermore, the study's exploration of fatigue's multifaceted influence on physical, emotional, and mental well-being highlights the importance of prioritizing pilot health and resilience. By shedding light on the nuanced challenges posed by fatigue, this research informs the creation of effective well-being strategies tailored to the specific requirements of aviation professionals. These initiatives not only promote a healthier workforce but also cultivate a culture of care and support essential for sustaining long-term safety and productivity in aviation operations.

By integrating these findings into training protocols and operational frameworks, stakeholders across the aviation industry can collectively strive towards safer skies and more resilient operations. As aviation professionals continue to prioritize knowledge, skills, and well-being, the industry stands poised to embrace a future defined by excellence, innovation, and unwavering commitment to safety, necessitating research and development utilizing various technologies in the aviation sector like artificial intelligence, particularly in regulatory assessment within institutions, among student pilots, and at governmental levels.

7.1 Recommendations

Training schools are the cornerstone of aviation education, and to excel in this role, they must embrace a holistic strategy. Beginning with fatigue management trainings, these schools ensure that instructors and staff are well-versed in recognizing and addressing fatigue-related risks, safeguarding both student pilots and the integrity of training operations.

Fostering a safety culture grounded in open communication establishes an environment where concerns can be freely discussed and resolved, nurturing a sense of trust and accountability among all stakeholders. Collaboration with regulatory bodies and industry stakeholders is paramount, as it ensures alignment with evolving standards and best practices, reinforcing the school's commitment to excellence and compliance. Embracing technological advancements, such as flight simulators,

enriches training experiences, providing students with immersive learning opportunities in a controlled setting.

Moreover, creating a supportive study environment and implementing continuous monitoring mechanisms not only enhance learning outcomes but also prioritize student well-being throughout their educational journey. By prioritizing these pillars, training schools set the stage for the development of skilled, safety-conscious aviators ready to navigate the skies with confidence and proficiency.

When it comes to students, prioritizing self-care, such as eating healthily, prioritizing both the quality and quantity of sleep, advocating for personal safety, and actively participating in fatigue management programs, are paramount. Utilizing available resources, maintaining transparent communication with peers and instructors, and staying informed about industry regulations significantly contribute to fostering a safety-oriented culture within the aviation training school, embracing continuous learning, they can develop resilience and skills related to managing fatigue. Regular self-assessment and reflection enable students to monitor their fatigue levels and make necessary adjustments to their routines.

7.2 Future Research Suggestions

Expanding the sample size and diversity could greatly enrich the research. Initially, the researcher collected samples from three flight training schools located in southern Europe and western Asia. However, broadening the participant pool to include aviation college students from a variety of regions across the country would offer a more robust dataset. This wider inclusion would not only provide a broader range of perspectives but also allow for a more thorough examination of the findings' applicability on a larger scale.

Expanding the developed conceptual framework for evaluating fatigue among student pilots to encompass professional pilots would enhance its effectiveness and applicability. By including professional aviators, the conceptual framework can

provide a comprehensive assessment across different experience levels, strengthening its utility and relevance. This extension would reinforce the conceptual framework capacity to address fatigue management needs across the aviation sector, ultimately contributing to improved safety and well-being for all pilots.

Based on our conceptual framework, the development of a computer software-based Decision Support System (DSS) integrated with Internet of Things (IoT) technology to address pilot fatigue by monitoring biometric data in real-time, providing alerts, and forecasting fatigue risk factors, will ultimately enhance flight safety and represent a promising research avenue.

For future research, during the testing of the framework, the researcher was limited to mitigation strategies related to the student pilot lifestyle, training, and workload. They should incorporate environmental aspects into their testing of our thesis framework. The research should not solely focus on student pilots; it should also consider professional pilots.

7.3 Limitation of the Research

Due to the sensitive nature of the research topic, several institutions have declined to share information related to fatigue. They perceive that disclosing such data might compromise their credibility or reputation. As a result, we were unable to collect the desired number of participants. They expressed concerns that disclosing such information might expose their weaknesses and potentially impact their reputation negatively.

Some institutions restricted the number of students allowed to respond to the questionnaire because they were the ones who helped us distribute the online survey.

One of the significant challenges I faced during my thesis data collection was the inconsistent access to flight training school leadership, which hindered my ability to gather sufficient data across various institutions.

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APPENDICES

Appendix A: Questionnaire

Dear Participant,

I am currently working on my master's thesis in Aviation Management at the University of Turkish Aeronautical Association. Your participation in this survey will contribute valuable insights to my research on the **"IMPACT OF FATIGUE AS A HUMAN FACTOR IN AVIATION: A CONCEPTUAL MODEL DEVELOPMENT AND AN APPLICATION ON FLIGHT TRAINING STUDENTS**.

Your responses will be kept confidential and used solely for academic purposes. We estimate it will take about 8 to 15 minutes of your time to complete the questionnaire.

DEMOGRAPHIC INFORMATION

Age:

☐ 18-22
☐ 23-27
☐ 28-32

Gender:

☐ Male
☐ Female
☐ Prefer not to say

Enrolment status:

☐ Freshmen (1st year)
☐ Sophomores (2nd year)
☐ Juniors (3rd year)
☐ Seniors (4th year)

Approximate total logged flight time

☐Less than 50 hours
☐50-100 hours
☐101–250 hours
☐251-500 hours

SECTION TWO: QUESTIONNAIRE

1. Please rank the accuracy of each statement describing contributing factors that may have led to fatigue during flight activities.

statement	Never	Rarely	Sometimes	Often	Always
1. Flying during night (sunset through sunrise).					
2. Flying a long cross-country (2.5 h or over).					
3. Working a long day.					
4.Stress caused by family or other psychological Conditions.					
5. Poor scheduling of flight lessons (e.g., too early, too late or too many).					
6. Poor scheduling of academic classes.					
7. Lack health or fitness.					
8. Personal activities or other commitments (e.g., 2nd job).					
9.Academic activities (e.g., midterms, student organizations, etc.).					
10. Quality of sleep (restlessness or interrupted sleep).					
11. Not of enough sleep.					

2. Please rank the accuracy of the statement describing your overall experience during all of your flight activities.

statement	**Never**	**Rarely**	**Sometimes**	**Often**	**Always**
12. I have struggled to stay awake during a flight.					
13. I have remarked (out loud or to myself) about how tired I was but proceeded with the flight anyway.					
14. I have overlooked mistakes during a flight because of reduced judgment caused by fatigue.					

15. I have felt disinterest during flight activities because I was fatigued.					
16. I have not given my best effort due to fatigue.					
17.I have made mistakes during flight activities because I was fatigued.					
18.I have felt heightened irritation during a flight because I was fatigued.					
19. My abilities to carry out tasks requiring concentration have been decreased due to fatigue.					

Thank you for participating in this survey.

I sincerely appreciate your time and cooperation.

Appendix B: THK Ethics Committee Approval

T.C.
TÜRK HAVA KURUMU ÜNİVERSİTESİ
Etik Kurulu

Sayı : E-63878715-619-37741 11.03.2024
Konu : Etik Kurul İzni

DAĞITIM YERLERİNE

Üniversitemiz Sosyal Bilimler Enstitüsü Havacılık Yönetimi Anabilim Dalı yüksek lisans öğrencilerinden 2208071009 numaralı **Alphonse NDAYAMBAJE**, 21.02.2024 tarihli ve 25812 kurum sayılı dilekçesinde "**Impact of Fatigue as a Human Factor in Aviation: Case Study Piloting Student**" başlıklı yüksek lisans tez çalışması için hazırlamış olduğu Aydınlatılmış Onam Formu, Çalışma Protokolü ve Veri Toplama Formunun Üniversitemiz Etik Kurulu tarafından etik açıdan değerlendirilmesini talep etmiştir. İlgili belgeler Türk Hava Kurumu Üniversitesi Etik Kurulunun **08.03.2024** tarihli toplantısında incelenmiş olup etik açıdan uygun bulunmuştur.

Bilgilerinizi ve gereğini rica ederim.

Prof. Dr. Rahmi ER
Rektör

Ek: Alphonse NDAYAMBAJE'in 21.02.2024 tarihli dilekçesi

Dağıtım:
Gereği:
İLGİLİ MAKAMA

Bilgi:
Havacılık Yönetimi Anabilim Dalına
Sayın Doç.Dr. Dursun BALKAN
Sayın Alphonse NDAYAMBAJE

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Fakülte Sekreteri

Appendix C: Results for the Detailed Verification of SEM Analysis Assumptions

POOR SCHEDULING OF LESSONS

1. Independence of Residuals

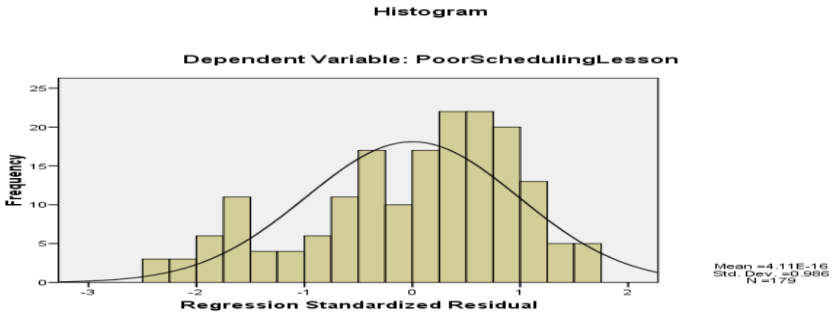
Model Summary[b]

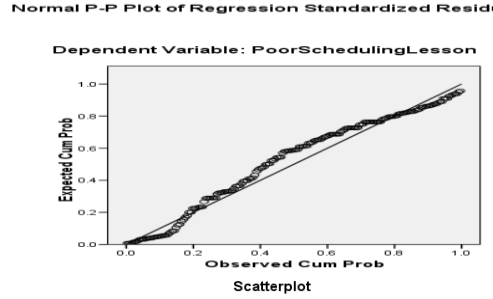
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.301[a]	.091	.065	1.056	.091	3.456	5	173	.005	1.810

a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

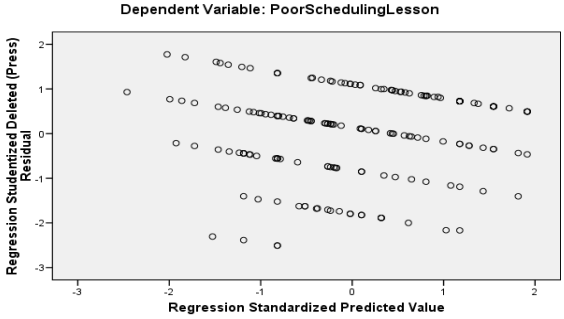
b. Dependent Variable: PoorSchedulingLesson

2. Normality/Linearity





Scatterplot



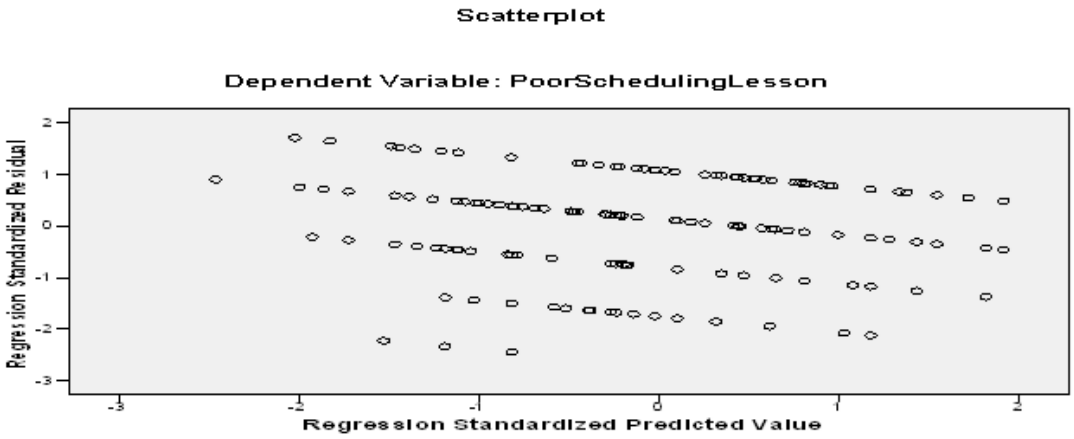
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	4.254	.378		11.251	.000		
	Struggling	-.147	.063	-.187	-2.349	.020	.828	1.208
	RemarkedHowTired	-.032	.123	-.021	-.265	.792	.828	1.207
	FeltDesinterested	-.053	.067	-.065	-.791	.430	.783	1.277
	NotGivenMyBestEffort	.121	.071	.126	1.717	.088	.980	1.020
	FeltHeightenedIrritation	-.144	.123	-.096	-1.170	.244	.781	1.281

a. Dependent Variable: PoorSchedulingLesson

4. Multicollinearity



POOR SCHEDULING OF ACADEMIC CLASSES

1. Independence of Residuals

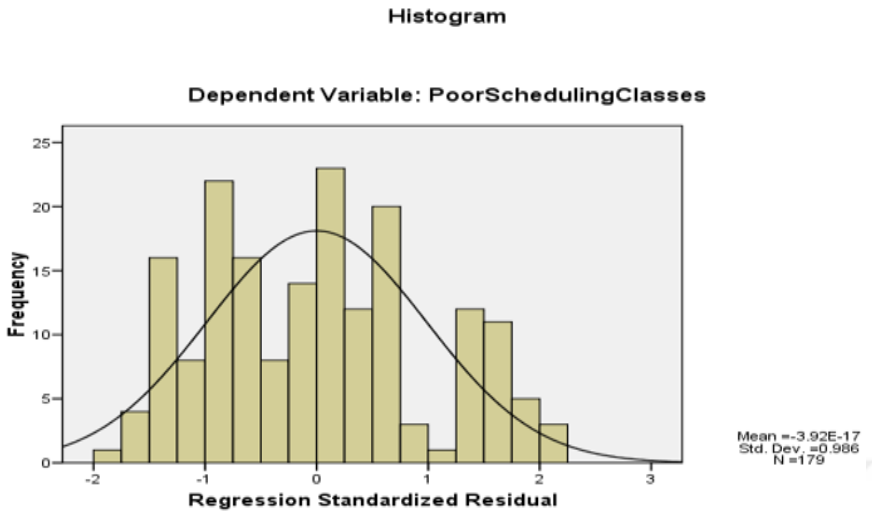
Model Summary[b]

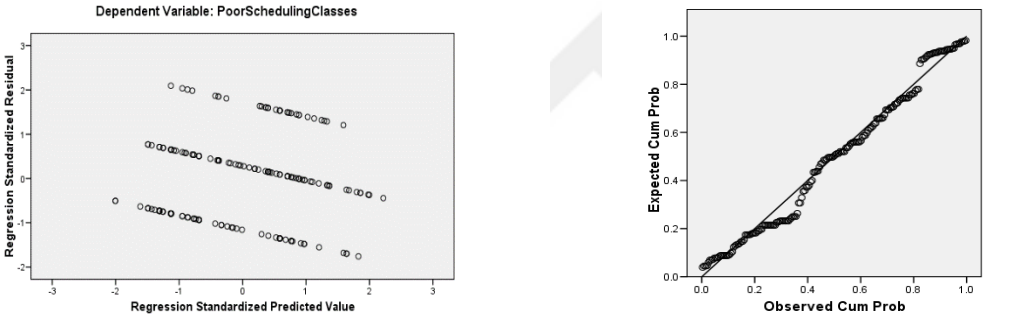
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.315[a]	.099	.073	.693	.099	3.814	5	173	.003	1.956

a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: PoorSchedulingClasses

2. Linearity /Normality





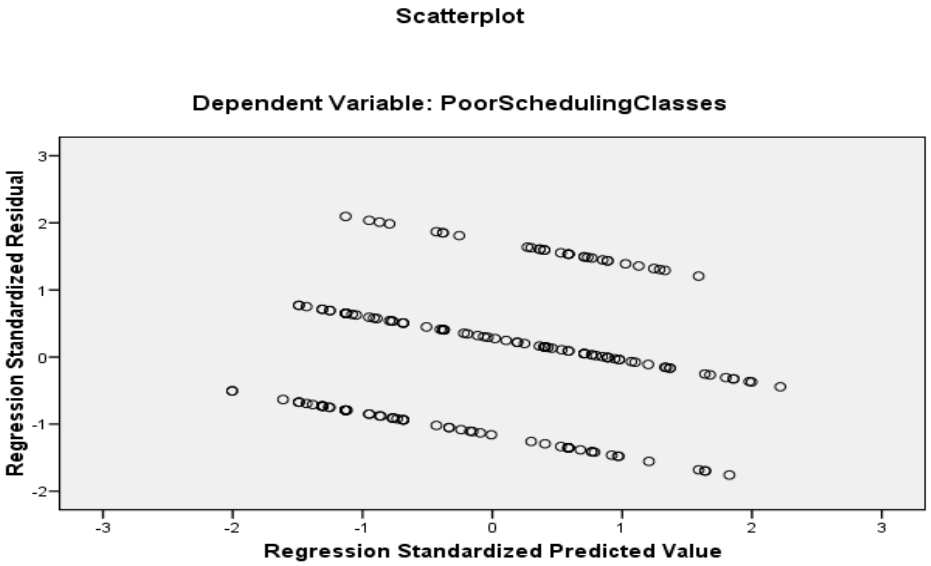
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	1.363	.248		5.495	.000		
	Struggllling	.100	.041	.192	2.421	.017	.828	1.208
	RemarkedHowTired	.158	.080	.156	1.972	.050	.828	1.207
	FeltDesinterested	-.039	.044	-.072	-.886	.377	.783	1.277
	NotGivenMyBestEffort	-.041	.046	-.064	-.882	.379	.980	1.020
	FeltHeightenedIrritation	.089	.081	.090	1.099	.273	.781	1.281

a. Dependent Variable: PoorSchedulingClasses

4. Homoscedasticity



STRESS

1. Independence of Residuals

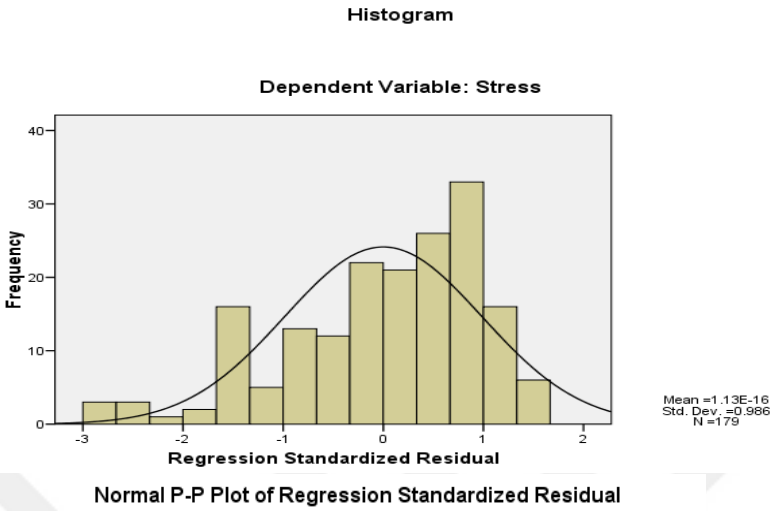
Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.273[a]	.075	.048	1.097	.075	2.795	5	173	.019	1.899

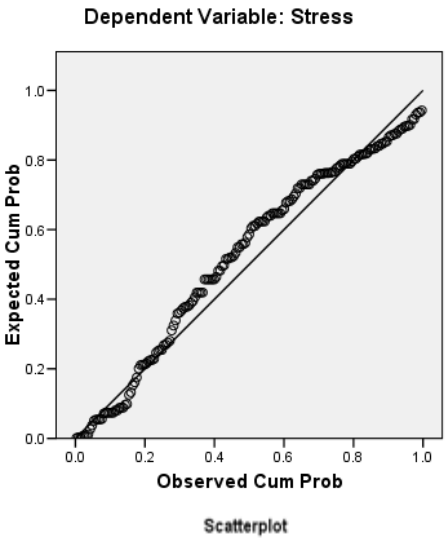
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: Stress

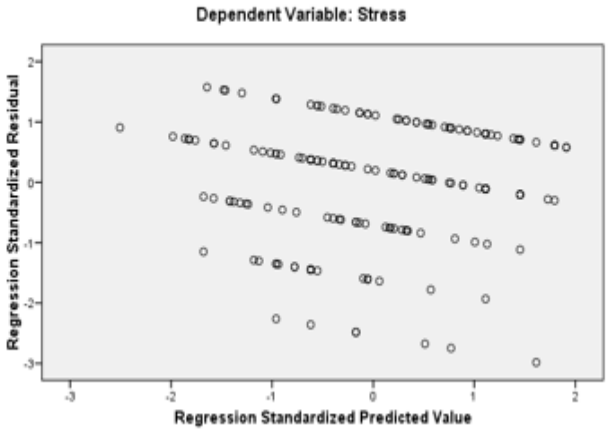
2. Linearity /Normality



Normal P-P Plot of Regression Standardized Residual



Scatterplot



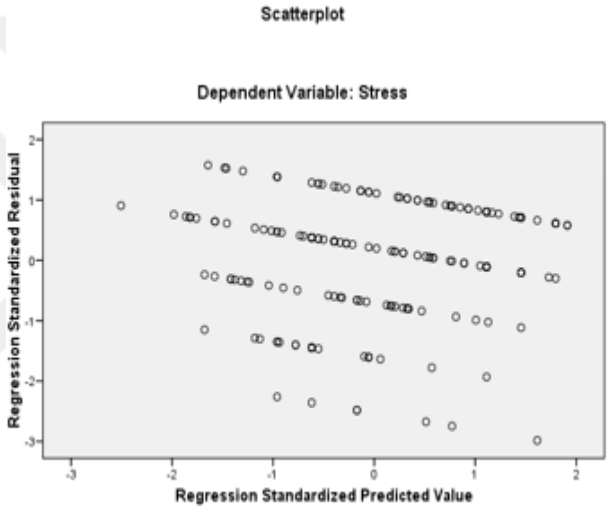
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.192	.393		10.672	.000		
	Struggling	-.136	.065	-.167	-2.083	.039	.828	1.208
	RemarkedHowTired	-.056	.127	-.035	-.440	.660	.828	1.207
	FeltDesinterested	.012	.069	.014	.170	.865	.783	1.277
	NotGivenMyBestEffort	.105	.073	.106	1.430	.155	.980	1.020
	FeltHeightenedIrritation	-.209	.128	-.135	-1.632	.104	.781	1.281

a. Dependent Variable: Stress

4. Homoscedasticity



PERSONAL ACTIVITIES

1. Independence of Residuals

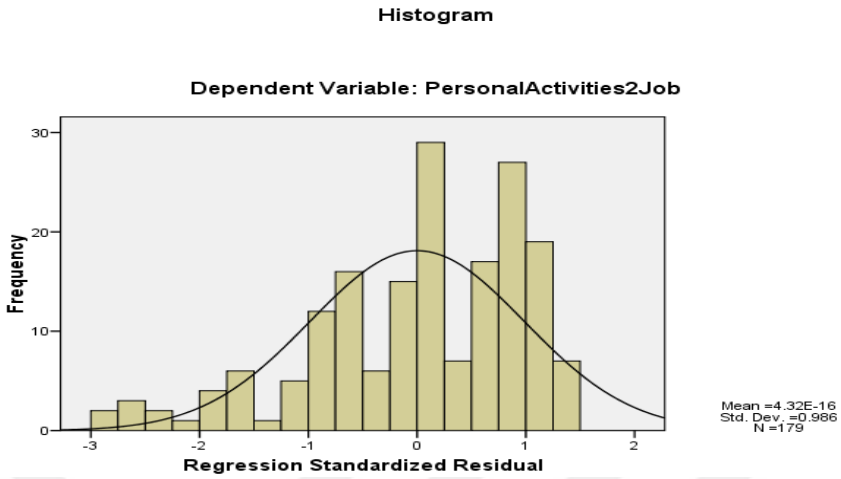
Model Summary[b]

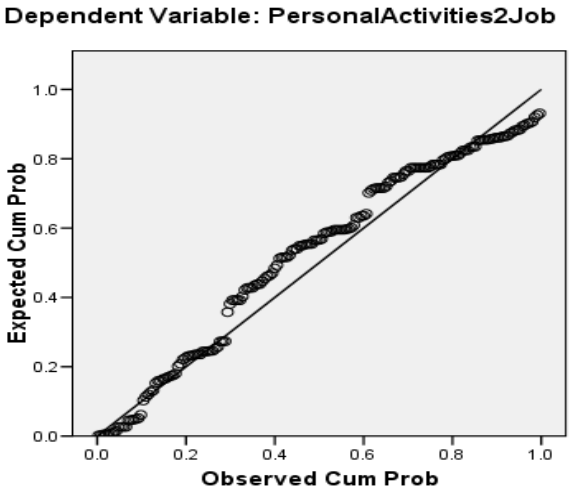
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.221[a]	.049	.021	1.071	.049	1.782	5	173	.119	1.742

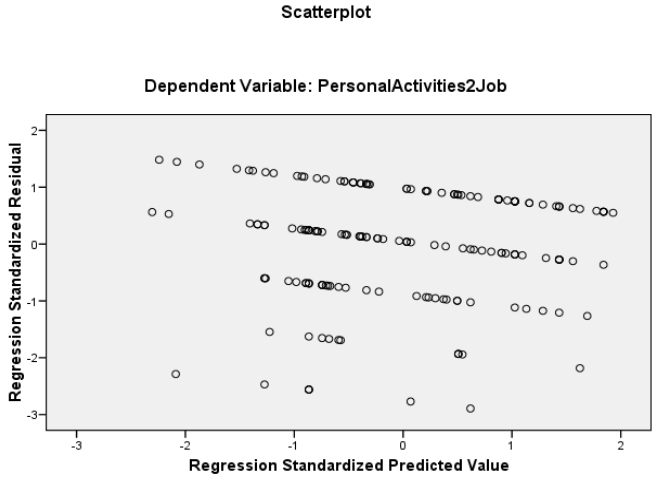
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: PersonalActivities2Job

2. Linearity /Normality







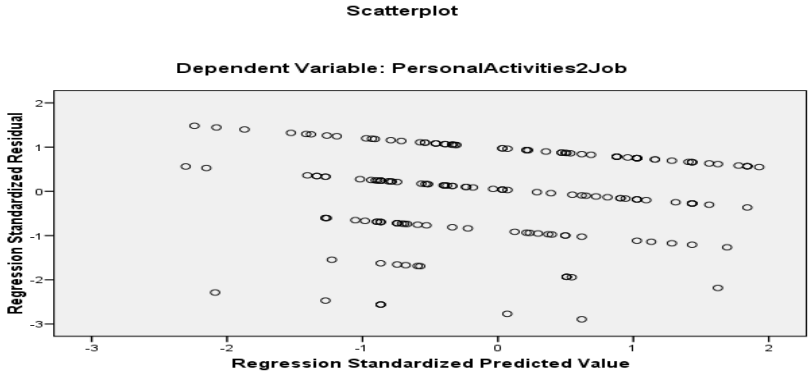
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.097	.383		10.686	.000		
	Struggling	-.124	.064	-.159	-1.949	.053	.828	1.208
	RemarkedHowTired	-.052	.124	-.034	-.419	.676	.828	1.207
	FeltDesinterested	-.054	.068	-.067	-.803	.423	.783	1.277
	NotGivenMyBestEffort	.098	.072	.102	1.361	.175	.980	1.020
	FeltHeightenedIrritation	.037	.125	.025	.293	.770	.781	1.281

a. Dependent Variable: PersonalActivities2Job

4. Homoscedasticity



QUALITY SLEEP

1. Independence of Residuals

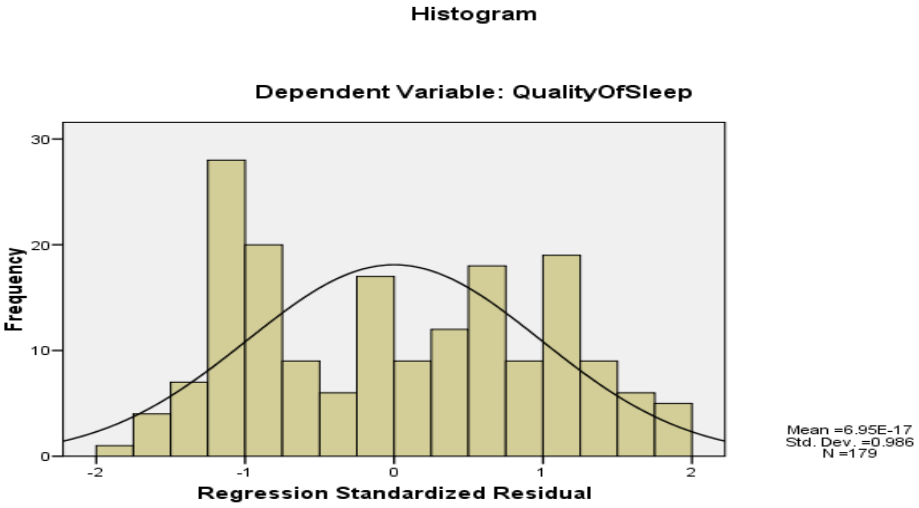
Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.397[a]	.158	.133	1.417	.158	6.476	5	173	.000	1.820

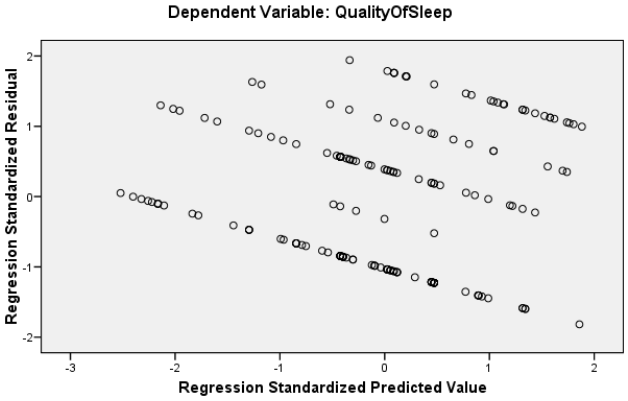
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: QualityOfSleep

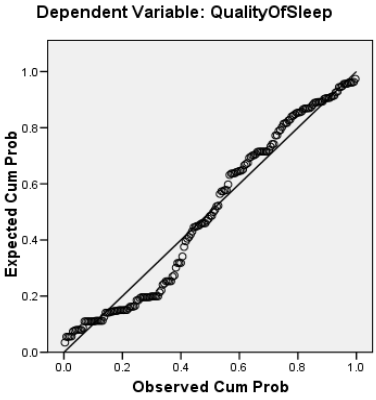
2. Linearity /Normality



Scatterplot



Normal P-P Plot of Regression Standardized Residual



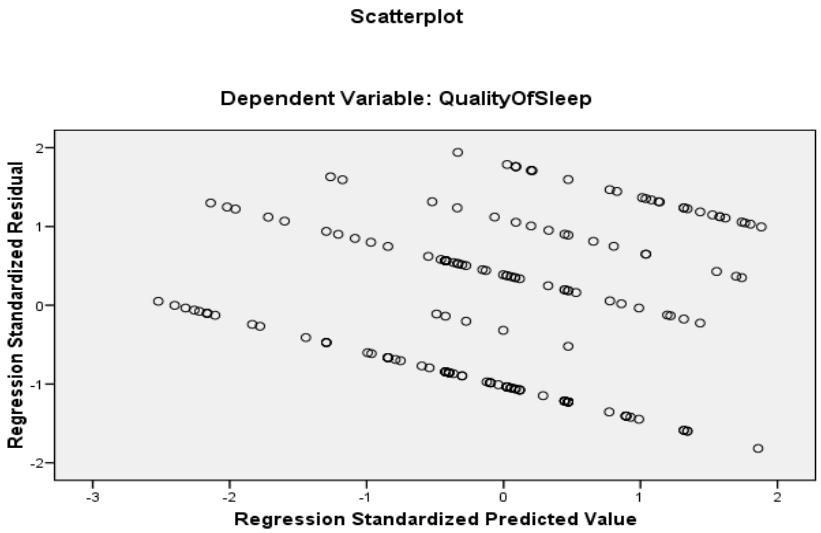
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	.491	.507		.968	.335		
	Struggling	-.109	.084	-.099	-1.291	.198	.828	1.208
	RemarkedHowTired	.072	.164	.034	.440	.661	.828	1.207
	FeltDesinterested	.053	.090	.047	.590	.556	.783	1.277
	NotGivenMyBestEffort	.526	.095	.391	5.541	.000	.980	1.020
	FeltHeightenedIrritation	.111	.165	.053	.671	.503	.781	1.281

a. Dependent Variable: QualityOfSleep

4. Homoscedasticity



NOT OF ENOUGH SLEEP

1. Independence of Residuals

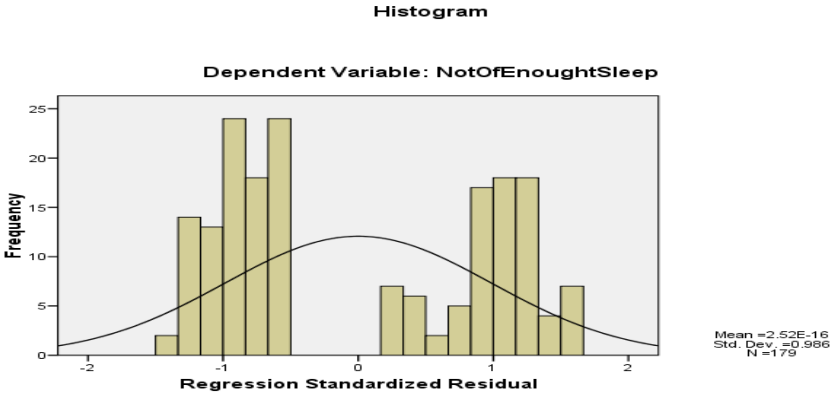
Model Summary[b]

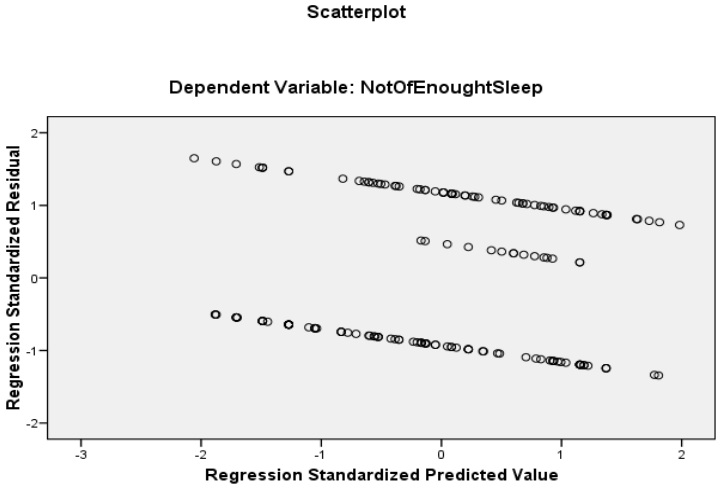
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.225[a]	.051	.023	1.420	.051	1.843	5	173	.107	1.710

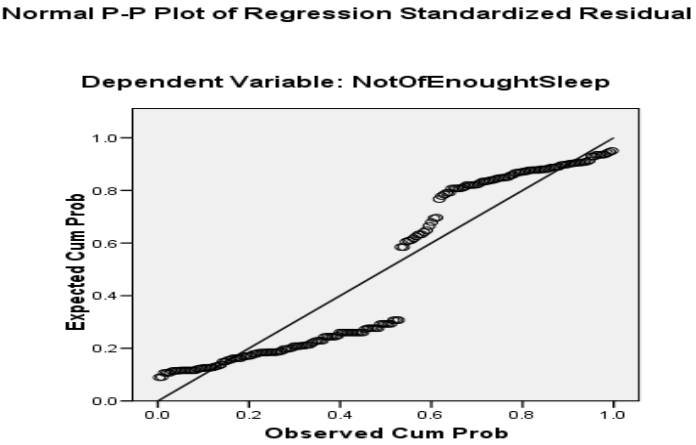
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: NotOfEnoughtSleep

2. Linearity /Normality







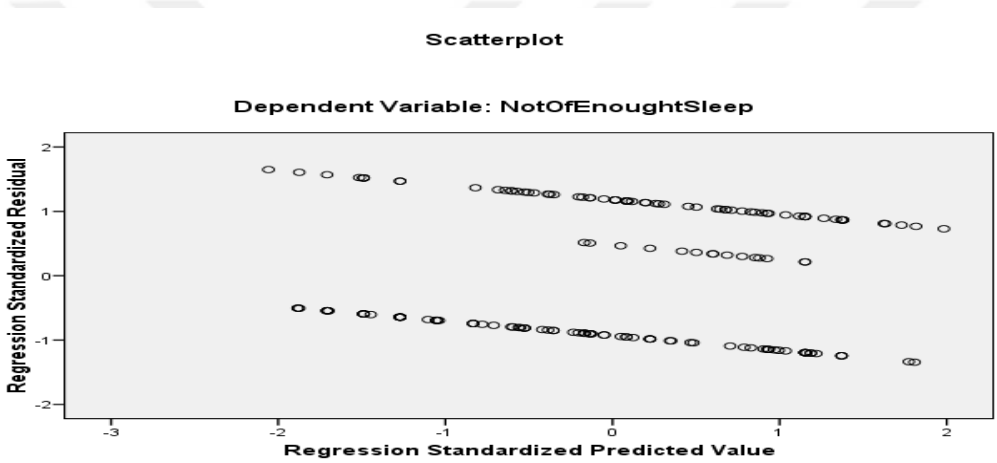
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	1.839	.508		3.618	.000		
	Struggling	.165	.084	.159	1.951	.053	.828	1.208
	RemarkedHowTired	-.057	.165	-.028	-.344	.732	.828	1.207
	FeltDesinterested	.119	.090	.111	1.322	.188	.783	1.277
	NotGivenMyBestEffort	-.071	.095	-.056	-.742	.459	.980	1.020
	FeltHeightenedIrritation	.059	.166	.030	.358	.720	.781	1.281

a. Dependent Variable: NotOfEnoughtSleep

4. Homoscedasticity



HEALTH OR FITNESS

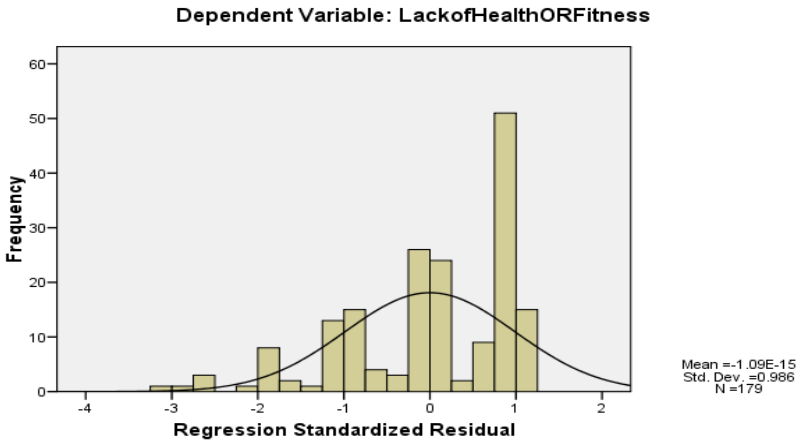
1. Independence of Residuals

Model Summary[b]

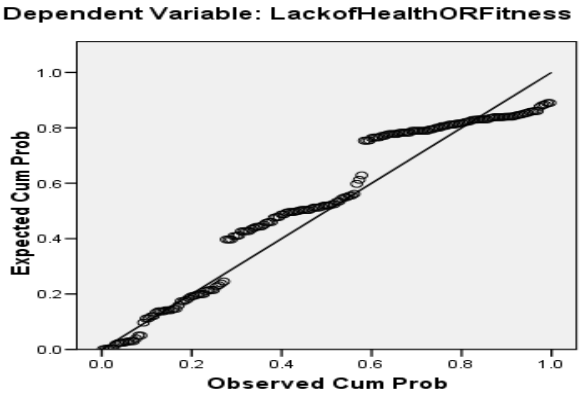
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.144[a]	.021	-.008	1.056	.021	.730	5	173	.602	1.702

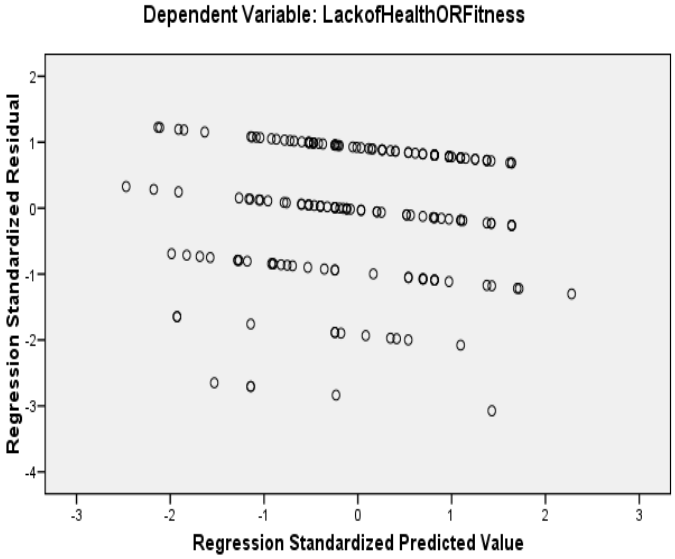
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

2. Linearity /Normality



Normal P-P Plot of Regression Standardized Residual





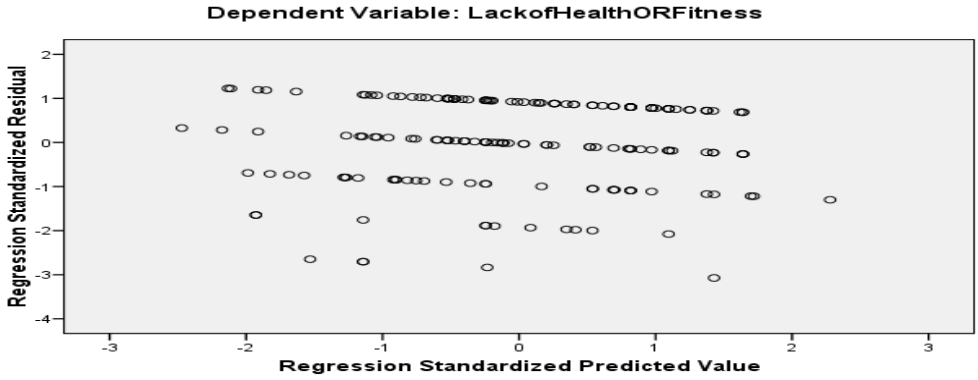
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.232	.378		11.197	.000		
	Struggling	.046	.063	.060	.726	.469	.828	1.208
	RemarkedHowTired	-.155	.122	-.105	-1.269	.206	.828	1.207
	FeltDesinterested	-.043	.067	-.055	-.646	.519	.783	1.277
	NotGivenMyBestEffort	.042	.071	.045	.597	.551	.980	1.020
	FeltHeightenedIrritation	-.054	.123	-.038	-.442	.659	.781	1.281

a. Dependent Variable: LackofHealthORFitness

4. Homoscedasticity



WORKING ALONG DAY

1. Independence of Residuals

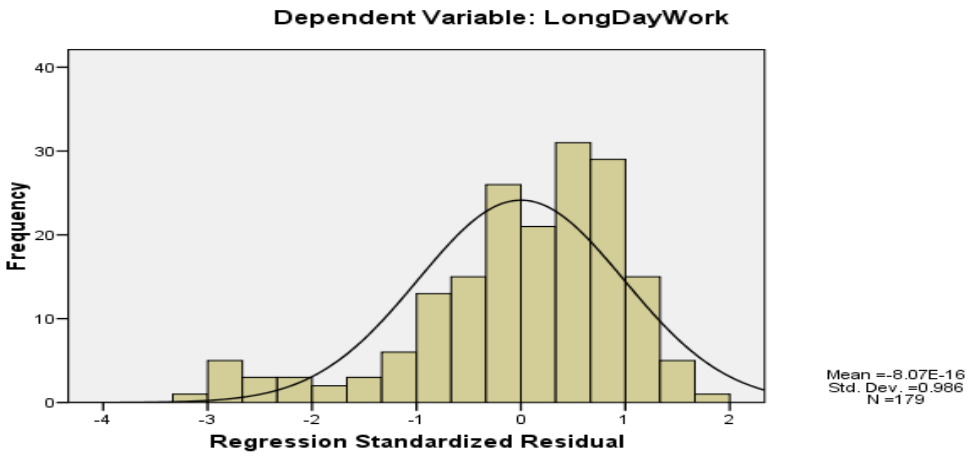
Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.316[a]	.100	.074	1.071	.100	3.827	5	173	.003	2.253

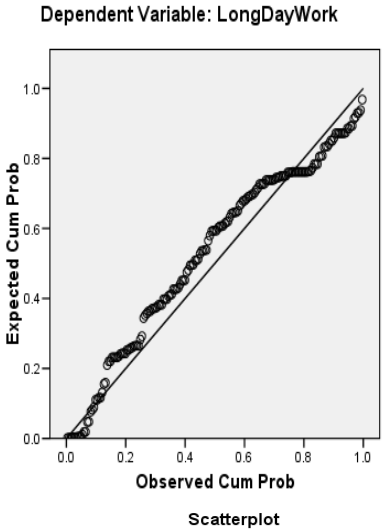
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: LongDayWork

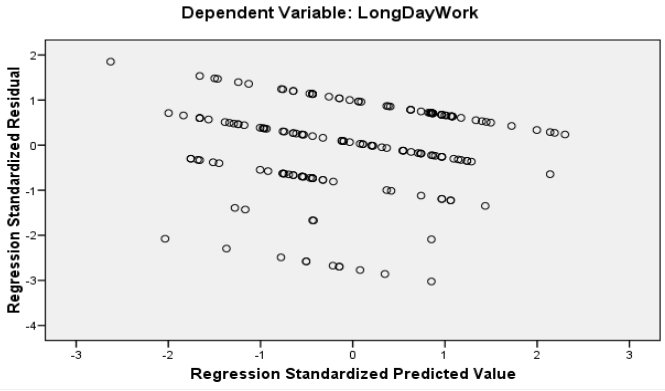
2. Linearity /Normality



Normal P-P Plot of Regression Standardized Residual



Scatterplot



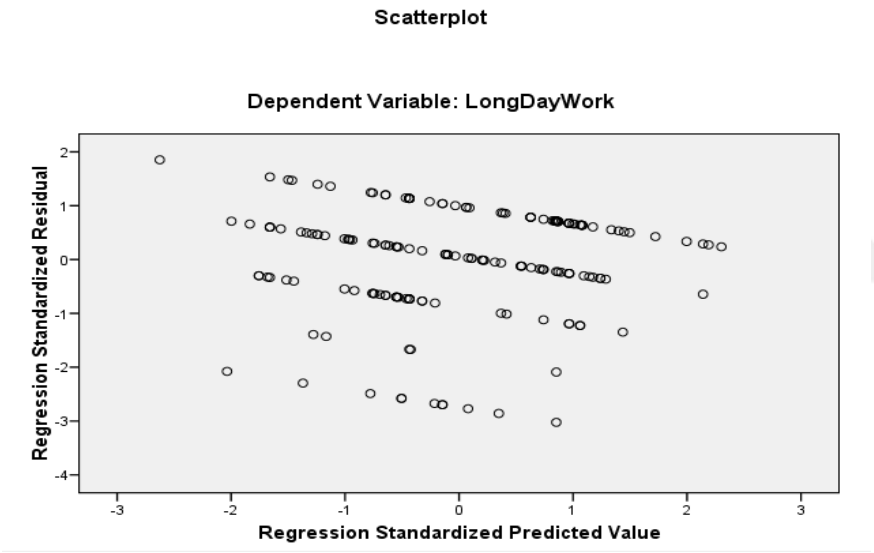
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	4.446	.383		11.595	.000		
	Struggling	-.207	.064	-.258	-3.258	.001	.828	1.208
	RemarkedHowTired	.057	.124	.036	.456	.649	.828	1.207
	FeltDesinterested	.124	.068	.149	1.834	.068	.783	1.277
	NotGivenMyBestEffort	.040	.072	.040	.551	.582	.980	1.020
	FeltHeightenedIrritation	-.300	.125	-.196	-2.398	.018	.781	1.281

a. Dependent Variable: LongDayWork

4. Homoscedasticity



FLYING A LONG CROSS-COUNTRY

1. Independence of Residuals

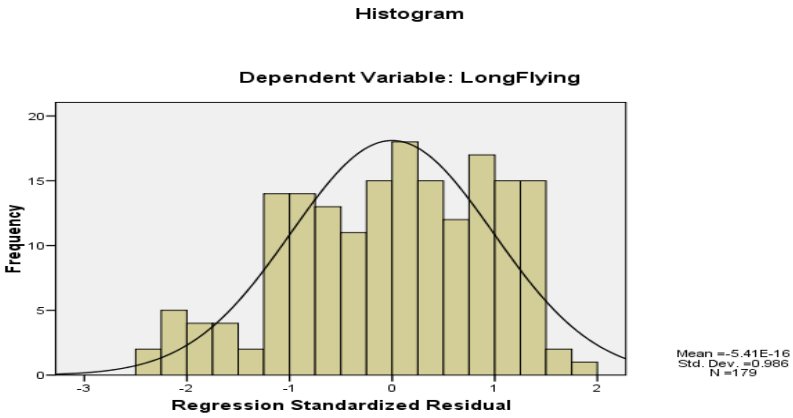
Model Summary[b]

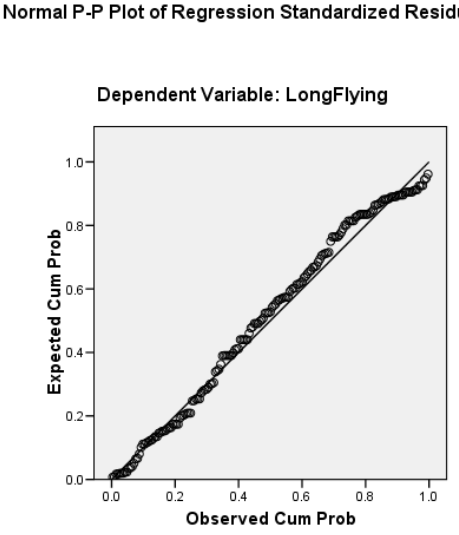
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.303[a]	.092	.066	.889	.092	3.508	5	173	.005	1.653

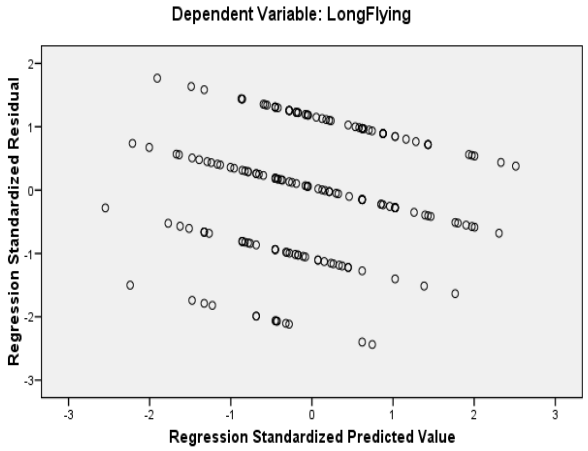
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: LongFlying

2. Linearity /Normality







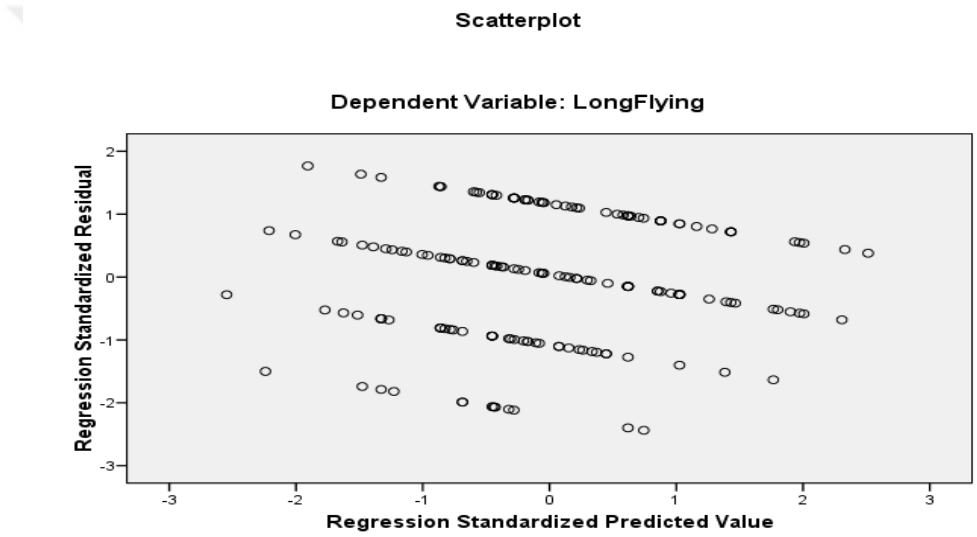
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	3.925	.318		12.325	.000		
	Struggling	-.172	.053	-.259	-3.251	.001	.828	1.208
	RemarkedHowTired	.151	.103	.117	1.464	.145	.828	1.207
	FeltDesinterested	.031	.056	.045	.553	.581	.783	1.277
	NotGivenMyBestEffort	.113	.060	.139	1.903	.059	.980	1.020
	FeltHeightenedIrritation	-.141	.104	-.112	-1.363	.175	.781	1.281

a. Dependent Variable: LongFlying

4. homoscedasticity



ACADEMIC ACTIVITIES

1. Independence of Residuals

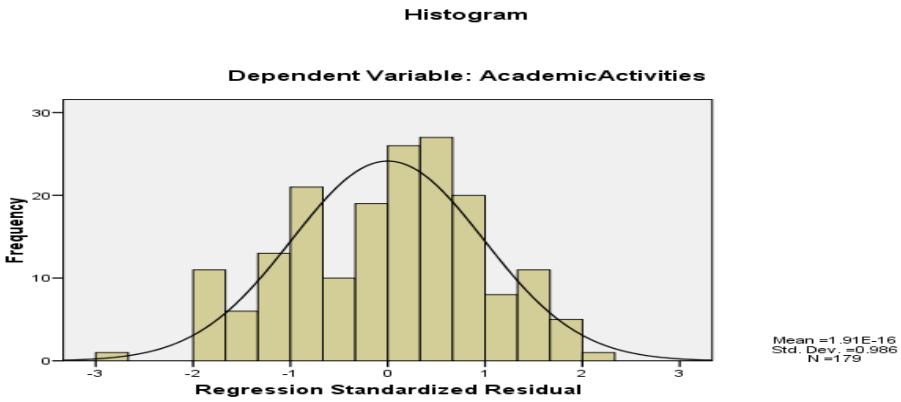
Model Summary[b]

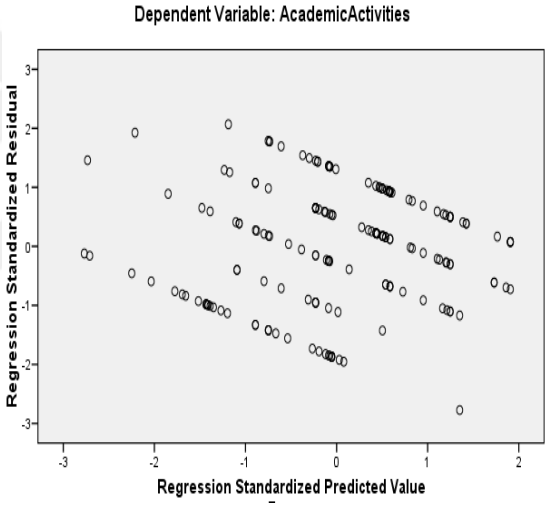
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.547[a]	.299	.279	1.247	.299	14.763	5	173	.000	1.733

a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

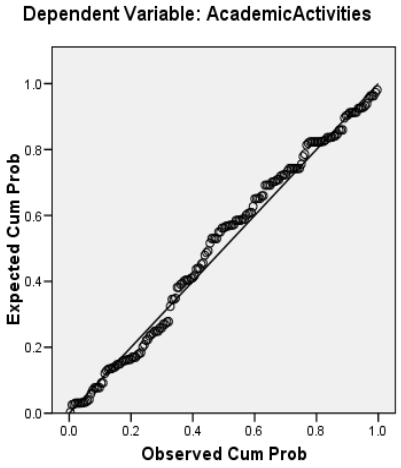
b. Dependent Variable: AcademicActivities

2. Linearity /Normality





Normal P-P Plot of Regression Standardized Residual



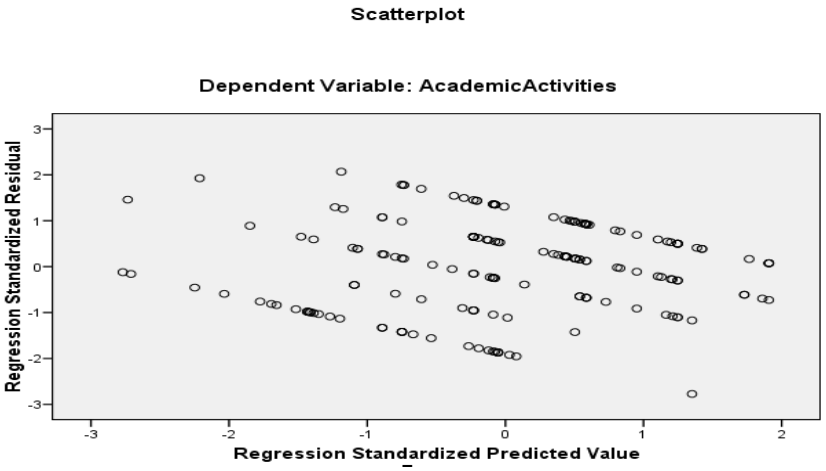
3. multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	2.927	.447		6.555	.000		
	Struggling	-.208	.074	-.197	-2.811	.006	.828	1.208
	RemarkedHowTired	-.447	.145	-.216	-3.088	.002	.828	1.207
	FeltDesinterested	-.048	.079	-.043	-.603	.547	.783	1.277
	NotGivenMyBestEffort	.531	.084	.408	6.353	.000	.980	1.020
	FeltHeightenedIrritation	.029	.146	.014	.196	.845	.781	1.281

a. Dependent Variable: AcademicActivities

4. Homoscedasticity



FLYING DURING THE NIGHT

1. Independence of Residuals

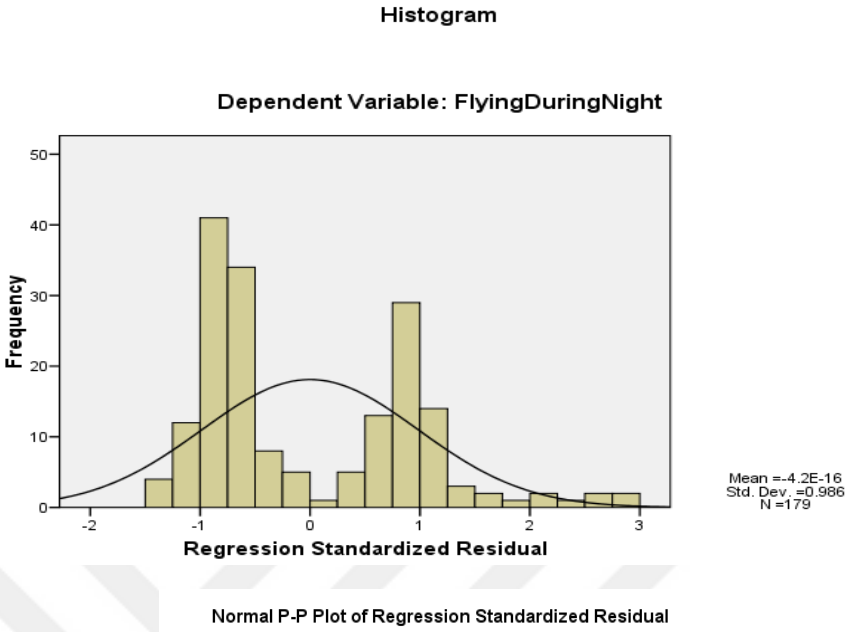
Model Summary[b]

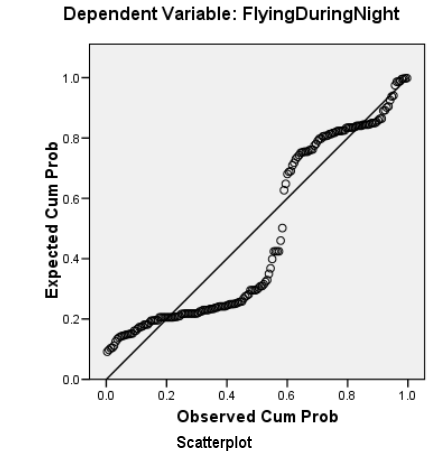
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.257[a]	.066	.039	.571	.066	2.451	5	173	.036	1.973

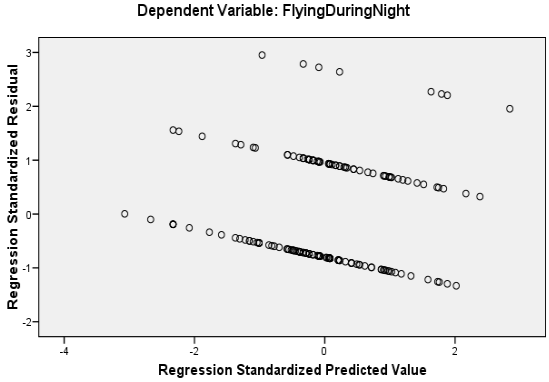
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: FlyingDuringNight

2. Linearity /Normality







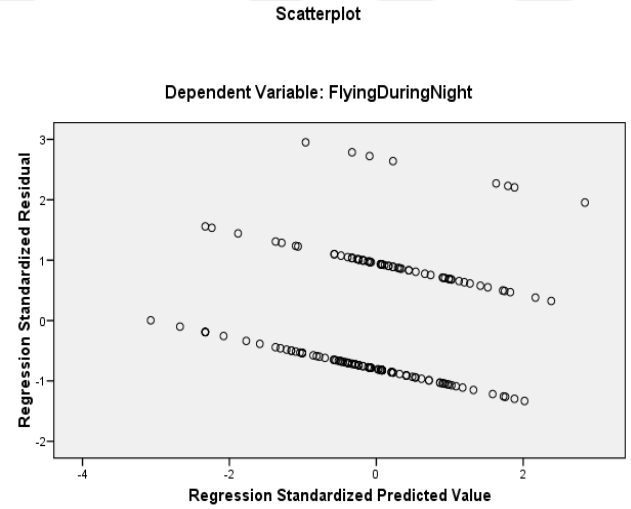
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	1.474	.205		7.207	.000		
	Struggling	-.060	.034	-.142	-1.761	.080	.828	1.208
	RemarkedHowTired	.166	.066	.202	2.503	.013	.828	1.207
	FeltDesinterested	.065	.036	.149	1.797	.074	.783	1.277
	NotGivenMyBestEffort	-.022	.038	-.043	-.583	.561	.980	1.020
	FeltHeightenedIrritation	-.134	.067	-.167	-2.004	.047	.781	1.281

a. Dependent Variable: FlyingDuringNight

4. Homoscedasticity



REDUCED JUDGEMENT

1. Independence of Residuals

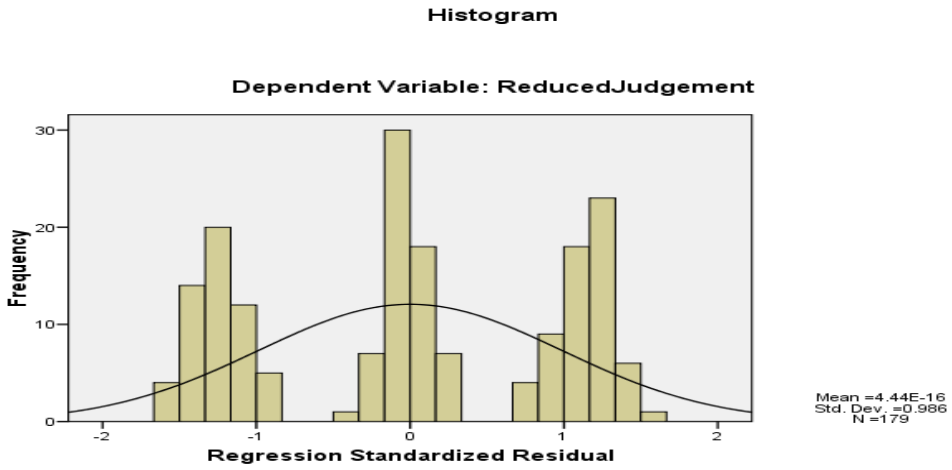
Model Summary[b]

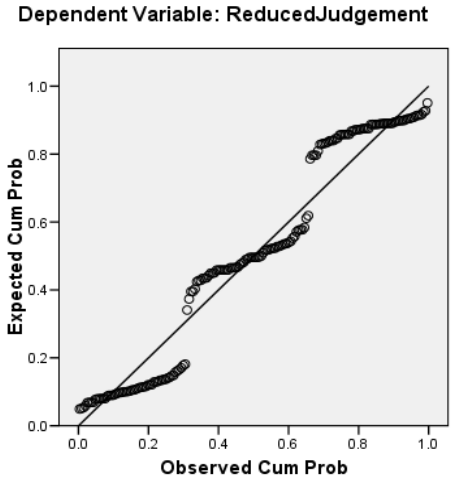
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.167[a]	.028	.000	.807	.028	.992	5	173	.424	2.045

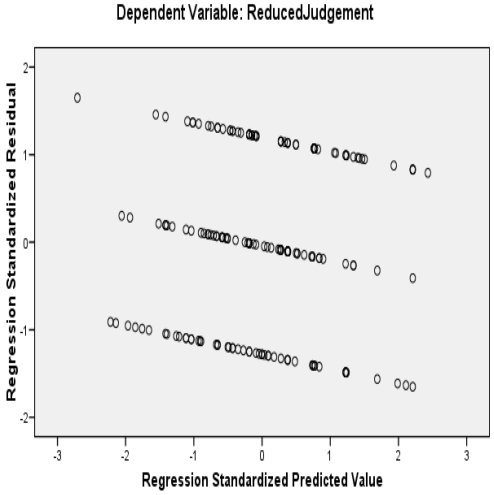
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: ReducedJudgement

2. Linearity /Normality







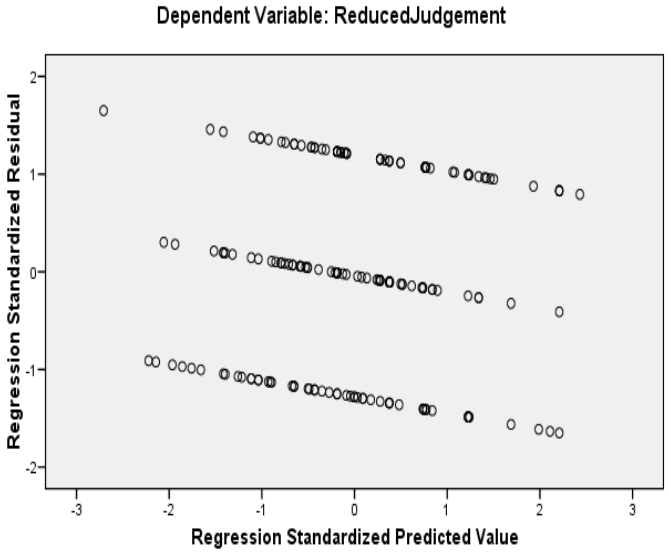
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Tolerance	VIF
1	(Constant)	1.861	.289		6.445	.000		
	Struggling	.076	.048	.130	1.583	.115	.828	1.208
	RemarkedHowTired	-.100	.094	-.088	-1.068	.287	.828	1.207
	FeltDesinterested	-.049	.051	-.081	-.960	.338	.783	1.277
	NotGivenMyBestEffort	.062	.054	.088	1.156	.249	.980	1.020
	FeltHeightenedIrritation	.033	.094	.029	.346	.730	.781	1.281

a. Dependent Variable: ReducedJudgement

4. Homoscedasticity



MADE MISTAKE DUE TO FATIGUE

1. Independence of Residuals

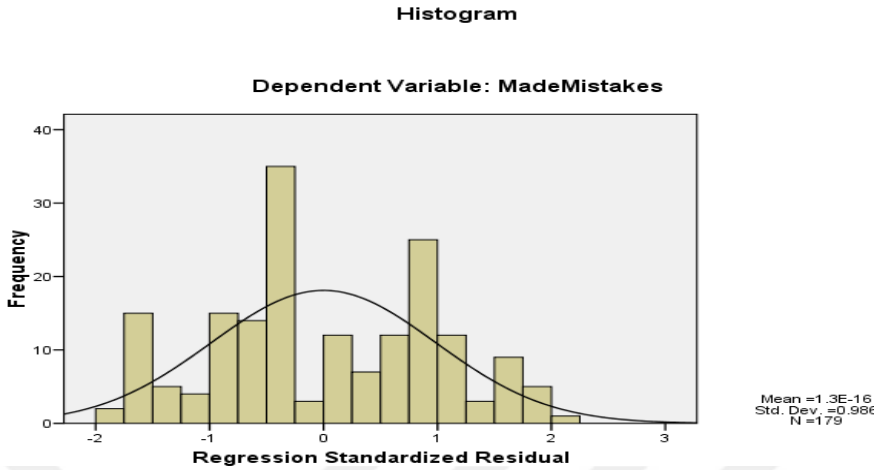
Model Summary[b]

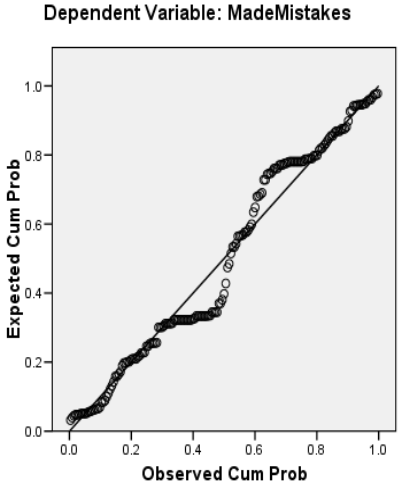
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.424[a]	.179	.156	1.245	.179	7.565	5	173	.000	1.483

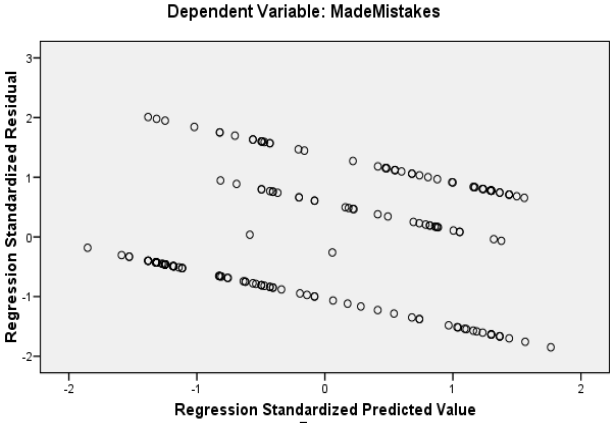
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: MadeMistakes

2. Linearity /Normality







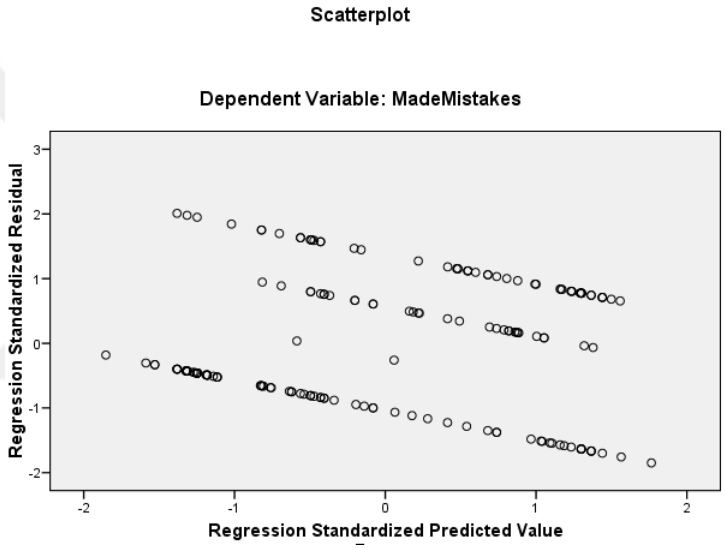
3. Multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	1.268	.446		2.843	.005		
	Struggling	.145	.074	.149	1.963	.051	.828	1.208
	RemarkedHowTired	.034	.144	.018	.235	.814	.828	1.207
	FeltDesinterested	.394	.079	.389	5.003	.000	.783	1.277
	NotGivenMyBestEffort	-.038	.083	-.032	-.458	.648	.980	1.020
	FeltHeightenedIrritation	-.153	.145	-.082	-1.050	.295	.781	1.281

a. Dependent Variable: MadeMistakes

4. Homoscedasticity



<u>DECREASED CONCENTRATION</u>

1. Independence of Residuals

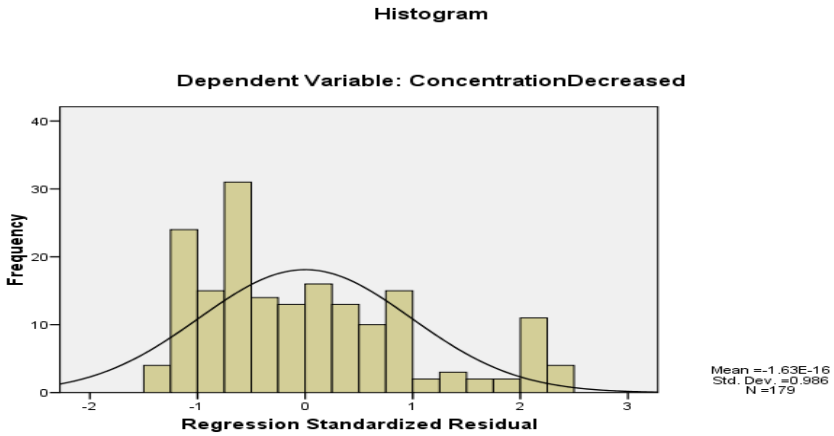
Model Summary[b]

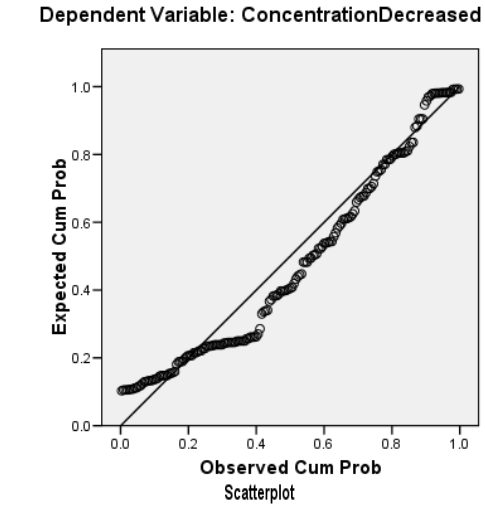
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.219[a]	.048	.020	1.275	.048	1.735	5	173	.129	1.663

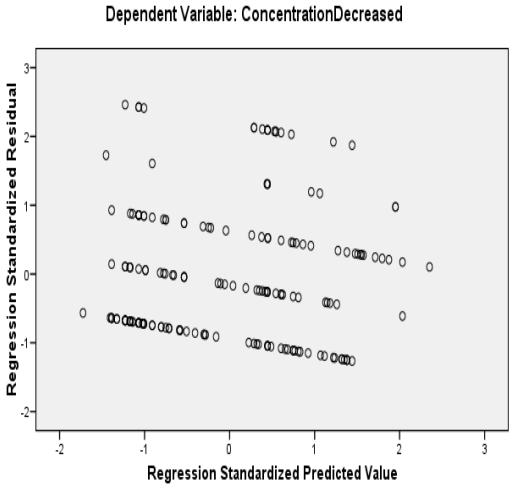
a. Predictors: (Constant), FeltHeightenedIrritation, NotGivenMyBestEffort, Struggling, RemarkedHowTired, FeltDesinterested

b. Dependent Variable: ConcentrationDecreased

2. Linearity /Normality







3. multicollinearity

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	1.615	.457		3.538	.001		
	Struggling	-.032	.076	-.034	-.417	.677	.828	1.208
	RemarkedHowTired	.112	.148	.062	.757	.450	.828	1.207
	FeltDesinterested	.055	.081	.057	.679	.498	.783	1.277
	NotGivenMyBestEffort	-.045	.085	-.039	-.525	.600	.980	1.020
	FeltHeightenedIrritation	.290	.149	.164	1.948	.053	.781	1.281

a. Dependent Variable: ConcentrationDecreased

4. Homoscedasticity